Eco-AlpsWater

Innovative Ecological Assessment and Water Management Strategy for the Protection of Ecosystem Services in Alpine Lakes and Rivers

Priority 3: Liveable Alpine Space. SO3.2 - Enhance the protection, the conservation and the ecological connectivity of Alpine Space

Deliverable D.T2.2.1

Identification of key lakes and rivers, and collection of previous knowledge

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Abstract

The output of the Deliverable D.T2.2.1 consisted of the detailed description of key lakes and rivers included as pilot sites in the project. The Project Partners provided information about physicochemical and biological characteristics, monitoring programme and past and emerging threats for water quality (for raw data see Annex 1).

The key lakes include Lake Mondsee (Austria), Lake Bourget (France), Lake Starnberg (Germany), Lake Garda (Italy), Lake Bled (Slovenia), and Lake Lugano (Switzerland). These natural and deep lakes are located in the peri-alpine area and are under a long term monitoring programme. They were affected by a eutrophication process around the 70s, which caused algal blooms and deoxygenation phenomena. Despite the recovery of the trophic status (from moderate to good) due to reduced external nutrient loading, in most of the lakes the oxygenation of deep waters is still hampered by weak winter turnover owing to climate warming. Consequently, the biological communities changed considerably during the last decades.

The key Alpine rivers selected include the Steyr (Austria), the Drôme (France), the Wertach (Germany), the Adige (Italy) and the Soca (Slovenia). In general, these rivers are moderate to large in size, with catchment areas ranging from 917 km2 (River Steyr) to 12’100 km2 (River Adige). These rivers are under a comprehensive monitoring programme, which cover the main biological elements for the evaluation of ecological status. Monitoring stations along these rivers span a wide range of ecological states, ranging from ‘poor’ to ‘very good’. One of the most pervasive ecological threats stems from hydropower facilities (power plants, dams), which affect all rivers except for the River Drôme. Further pressures include agricultural impacts, including runoff and water abstraction (Drôme, Adige), urban and industrial pollution (Drôme), channelization (Wertach) and gravel extraction (River Soca).

This report highlights common ongoing threats and future needs of water quality assessment program, which can be solved by eDNA approach.

KEY LAKES

Lake Bled

General description

Lake Bled is a typical small subalpine lake situated in the north - west of Slovenia. (North latitude 14º 7’ and 46º 23’ East longitude)

The lake basin has a glacial-tectonic origin. A natural tectonic, depression had been deepend and shaped by the Bohinj glacier after the final Würm glaciation 10. – 15.000 years ago.

The most part of Bled’s wider catchment is calcareous, composed mainly of limestones and dolomites (M.Novak, M.Bavec, 2013). Wood (60%) and agriculture areas, mainly pastures (27%) cover the main part of the lake small catchment area (8,4 km^2). The rest (13%) is buil up - urban area. Bled was a famous tourist resort already at the end of the 19th century and tourism is the main social and economic activity in the region also nowadays.

Table 1 Hydromorphological characteristics of Lake Bled (Rejic & Sketelj 1962)

Height above See level	475 m
Surface area	1.438 km^2
Maximal depth	30.1 m
Average depth	17.9 m
Volume	25.69 mio. m^3
Catchment area	8,4 km^2
Theoretical retention time before sanitation	3.6 years
Theoretical retention time in the last 5 years	~1.5 years

Lake Bled is a small, spring type lake. It it covers only an area of 1,438 km^2 and its water volume is 25,7 mio.m^3. With an average depth of 18 m and maximum depth of 31 m, the Lake Bled belongs to the deep lakes according to the WFD inter-calibration typology. The Lake Bled littoral zone is limited to only 3% of the lake ecosystem, because banks of the lake fall steeply towards the bottom due to the lake glacial origin. By an underwater ridge the lake basin is divided into western deeper and eastern shallower basins.

Lake Bled has no major natural inlets of water of its own. Prior to 1964 only 13 small streams had been feeding the lake with the total inflow smaller than 0,35 $m^3 \cdot s^{-1}$. The natural retention time of the lake was 3,6 years.

Existing monitoring and restoration programme

As in most lakes throughout Europe Lake Bled underwent a peak period of the intensive eutrophication. As early as the beginning of the 1950's a permanent cyanophyte water bloom consisting of the species *Planktothrix rubescens* (DC. ex Gom.) Anagn. et Komárek (syn. *Oscillatoria rubescens* DC. ex Gom.) indicated a warning signal of the increased eutrophication and disturbance of the natural balance of Lake Bled system. The unpleasant appearance of the lake during the prolongated cyanophyte water blooms resulted in the initiation of a restoration programme including sanitation and other restorative measures, coordinated by Slovene Water management administration and the Institute for sanitary hydro-engineering at the Faculty of Civil and Geodetic Engineering

Some preliminary and occasion survey measurements were carry out already in the period 1954 – 1958 but the regular Lake Bled monitoring as a part of the Slovene National Water-Quality Monitoring Programme started in 1975.

The main cause of the Lake Bled eutrophication was the resort's overloaded and poorly managed sewerage system that was closely linked to the rapid development of massive tourism. The lake poor natural inflow accelerated the speed and intensity of the eutrophication processes.

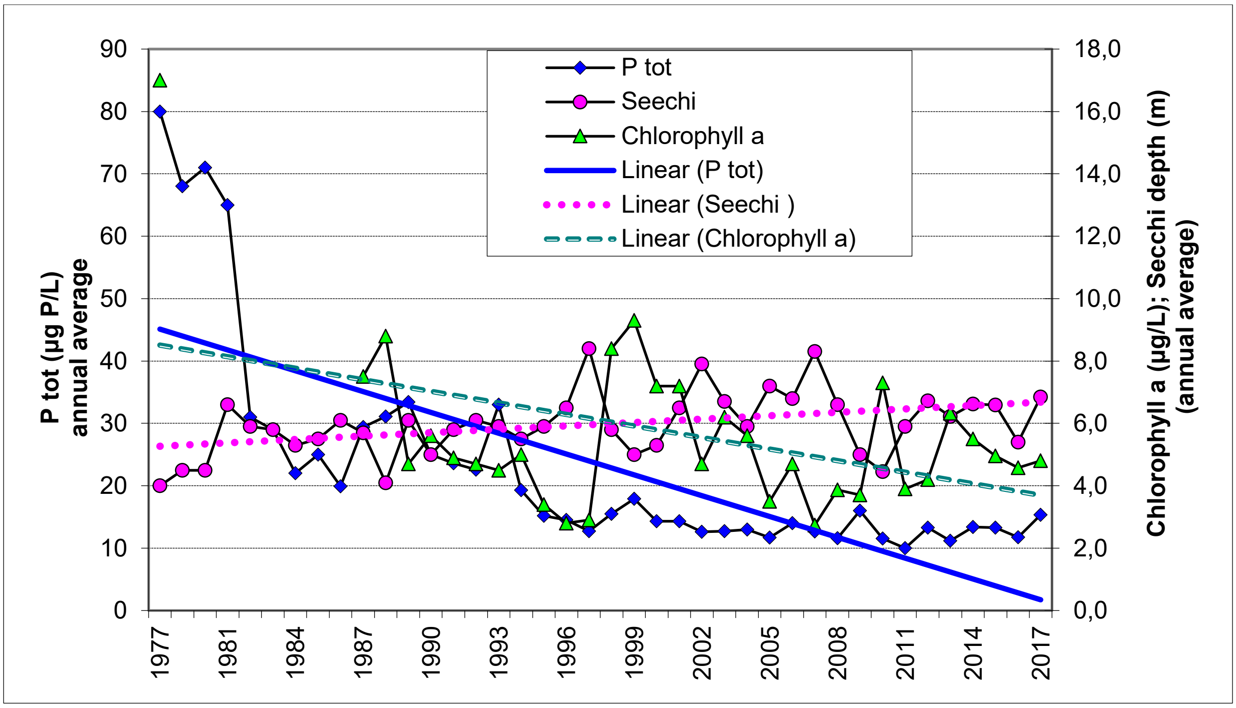
In order to increase the natural flow of water and to aerate the lake, oxygen rich water from the Radovna River was channelled into the lake in 1964. On the basis of the

Imboden's model a depth outlet from the lake, a siphon, was built in 1980/82. In years 1982-85 renovation of the Bled's sewerage system decreased inflow of wastewater into the lake.

Monitoring data survey

Monitoring data from the period 1975–2017 show relatively effective reoligotrophication of the Lake Bled and according to OECD 1982 criteria, it is classified again as a mesotrophic lake since 1990 (Remec – Rekar 2018).

Nutrient concentrations have been gradually decreasing. This has been reflected in a lower total phytoplankton biomass, lower average chlorophyll concentration and increased transparency of the lake.



Graph 1: Trend of basic parameters for a trophic state determination in the Lake Bed during the period 1977 – 2017.

Table 2: Lake Bled parameters for trophic status assessment according to OECD criteria, (Annonymus Paris 1982, Eutrophication of waters, Monitoring, Assessment and Control)

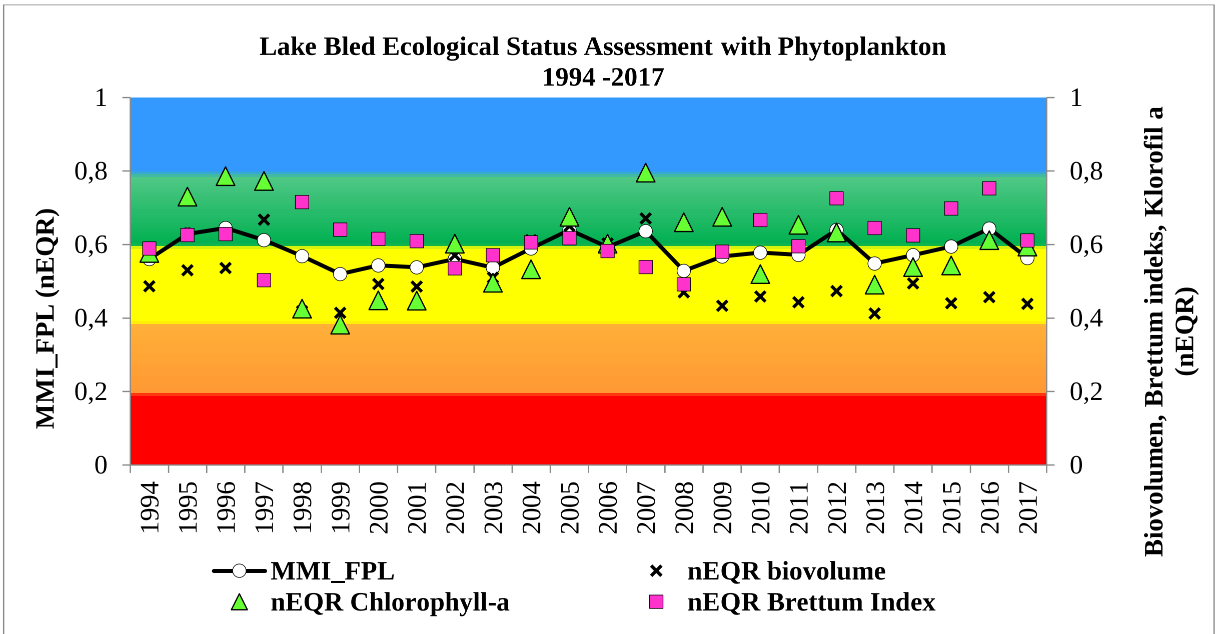
Period	Total phosphorus	Nitrogen anorganic, total	Seechi depth minimum	Seechi depth average	Chlorophyll a average	Chlorophyll a maximum
	(µg P/l)	(µg N/l)	(m)	(m)	(µg/l)	(µg/l)
1975-1979	80	986	0,5	3	22,3	80,5
1980-1989	35,8	456	2,1	5,7	11,2	45,6
1990-1999	19,9	406	2,4	6	5,1	25,8
2000-2005	13,1	269	3,4	6,6	5,8	21,3
2006-2008	12,8	342	4,3	7,2	3,8	14,8
2009-2010	13,8	370	2,7	4,7	5,5	19,4
2011-2012	12	284	4	6	4,1	5,8
2013-2014	12,3	301 (440)	4,4	6,4	5,7	9,8
2015-2016	12,5	266 (393)	3,5	6,0	4,8	8,3
2017	15,3	223 (458)	5	6,9	4,8	7,2

The principals of the monitoring has been changed with the WFD (Directive 2000/60/ES) implementation in 2007.

The main reason for the Lake Bled moderate ecological status is the assessment with phytoplankton what means, that Lake Bled is still overloaded with nutrients. This is not surprising, because pressures of quickly rising tourism are great.

Table 3: Lake Bled Ecological status in accordance with WFD (Directive 2000/60/ES) 2007– 2017

Boundary Classes Criteria	Biological Quality Elements				Physico - Chemical Quality elements					SPECIFIC POLUTANTS	ECOLOGICAL STATUS (FINAL)
	Phytohytoplankton (MMI_FPL)	Phytobenthos and Macrophytes (TI, SMILE)	Benthic invertebrates (LBI)	FISH	Secchi (m)	Phosphorus (µg/L)	Oxygen saturation in the hipolimnion (%)	pH	Specific electrical conductivity (25 ºC)		
H/G	0,8	0,8	0,8	-	6,0	10,0	≥ 70	7,5-9,0	720		
G/M	0,6	0,6	0,6	-	4,0	14,0					
LAKE BLED ECOLOGICAL STATUS											
WMP I 2006-2008	0,59	-	0,64	-	7,2	13	78	8,3	336	Good	MODERATE
WMP II 2009-2015	0,58	0,68	0,73	-	5,9	13	72	8,1	333	Good	MODERATE
2016	0,64	0,58	-	-	5,4	12	50	8,2	327	Good	"
2017	0,56	-	-	-	6,9	15	54	8,2	322	-	"



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Lake Bourget

General description

Largest natural lake in France (with the exception of Lake Geneva, partly located in Switzerland), Lake Bourget is a deep peri-alpine lake. It was formed after the last Glaciation of Würm, about 19,000 years ago by the retreat of the great Quaternary glaciers. It has a major ecological interest, but it is also an important tourist destination since the nineteenth century.

Covering an area of 44.5 km^2 (4,450 hectares), the lake stretches in length along a north-south axis for 18 kilometers, and with a width between 1.6 and 3.5 kilometers. Its average depth is 80 meters, and its maximum depth is 145 meters. From an average altitude of 231.5 meters, the lake is bordered on the west by the last foothills of Southern Jura, and on the east, by the Massif of Bauges.

Its catchment area of 560 km^2 is occupied by the spa town of Aix-les-Bains, which borders it on its eastern shore, and further south, by the city of Chambéry, historic capital of the kingdom of Savoy, today prefecture of the department of Savoy. . Another important town on the shore (SO) of the lake is Le Bourget du Lac. These 3 main agglomerations bordering the lake are located about fifteen kilometers and have about 200,000 inhabitants.

The average temperature of the water is about 14.4 ° C and 24.1 ° C in summer. With a volume of 3.6 billion cubic meters of water, the lake served, until the construction of a dam in 1982, of natural spillway for the floods of the Rhone, which meanders beyond the swamps of Chautagne, located in the north. This regulation, now voluntary, still exists and the lake level varies (about one meter) depending on the season. The lake is mainly fed to the south by the waters of the river Leysse, and to the east by those of Tillet and Sierroz. The waters of the Leysse take about 10.25 years to cross the lake and reach the Rhone.

Existing monitoring programme

During the 1970s, major works were carried out by municipalities in the Lake Bourget watershed to clean up the lake, which was suffering from eutrophication. This pollution manifested itself on the surface by an excess of living organic matter (typically microalgae) which, after settling in the bottom by sedimentation, led to deoxygenation phenomena, impacting fish fauna and more generally water quality. Sediment archives analysis, of geochemistry and particle size in sedimentary cores of Lake Bourget allowed to reconstruct the trophic evolution and anoxia of the bottom waters during the last 100 years (Giguet- Covex et al. 2011). The start of eutrophication could be dated, just like the first date of anoxia in 1943. More recently, the impact of Climate change on anoxia processes over the past century has also been revealed (Jenny *et al.*, 2013).

In parallel with the remediation work carried out, the Lake Bourget water quality has been monitored and continues to be monitored to determine the evolution of phosphorus and nitrogen concentration in water, water transparency, total chlorophyll a, temperature and dissolved oxygen concentrations. This monitoring, called lightened, was carried out by the Technical Unit of the Aquarium of Lake Bourget until the 80s, then by the CCLB which improved it during three periods: 1988-1989, 1995- 1996 and 2004-2005. INRA (UMR CARRTEL) and university research laboratories participated each time. Since 1999, INRA (UMR CARRTEL) has participated in this evaluation and has paid particular attention to the proliferation of filamentous and toxic cyanobacteria (*Planktothrix rubescens*). Since 2004, regular monitoring of the main biological compartments has been carried out, in addition to physicochemical, dissolved oxygen and transparency studies. This monitoring is done by the CISALB (Intersyndical Committee for the Sanitation of Lake Bourget) and INRA (UMR CARRTEL) and is intended to track and detail the main variables of physicochemical and biological evolution of Lake Bourget, during 20 annual campaigns, to which is added one annual monitoring of the fish resource.

Past, emerging and potential threats

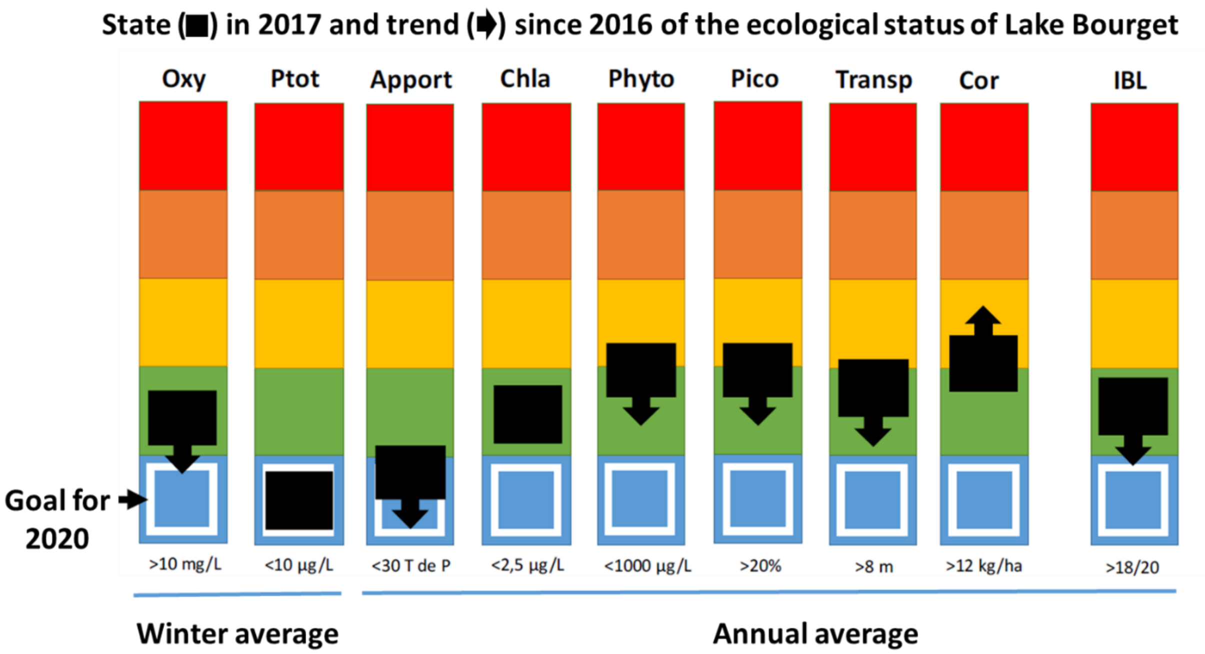

Figure 1: State and Evolution of the lake between 2016 and 2017. The color code reads from blue (excellent) to red (bad). The figures proposed as objectives to be achieved for 2020-2021 remain to be validated by the scientific council. (Adapted from Jacquet et al., 2018)

The trend for all parameters that characterize the ecological status of Lake Bourget is globally positive (Figure 1):

-The total winter phosphorus levels are in very sharp declines over the past 30 years and the trend is continuing. The goal of staying below the 10 µg / L level is reached and seems to be maintained. This tendency could be explained in particular by a recent drop in total phosphorus of the two major tributaries (> 90% of the water transferred to the lake), Leysse and Sierroz, measured in 2017 height of 24 tonnes (thus falling below the threshold recommended by the scientific council), against 40 T in 2016 and 60 T in 2015 (Jacquet et al., 2018).

-Regarding phytoplankton, the functional indices of Brettum, most suitable index to evaluate the level trophic of large alpine lakes (Kaiblinger 2008, Anneville & Kaiblinger 2009, Kaiblinger et al 2009), and IPLAC index have in recent years been the highest measured since the beginning of the chronicle and confirm the overall good state of the ecosystem.

-The fish population is in satisfactory condition with a relatively stable fishery yield on the series but declining steadily. The highlight of the year 2017 has indeed been the decline of the whitefish population ('cor' on figure 1), an indicator of a restoration of the water quality, which may be linked to poor recruitment, but also associated with excessive fishing effort and/or a drop in the trophic level. However, the regression of indicator species (from a medium to less good quality) like zander and catfish has been confirmed. The other fish species are in a relatively stable state, with fluctuating yields in particularly those of perch juveniles, whose population is at a level considered as "medium" in 2017.

- The benthic zone, deep and littoral, is also studied via macrobenthic compartment analysis (e.g. chironomids, bivalves, oligochaetes) to obtain a biological index of quality, the lacustrine biological index (IBL). Lake Bourget presented in 2017 an IBL of 16.8 / 20 putting in evidence its high biogenic capacity. The stability of the community of invertebrates and the IBL between 2012 (rated 16/20) and 2017 suggests that the lake had a stable ecological functioning during this period. This information on the coastline quality is reinforced by data acquired on macrophytes (IBML), benthic diatoms (IRS) and mollusks (IMOL) that confirm also the overall good ecological status of the lake shores.

The general dynamics of re-oligotrophication of the lake is clear and even seems to be even more advanced. The response of the ecosystem to the restoration, however, remains a little surprising with the presence, still notable among the phytoplankton, of *Planktothrix rubescens*, although a drastic decline of this species has been observed since 2009, (Jacquet et al., 2014) 2016 and 2017 were marked by a reappearance of moderate blooms. After being described as eutrophic, Lake Bourget is now oligo-mesotrophic, and is about to become oligotrophic.

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Lake Garda

General Description

Lake Garda, the largest lake in Italy (Area = 368 Km^2; Vol = 49 Km^3; z_{max} = 350 m), is a deep natural subalpine lake located in the southern edge of the Alps, across the border between autonomous Province of Trento, Lombardia region and Veneto region. The lake occupies a deep fluvial valley originated 5-6 million years ago during superior Miocene related to Messinian marine regression (Bini et al., 1978; Cita et al., 1990).

Quaternary glaciations, superimposed with the Adige-Sarca glacier on the pre-existing fluvial morphology, modelled this basin.

The lithology of the catchment area is dominated by sedimentary rocks such limestones, marl and sandstone, but there are also glacial and fluvial deposits with igneous and metamorphic rocks (Sauro, 1974).

In the northern edge of the lake is located the River Sarca, the principal inflow, with an average flow of 30.5 m^3 s^{-1} (Provincia Autonoma di Trento, 2004). At the southern edge there is the outflow (River Mincio) with an average discharge of 58 m^3 s^{-1} (Salmaso, 2010).

The lake is divided in two different basins by one underwater ridge connecting the Sirmione Peninsula to Punta San Vigilio. The west basin is the biggest and the deepest one (350 m) whereas the east basin is more shallow with a maximum depth of only 80 m accounts for only 7% of the overall lake volume (Salmaso, 2002).

The catchment area is about 2,350 km^2 and extends from the 3,556 m a.s.l. of the Mount Presanella to the 65 m a.s.l. of the lake and the ratio of the catchment area to lake area is relatively small (6:1) (Bonomi, 1974). Lake Garda, compared to other deep southern subalpine lakes, has a long water renewal time of 27 years due to its low catchment area to lake volume ratio and lower annual rainfall (790-1150 mm) (Salmaso, 2010).

Lake Garda is classified as warm monomictic lake, circulating completely once a year in the winter. Complete mixing, due to its great depth, occurs only during cold winters (oligomictic).

Existing monitoring programme

Since the 1950s Lake Garda was affected by a slow but continuous eutrophication process connected to economic development and increase of the tourism with sewage input from the coast. A system for collecting urban wastewater was built in the '80s to transport wastewater to a single treatment plant located in the municipality of Peschiera del Garda (south basin) discharging sewage cleaned effluents in the river Mincio, downstream the lake. The collecting system, after a series of adjustments and repairs, began to works quite well only in the mid-2000s. The analysis of subfossil diatoms and pigments of a sediment corer revealed that before the 1960s the TP concentration were around 5 µg P L^{-1}(Milan et al., 2015). TP showed a continuum increase in the water column during the spring overturn from around 5-10 µg L^{-1} in the 1970s up to 20-25 µg P L^{-1} in 2000s (Mosello et al., 2010).

Since the beginning of the 1990s, continuous monthly samplings and measurements were carried out by the Department of Biology of the Padova University (Responsible, Nico Salmaso), with the collaboration of ARPAV. Since 2005 the whole limnological research is performed by the Limnological research group of the Agrarian Institute of S. Michele all'Adige – E. Mach Foundation (S. Michele all'Adige, Trento; coordinator, Nico Salmaso) while the monitoring activities are performed by ARPAV, ARPA Lombardia and APPA-Trento.

Since 2006, the station was included in the LTER (Long-Term Ecological Research) network (http://www.lteritalia.it/en).

In 2010 started the Eulakes Project (2010-2013), founded by the European Programme Central Europe and coordinated by the Lake Garda Community, with the aim to promote a new integrated approach in order to improve the sustainable management of Central European lakes to respond to climate change and other environmental stressors.

The last regular sampling period for biological monitoring in Lake Garda was performed in 2014-2015-2016 years for the classification of the ecological status of the lake, as required by Legislative Decree no.152/2006, in application of the WFD. This was the first evaluation period of the six-year period (2014-2019) defined by the Basin Authority of the Po as a reference for the classification of the Lake Garda, in agreement with the Regions of Lombardy, Veneto and the Autonomous Province of Trento.

For the classification of the quality, the Lake Garda has been divided into two distinct water bodies that, for the period 2009-2013, were classified as follows:

- Western Garda: moderate ecological status

- South-east Garda: good ecological status.

(DGR of Veneto No. 1856 of 12/12/2015 and 2015 Management Plan of the Po Basin Authority).

The update of the classification of the lake will be performed with the data collected in the years 2014-2019.

The classification of the quality was performed with the following Elements of Biological Quality (EQB): Phytoplankton, Macrophytes, Diatoms and Benthic macroinvertebrates.

The bathing water monitoring on the Veneto shore, started in 1982 by the ULSS 25, are performed by ARPAV. During the period of recurring breakdown of the intake wastewater pipeline (1982-2003) there was many poor bathing water quality events. After 2003 all the bathing areas have been classified as excellent.

Past, emerging and potential threats

In Lake Garda the increase of total phosphorus (TP) supported the growth of cyanobacteria like the microcystins (MCs) producer *Planktothrix rubescens* (DeCandolle ex Gomont) Anagnostidis & Komarek) and large diatoms. The highest development of cyanobacteria (2005-2007) was observed during or after spring overturns with the enrichment of surface water with TP (Salmaso et al., 2018).

The phasing out of phosphate detergents and the improvement of sewage collection systems around the lake led to a reduction of external phosphorus loading.

The warming of winter temperatures produced a decrease of the frequency of full mixing episodes, which stopped completely after 2006, leading a further reduction of nutrients to the upper layers.

The decrease of nutrients caused a decline of the mesotrophic *P. rubescens* which was partially replaced by anatoxins (ATX) producers *Tychonema bourrelly* (J.W.G. Lund) Anagnostidis & Komarek, as confirmed by the opposite trends of ATX and MCs observed since 2009 (Salmaso et al., 2016).

Lake warming supports the development of mixotrophic dinoflagellates and cryptophyte observed since the mid-2000. This two flagellates groups are favorited in warm and (meso-)oligotrophic environments due to their ability to move in stable water columns and to sustain autotrophy with mixotrophy (Salmaso et al., 2018).

From in situ and MIVIS (Multispectral Infrared and Visible Imaging Spectrometer) data analysis results that there was a loss of well-structured submerged macrophytes vegetation replaced by destructured stands (Bresciani et al., 2012). In 2016 ARPAV, during the last monitoring, observed the disappearance of Charophytes in a long stretch of coast.

Another emerging threat is the introduction of non-indigenous species. In Lake Garda was observed an increase of invasive or potentially invasive species among which vertebrates, invertebrates, aquatic plants and algae (Ciutti et al., 2011).

Since 1960, Lake Garda has received up to 323,300,000 m^3 of water diverted from the River Adige through the Adige-Garda canalization, built to prevent overflowing during extreme flood events. During the last flood event happened in October 2018 17,000,000 m^3 of water and mud have been discharged from Adige River to Garda Lake and actually we don't know exactly the effects on the ecosystem but the studies are underway.

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Lake Lugano

General description

Lake Lugano is a deep natural subalpine lake located across the border between Switzerland (Canton Ticino) and Italy (Lombardia region). The basin has a pluvio-glacial origin: the valley originated from river erosion over the Tertiary period (Messiniano) and was shaped by glaciers during the Pleistocene. The geology of the catchment is dominated by calcareous rocks, gneiss and porphyry, while woodland and built-up (urban) areas represent the main land-cover types. The lake has eight main tributary streams (average flow $\geq$ 0.2 m^3 s^{-1}) and one outlet (River Tresa). The lake is divided into three sub-basins, each one presenting different geo-morphological and hydrological characteristics.

The North basin has a maximum depth of 288 m and a relatively small catchment surface area, which determines a long water renewal time (12 years). This basin became meromictic during the eutrophication phase (*c*. 1940-1970), leading to anoxia below *c*. 150 m of depth. Since then, this basin turned over only twice, following exceptional cold winters (i.e. in March 2005 and February 2006; Holzner et al., 2009).

The South basin, which is separated from the North basin by an artificial damn built on a morainic front, is shallower (maximum depth: 95 m) and has a shorter water residence time (1.5 years). Like the North basin, the South basin has a warm-monomictic turnover regime, with turnovers occurring at the end of the winter (February–March). However, this basin has remained essentially holomictic, although turnovers have been skipped following exceptionally warm winters. The two main basins are connected by a narrow channel that has an average discharge of *c*. 24 m^3 s^{-1} (north to south flow).

Finally, the small Ponte Tresa basin (max. depth 50 m), located to the western side of the lake, is regulated by a dam at the outlet (River Tresa) since 1963 and has a short water residence time of 0.04 years (Barbieri & Polli, 1992; Barbieri & Simona, 2001).

Existing monitoring programme

Like other peri-alpine lakes, Lake Lugano was affected by a process of increasing eutrophication, which started around the 1940s and peaked between the 1970s and early 1980s. This process, mainly caused by increased sewage input from the developing conurbation, led to eutrophic conditions in the North basin and hyper-eutrophic conditions in the South basin. During the eutrophication peak, for example, phosphorous concentrations reached values close to 140 mg m^{-3} and cyanobacteria blooms (including *Planktothrix rubescens*) became frequent (Polli & Simona, 1992). Since the 1970s, the Swiss and Italian governments have been promoting a restoration program, coordinated by the International Commission for the Protection of Italian-Swiss Waters (CIPAIS). At present, the long-term monitoring program of the trophic evolution of Lake Lugano is run by SUPSI on behalf of the administration Canton Ticino.

Although the pre-industrial (reference) conditions of the lake are probably represented by oligotrophic conditions, the main goal of the restoration program is to restore mesotrophic conditions, which would allow the sustainable use of the lake's water as water supply, for fishing and tourism. Specific restoration objectives were set for total phosphorus (30 mg m^{-3}), primary production (150 g C m^{-2} $year^{-1}$), and dissolved oxygen (4 mg l^{-1}). In the 1990s, objectives were set also for the maximum acceptable external phosphorus loads, which were estimated at 18 t $year^{-1}$ for the North basin and 22 t $year^{-1}$ for the South basin (Barbieri e Mosello, 1992).

Past, emerging and potential threats

During the last 30 years, the phasing out of phosphate detergents and the improvement of sewage collection systems and treatment plants from both the Italian and Swiss sides of the lake led to a reduction of the external phosphorus loadings and a recovery of the lake's trophic status (Barbieri & Simona, 2001; Lepori & Roberts, 2017). Despite the decreasing trend of phosphorus, however, the restoration process is still incomplete (Lepori et al., 2018a). For example, while in the North basin current phosphorus concentrations and external P loading have essentially reached the restoration targets, in the South basin the targets are still substantially exceeded. Furthermore, primary production is still high (indicating persisting eutrophic conditions) and water oxygenation remains critical in the deep waters of the whole lake.

The recovery of deep-water oxygenation might have been partly hindered by climate warming, which has weakened winter turnovers and therefore has reduced the resupply of oxygen to deep waters. In addition, during the last decade, warming has also apparently favored the accumulation of phytoplankton biomass in summer (Lepori et al, 2018b), especially that of cyanobacteria. On the other hand, in the meromictic North basin, exceptionally cold winters (e.g. years 2005-2006) have led to temporary offsets of any restoration progress by causing sudden events of deep mixing, which in turn have led to upwelling of phosphorus previously accumulated below the chemocline (Lepori et al., 2018a).

Monitoring data show that the biological communities of the lake have varied considerably in space and time during the last few decades. Despite similarities (e.g. in the seasonal succession of the main taxonomic groups: diatoms in late winter and spring, chlorophyceans in summer, and cyanobacteria in summer-autumn), the North and the South basins show differences in phytoplankton composition. During the last 30 years, the zooplankton biomass has shown a tendency to decrease, driven mainly by herbivore species (Lepori & Roberts, 2017). The causes of this decline are complex and probably involve a reduction the nutritional quality of phytoplankton. The fish assemblage has displayed some of the largest changes, owing to the decline or disappearance of endemic species (e.g. the planktivorous bleak) and the colonization by non-native ones (Polli 2004). These biological changes, which reflect changes in the structure of the lake's food webs (Lepori & Roberts, 2017), have also contributed to shape the trajectory of the lake and may therefore have added to the delay in achieving the targets of the restoration program. Nonetheless, the lake's trajectory probably results from an interplay of different internal and external factors, whose disentanglement is currently object of research.

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Lake Mondsee

General description

Lake Mondsee is a deep prealpine lake located at the northern fringe of the European Alps in Upper Austria at an altitude of 481 m above sea level. The lake has a mean depth of 34 m, the maximum depth is 68 m. Due to ongoing climate- and associated lake warming, Lake Mondsee changed from from dimictic to monomictic mixing pattern (Ficker et al. 2017). The catchment area (247 km²) is divided into two geological units by a main Alpine thrust fault (Van Husen, 1989) following the southern shoreline of the lake. The norther catchment (ca. 75% of the total catchment) is formed by peri-Alpine hills up to 1100 m above sea level, which are built up by Cretaceous Flysch sediments (Sandstone, Argillite). The valleys are covered by moraines formed by latest Pleistocene glacier activity (Van Husen, 1989).

Three tributaries drain the northern catchment: the Fuschler Ache in the west, the Zeller Ache in the North and the Wangauer Ache in the East. Regarding its size and runoff variability, the Fuschler Ache is the largest tributary to Lake Mondsee. The southern sub-catchment (ca 25%) reaches an evelation of 1700 m above sea level and is part of the Northern Calcareous Alps. The base rock is composed of Jurassic and Triassic units of limestone and dolomite forming steep slopes at the southern lake shoreline. Via the river Seeache, Lake Mondsee drains into Lake Attersee at the south-eastern end of the lake (Kämpf et. al 2015).

Existing monitoring programs

Lake Mondsee is among the best studied lakes in Austria with long-term phytoplankton datasets from the last 40 years (Bergkemper & Weisse 2017). Even longer records (50 years) are available for some abiotic parameters such as Secchi depth (Dokulil et al., 2000). According to the Water Framework Directive Lake Mondsee was sampled 4 times a year: in spring circulation, beginning of summer, summer stagnation, and at the beginning of the autumn.

As lake Mondsee didn`t reach the ‘‘good ecological status’’ required by the WFD in 2008, the seasonal sampling was replaced by a monthly sampling in 2009. By 2012, Lake Mondsee had reached the ‘‘good ecological status’’ (Schafferer & Pfister, 2016). The Federal Agency for Water Management analyses 14 parameters (water temperature, conductivity, pH, SBV, oxygen content, oxygen saturation, ammonium, nitrate, total phosphorus, filtered phosphorus, insoluble phosphorus, orthophosphate, chloride, nitrite, chlorophyll-a) on a monthly basis.

Past, emerging and potential threats

Eutrophication and massive algae and cyanobacteria blooms where caused by the sewage plant in Mondsee. Due to system improvements, this source of pollution was eliminated.

In the north, Lake Mondsee shows higher eutrophication levels than in the south, this is caused by runoff and diffuse pollution (the city of Mondsee is located at the north shoreline, furthermore agriculture is one of the dominant forms of landuse around the lake).

Increasing stratification periods lead to anoxic condition in deep areas of the lake, fish can no longer inhabit this areas. Most likely this trend will be continued due to climate change (Ficker et al. 2017).

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Lake Starnberg

General description

Lake Starnberg is a deep natural subalpine lake located in the Bavarian district of Oberbayern, which lies South-West of Munich in Germany. The basin has a fluvio-glacial origin: the valley was shaped by river erosion (Urwürm) and glaciers during the Pleistocene. Calcareous rocks and gneiss dominate the geology of the catchment. Woodland and crop areas represent the main land-cover types. The lake has only a small main tributary stream (average flow ≤ 3.6 $m^3 s^{-1}$) and one outlet (River Würm). The lake has only one elongate North-South orientated basin, which is approximately 25km long, with the deepest part being in the North. The lake lies 584.2 m above sea level.

The basin has a maximum depth of 127.8 m and a relatively small catchment surface area of 314.7km^2, which causes a prolonged water renewal period of 21 years. The lake surface area is second largest in Bavaria with 56.36 km^2. The basin is monomiktic (winter mixing).

Existing monitoring program

Like other pre-alpine lakes, Lake Starnberg was affected by eutrophication. The peak occurred in 1980-1985 with annual means of 25-30µg/L TP and 6-9µg/l chlorophyll, resulting in a mesotrophic status. Nutrient reduction measures were implemented successfully (see figure 1), returning the lake to its oligotrophic state by 2001, including the recovery of deep-water oxygenation, with dissolved oxygen above 4 mg l^{-1} during all seasons.

The construction of a perimeter sewage system in the years 1964-1976 was the key to reducing nutrient input. A further restoration program (Bucksteeg 1984, Henschel & Melzer 1992) was set to improve sewage plants and also deal with the second main stressor, the overuse of the lake shorelines for recreation. Macrophyte and especially reed cover and the sensitive Chara taxa was lowest before 2000. Large areas of the lake shoreline were declared protected areas. At present, the long-term monitoring program of the trophic assessment of Lake Starnberg is run by the regional water management administration (WWA Weilheim;

www.wwa-wm.bayern.de). Information about water chemistry, as well as biological and hydrological data and are regularly published on the internet platform GKD (GKD 2018) of the Bavarian Environment Agency. Recent results showing effects of implementing the European Water Framework Directive (WFD) which have also been reported in the second river management plan. According to the most recent assessment of the lake, in line with the EU-WFD, the overall ecological status is good, with good status of the biological elements phytobenthos and macrophytes and high for phytoplankton.

To support the objective of maintaining the oligotrophic status, the total phosphorus (TP) target is set to a range of 6-8 mg m^{-3}. Observed TP concentrations comply with this target since 1999. Since there is no publication of long term data including the most recent years, the following figure demonstrates the decrease of TP concentrations since 1985 and the oligotrophic status of lake Starnberg in the last 16 years.

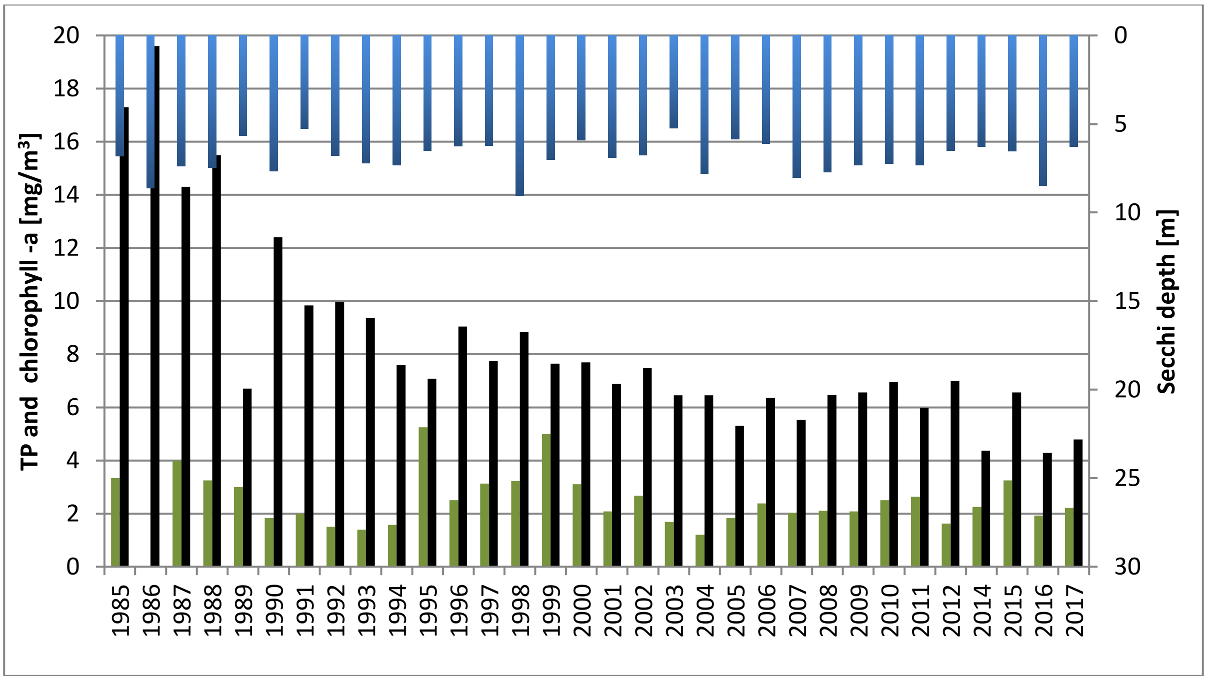

Figure 1: Annual means of the trophic parameters chlorophyll a (green), total phosphorus (TP, black) and Secchi depth (blue) in Starnberger See in period 1984 – 2017. Source: data management system LIMNO of the Bavarian Environment Agency (LfU) based on data input from WWA Weilheim.

Past, emerging and potential threats

During the last 30 years, the restoration process has reached its target (see figure 1). Still, the composition of macrophytes and low reed coverage still deviates from the natural and high status. Since the lake is very large, remote sensing methods are being tested to investigate seasonal changes (Fritz et al. 2017). The next lake monitoring in line with German WFD methods and including all biological elements will take place in 2020.

The lake is still under human pressure by strong recreational use and an increasing human population will likely intensify use of the lake. Climate warming, which has weakened winter turnovers and therefore reduced the resupply of oxygen to deep water layers, may add a further risk to the lake ecosystem.

Monitoring data show that the biological communities of the lake have varied considerably in space and time during the last few decades. The causes of this decline are complex and probably involve a reduction of the nutritional quality of phytoplankton. A large change was seen in growth, weight and catches of whitefish in the commercial fishery (Schubert 2017).

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KEY RIVERS

River Adige

General Description

The River Adige is the second longest italian river and the third for catchment area (12,100 km2). The spring is placed in Val Venosta near the Lake Resia at 1,586 m a.s.l.. The main stream is 409 km long and is spread in the Trentino Alto Adige and Veneto regions, to flow to the Adriatic Sea south of Venice (Distretto Idrografico delle Alpi orientali, 2010). The River Adige is connected to Lake Garda by the Mori-Torbole tunnel, an artificial underground canal built for flood prevention.

The geological settings of the watershed is characterized by a great variety of rocks types belonging to different terranes of the Eastern Alps from the inner chain to the piedmont area. These rocks represent portion of metamorphosed units of ocean floor (Penninic and Austroalpine nappes) and mostly un-metamorphosed rock units of continental margin and shallow sea (Southern Alps). The metamorphic siliceous units are located in the Northern portion of the catchment area as far as South to Bozen, while further South carbonatic and terrigenous sedimentary rocks prevail.

The lithological variability represents also a large number of different ions to be soluted or transported in water. The ion availability is related to the rock resistance to weathering and how the debris are transported. The metamorphic rocks, exposed to the grinding and long transportation operated by the glaciers, are the source of a lot of loose material into the valleys, as far as South to the piedmont (Verona).

The rocks from the Southern Alps are mainly carbonates (triassic and jurassic dolomite and limestones) or locally gypsum that are easily soluted even if slightly weathered.

Carbonates fragments and terrigenous (sandstone, marls, clay) and magmatic (tuff, ryolite, granite) units are also source for clasts transported into the main valleys in the past by local glaciers and nowadays mostly by gravity and rill erosion related to the steep slopes.

The mixed debris, both from the alpine valleys and the prealps slopes, have been reworked and accumulated into the main valley to fill in the deep Adige valley with the so called fluvio-glacial sediments up to 400 – 600 m thick. More recently, the Adige River, out of the mountain area, has incised its own deposits in the piedmont near Verona where now it flows trenched between fluvial terraces.

The main tributaries of the River Adige are the Isarco, the Noce and the Avisio rivers. For the basin surface, the most important is the Isarco, which has an extension of more than one third of the whole Adige basin.

In the northern part of the basin 31 major reservoirs have been built over the last 70 years for hydropower production, with a total capacity of 571 x 106 m3 of water (Bruno et al., 2009a; Bruno et al., 2009b).

In the lowland area the water of the River Adige is used for drinking purpose (ca. 2.3 m3s-1) but between the provinces of Verona and Venezia the prevalent use of the water is for the irrigation of agricultural fields (up to over 150 m3s-1 during the vegetation season, from May to August) (Salmaso & Zignin, 2010)

The river channel slope from the source to the mouth, is ranging from 53 to 0.1 ‰ and the width of its sections goes from 40 m between Merano and Bolzano to 269 m close to Zevio, in the southern part of the basin (Distretto Idrografico delle Alpi orientali, 2010)

In the upper basin, characterized by a continental climate, precipitation is highest in summer and lowest in winter, whereas in the lower basin, with a sub-littoral climate, the precipitation is higher in autumn than in spring. Discharge is generally higher in spring-early summer due to snowmelt and rain contribution (Gumiero et al., 2009). The precipitation regime shows a strong variability along the basin: from 400-500 mm yr-1 of Val Venosta (northern part) to 1600 mm yr-1 of the highest part of Avisio basin with an average value of 900 mm yr-1 in the whole Adige basin. (Distretto Idrografico delle Alpi orientali, 2010). Headwaters are mainly fed by snowmelt and rain by the 185 glaciers (covering around 200 km2) scattered around the basin that have retreated over the last 50 years (Gumiero et al., 2009).

Existing monitoring programme

In the past River Adige has been subject of targeted studies of its ecological status, to support initiatives directed to the drafting of basin plans or regulatory obligations. At the end of the 90s an exhaustive work was promoted by the Basin Authority the Adige which involved the autonomous provinces of Bolzano and Trento, the Veneto Region and numerous Research Institutions (Braioni, 2001). In 1997-1998 was performed a study on the principal environmental factors influencing the seasonal dynamics of potamoplancton in three stations of the lowland course (Salmaso & Braioni 2008). The survey on potamoplankton has been extended from 2007 to five stations representative of the submontane valley and plain features (PlanAdige Project; Salmaso et al., 2007). In the same period started also a project to identify effective protocols for the sustainable management of marble trout (Salmo trutta marmoratus) through genetic, phenotypic and ecological characterization of the populations present along the River Adige (Project GAME; Baraldi et al., 2007). The Adige River is one of the “case studies” of the Interreg Alpinespace project HyMoCARES (2017-2019), research that aims to clarify the links between human uses, hydromorphological processes and the availability of characteristic ecosystem services (ES) of Alpine rivers.

In according with the Water Framework Directive 2000/60/EC the River Adige has been divided in 25 water bodies: 9 in the Province of Bolzano, 8 in Province of Trento and 8 in Region Veneto.

The rivers are mostly natural (18 water bodies), but 6 rivers, with morphological alterations, are strongly modified.

Monitoring, in according with WFD, are performed by Environmental Agencies (APPA BZ, APPA TN and ARPAV Veneto).

In the last classification (2015-2016) the chemical status was good for all the rivers whereas the ecological status was good for 22 and moderate for 2 (Distretto Idrografico delle Alpi Orientali, 2016)

In 2017 the trophic index Pollution Level from Macrodescribers for the Ecological State (LIMeco) of the Adige river in Veneto results “high” (Agenzia Regionale per la Prevenzione e Protezione Ambientale del Veneto, 2018). In the previous year (2014-1016) the LIMEco index was between “good” and “high”. Furthermore for Adige river in Veneto, both in the period 2014-2016 and 2010-2013 the Chemical Status Index and the Biological Status Index were “good”. Just an exception for the water body n. 114_48 (Piacenza d'Adige-PD) where the Ecological status (2014-2016) was “moderate” due to the presence of herbicides

Past, emerging and potential threats

Most of the outflow in River Adige is regulated by hydroelectric and irrigation purpose (Manfreda & Fiorentino, 2008; Gumiero et al., 2009; Bruno et al., 2009a). These barriers (seven between Bolzano and Verona) almost entirely stop the natural flow of the river, determining situations of scarcity of water into the natural bed for long periods of the year (0.5-2.5 m3s-1, mostly from the end of November to the beginning of May) (Salmaso et al., 2010). It has been shown that their effects is very destructive for the communities living in the watercourse (Bruno et al., 2009a; Centis et al., 2010; Salmaso & Zignin, 2010). These barriers can create several troubles, including health problems due to insufficient dilution of unauthorized discharge, lowering of the water table with the consequent desiccation of the watercourses that flow alongside the river, negative effects on aquatic biocenosis and therefore on the self-purification potential of the river (Salmaso et al., 2010).

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River Drôme

General description

The river Drôme is a tributary of the left bank of the Rhone, which is born in La Bâtie des Fonds, at the East of the Diois. Its catchment area covers 1,640 km² and the watercourse stretches for nearly 110 km. Composed mainly of limestone and marl, the catchment area has a mid-mountain relief culminating at 2,041 m at Glandasse. Nevertheless, the most frequent altitudes range from 800 to 1,400 m. Locally, limestone outcrops favor the formation of slopes very stiff.

The main permanent tributaries of the Drôme come from the Vercors, the Bez, the Sure, the Gervanne and the Sye. Only one important tributary comes from the Diois, the Roanne. The Grenette, another tributary of relative importance, drains the hillside massif south of the plain of Val de Drôme (FRAPNA 2005 study).

According to Landon (1999), the Drôme presents a pre-spin hydrological regime sub-mediterranean trend. This regime is characterized by very low water summer period, low water in winter and maximum flow in March-April (contributions due to melting of snow on the upper basin). However, all year round but especially in autumn and spring, very powerful floods can occur ("cévenol" type floods). During the summers of 2003, 2004, or 2009, very dry, the bed of the Drôme dried up on important sections in its downstream part, but also in an area upstream of the marsh of Beaurières in the high Diois.

Characteristic of the submediterranean hydrosystems, the Drôme presents strong slopes upstream then a watercourse in braids downstream, an abundant bottom load from close hillsides, a contrasting hydrological regime, marked by high intensity, and fragile banks drawn in gravelly alluvium. On the geometrical point of view, these braided watercourses present a plan multiple, not sinuous and unstable. The different arms spread quite widely in the bed and have a shallow topography. They enclose benches composed of sand and pebbles not very vegetated because of an intense and frequent reworking especially during floods (Liebault., 1999 and 2002).

Existing monitoring programme

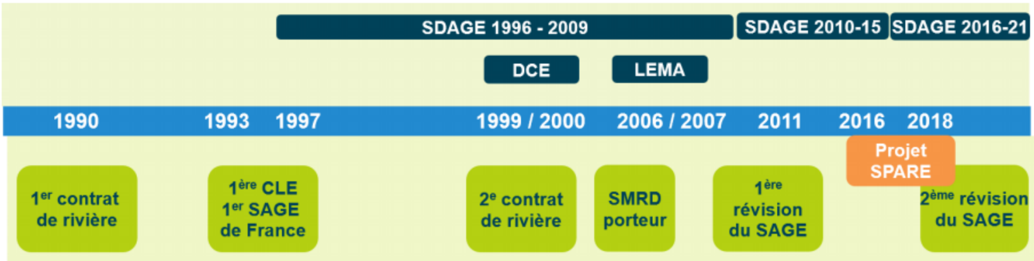

Figure 1: History of the local water management

Before the 90s, there was little or no sanitation equipment in the watershed. The effluent was then directly discharged into the natural environment with very damaging causes for it, but also for the economic and touristic development of the valley (at the beginning of the Eighties, 80% of the linear one of the Drôme was forbidden to bath) (Margat., 1986). The poor water quality and the increasing tourist stakes required an ambitious policy of treatment of the effluents on many municipalities: the implementation of the first river contract (Figure 1). Then, The SAGE (Scheme of Development and Management of Waters) which sets the general objectives for the use, development and the protection of surface and underground water resources (Girard e Riviere-Honegger, 2014) has been put in place. In particular, the SAGE manages the quality of groundwater, surface water and drinking water. The Local Water Commission (CLE) is a deliberative, independent and decentralized assembly responsible for the preparation and implementation of the SAGE (Landon et al., 1995). Today, the SAGE is under review to establish the next management objectives of the Drôme River, and the INTERREG SPARE project aims to a further harmonization of human use requirements and protection needs.

In the initial state of the SAGE, the quality of the surface waters is apprehended through physicochemical quality, bacteriological quality, hydrobiological quality and fish. According to the stations, different parameters are monitored: oxygen balance, temperature, nitrate and phosphorus contents, acidification, specific pollutants, benthic invertebrates, diatoms, macrophytes, fishes, hydromorphology and hydromorphological pressures, in order to evaluate water quality and ecological status of the river. Most of the parameters are monitored every years (http://sierm.eaurmc.fr/surveillance/eaux-superficielles/index.php).

Past, emerging and potential threats

The physicochemical quality was considered overall good on the Drôme between 1994 and 2002, the quality of the tributaries is more variable, from very good on the Roanne to bad on the upstream of the Grenette. The 2006 seasons show an alternation of good quality and very good quality sections, the main declassifying parameters being, a priori, of urban and "industrial" origin (wine cellars) upstream (organic materials and nitrogenous materials) and agricultural downstream (nitrates).

The evolution of the bacteriological quality is very clear, since 88% of the rivers are "swimmable" (quality good or very good), while 30% of the linear could display bathing bans in 1997 (average quality or bad). Some black spots remain, however, on the Bez downstream and upstream of the Drôme due to wastewater treatment plants.

The hydrobiological quality is good to very good throughout the basin since 1994, with the exception of the downstream of some tributaries such as Sye and Grenette. The fish farms are salmon-type upstream (Drôme and tributaries), intermediate (mixed) on the Drôme between the jump of the Drôme and the confluence of the Gervanne, as well as on the Roanne downstream of Saint-Benoît, and cyprinicole on the Drôme downstream of Gervanne. The watercourses of the basin heads (Comane, Meyrosse, Roanne, Gervanne ...) are home to species (crayfish with white feet) and heritage habitats. The works and developments undertaken as part of the River Contract have sought to promote the diversity of environments (data: http://sierm.eaurmc.fr/surveillance/eaux-superficielles/index.php).

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River Wertach

General description

Study site river Wertach is originating in the northern Alps near the border between Austria and Germany, and is then running in roughly north direction through Bavaria towards the Danube River. Wertach has been a typical pre-Alpine river with high sediment load. The seasonal discharge regime is shaped by snow melt in spring. This snowmelt regime may be superimposed by sudden floods which may appear after heavy rains (orographic lift rains) occurring with northerly winds at the northern rim of the Alps. Drainage area of river Wertach comprises 1441km^2 and total length is 137 km.

In period 2013-2017 the annual mean of discharge was 16.4m^3/s, with distinct maxima up to 190. An additional description of the river Wertach is available by the Alpine Space project HYMOCARES (2016-2019).

Existing monitoring program

At present, the long-term monitoring program of river Wertach is run by the regional water management administrations (WWA Kempten; www.wwa-ke.bayern.de and WWA Donauwoerth). Five different water bodies are assigned to river Wertach by the Bavarian Environment Agency. Parameters such as nutrients and solid matter data are monitored monthly at the main station “Ettringen Wehr Unterwasser”, and at several further stations in those years with monitoring according to the EU-WFD.

Chemical, biological and hydrological data are regular published by the internet platform GKD (GKD 2018) of the Bavarian Environment Agency in all details including taxa lists. Results of the recent years with implementing the European Water Framework Directive (WFD) have been reported also in the second river management plan (2nd RMPL). Focusing on the Wertach water body (OWK 1_F149), which is covering the project stations “Tuerkheim Pegel” and “Ettringer Wehr”, the assessment in line with the German WDF-assessment provides the overall ecological status “moderate” in the 2nd RMPL (details see table 1). The up-stream water body (OWK 1_F149) covering fish sampling station “bridge Goerrisried” is in poor status caused by low quality of the fish community.

Tab. 1: Assessment status classes of the water body “Wertach von Einmündung Lobach bis Staustufe Inningen”. Ratings for the different bio-components, water chemistry as well as for overall ecological status (EQS).

OWK 1_F149	EQS	Fish	Makro-zoobenthos	phytobenthos & macrophytes	chemical status
2nd RMPL	moderate	moderate	good	moderate	good except Hg

Past, emerging and potential threats

In the past, the river has historically been used for extensive fishing, timber rafting and water mills; artificial lakes operating as seasonal water reservoirs, in order to more smoothly feed to the hydropower plants constructed downstream. River Wertach is channelized, the longitudinal slope of the channel increased, and the width decreased, which resulted in higher flow velocity. Also, the input of new sediment into the river was decreased by artificial bank stabilization, and by the construction of dams in the main channel as well as in tributary streams. As a result, the river incised its river bed for several decades, and thus lowered its river bed. River channelization caused a reduced water retention capability, so that the flood risk has risen again. In addition, the ecological integrity of former river floodplains has been greatly affected by channel incision and by the loss of longitudinal continuity.

A restoration program has started according the Bavarian plan “Wertach Vital”, managed by the regional water management administration (WWA Donauwoerth) under tight involvement of the public community. A first measure was realized at the dam Ackermann-Wehr already in October 2000 and further measures were continuously implemented until today. The EU-Interreg project HymoCare (2016-19) supports this plan in the region of the large city Augsburg by implementing and monitoring the hydro-morphological revitalization of a 14km long river stretch before the confluence to river Lech.

Most importantly, the human population of city Augsburg have to be reliably secured from destructive floods. To prevent the river from further erosion, measures have to be taken to reduce shear stress. Construction of a dynamic and continuous river system will help generating a continuous habitat for aquatic fauna and flora. The „Wertachauen", as an urban recreation area, will be re-designed in a more natural way, and be accessible for everyone.

According the plan of measures (2016-2021) in the Bavarian Danube catchment further measures will be realized also in upstream sections of the Wertach (Bavarian Environment Agency: 2015).

The fish assemblage has displayed some of the largest changes within the river fauna. According to the WFD-Reference, 27 species should be present within the metarhithral to epipotamal regions of the River Wertach. Nase (*Chondrostoma nasus*), a potamodromous middle distance migratory species, for example, has experienced a drastic reduction.

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WWA-Donauwoerth: Wertach Vital: www.wwa-don.bayern.de/hochwasser/hochwasserschutzprojekte/wertachvital/

River Soča

General description

Soča is a transboundary river flowing through Slovenia to Italy. Soča River, with lenght of 140 km, has source in the Southern Julian Alps in Trenta Valley at 1000 m a.s.l. (NW Slovenia, SE Europe), west/southwest of the Mediterranean – Black Sea divide. The Soča River run for 95 km through Slovenia before crossing into Italy and drain into the Adriatic Sea (Maddock et al., 2007), passing the Bovec Basin and southern foreland of the Alps. The total area of its basin is 3400 km^2.

The course of the Soča River can be divided into 3 parts:

1) Upper Soča Valley: from its source to village of Most na Soči where the river flows in its natural course,
2) Medium Soča Valley: from Most na Soči to the border between Slovenia and Italy where 3 major dams and accumulating lakes are regulating the river,
3) The lower Soča: from border to its mouth where river is freely flowing on north Italian flats.

Structurally the Soča Valley is set within the nappe system of the Julian Alps and it consists mainly of Mesozoic carbonate rocks with rare patches of Cretaceous clastic rocks (''flysch'') exposed in some intramontane basins and valleys. River valleys of Soča River and its tributaries are partly filled with lithified and non-lithified clastic sediments of Quaternary age (Bavec et al., 2004).

Soča River has a catchment area of 1576 km^2 and a torrental flow regime, with high flows occuring at any time of year. The lowest natural flows are experienced both in summer (normally in August) and winter months (December to April) with generally higher snow-fed flows in spring and rain fed flows in autumn (Maddock et al., 2007; Smolar-Žvanut and Mikoš, 2014).

The main tributaries of the Soča River are Koritnica River in the upper part, Idrijca River in the middle part and Vipava River in the lower part. The rest of the tributaries are smaller with torrential character. Average decline of the Soča River from the source till confluence with Koritnica River is 29 ‰. The decline is afterwards much lower with decline of 4.9 ‰ till confluence with Idrijca River and decline of 3.3 ‰ till Italian border (VGP, 1991).

In the upper Soča Valley 35% of the land is covered with forests and 35% are pasture lands. In the lower Soča Valley 36% of the land is covered with forests and 59% are agricultural lands (Ranfl, 2010).

Existing monitoring programme

Sampling is carried out during low flow season, optimally during the natural low-water period, when hidrological conditions are stable for a longer period of time. The most appropriate time for taking samples in Slovenia is between June and September.

There are 6 sampling sites in river Soča which are included in national programme for monitoring of ecological status.

- Soča spodnja Trenta GKY: 400340, GKX: 135598
- Soča Kamno GKY: 395073, GKX: 119383
- Soča nad Kanalom GKY: 394700, GKX: 105778
- Soče Deskle GKY: 393157, GKX: 101918
- Soča Plave GKY: 391433, GKX: 100227
- Soča Solkanski jez GKY: 395366, GKX: 93091

In National Monitoring Programme for years 2016-2021 one phytobenthos sampling (2018) was carried out in sampling site Spodnja Trenta and one sampling (2017) was carried out in sampling site Solkanski jez. Sampling in sampling site Solkanski jez and in sampling site Kamno is forseen in year 2020. Water body at sampling site Solkanski jez is heavily modified. It is a water reservoir for HPP.

Past, emerging and potential threats

The Soča River is one of the Alps' cleanest waters, especially in the section from its source to the town of Tolmin. Downstream from Tolmin, the river changes significantly due to hydro-electric power plants, extensive farming, transport (railway and main road) and industry. Therefore, it is ecologically degraded.

The main pressures in Soča River corridor are:

a) Water abstraction for electricity production:

The Soča River has high hydroelectrical potential because of the high precipitation, high gradient and favorable natural conditions. The flow in the middle course of the Soča River in Slovenia is highly regulated by a chain of three large (and one small) hydro power plants (HPPs), which produce 450 GWh of electric power per year:

b) Gravel extraction:

Regarding sediment management in the Soča catchment, the main driving forces are the economic goals of the HPPs for optimal functioning of HPPs, the governmental policy for maintainance of river channels in order to protect citizens from detrimental effects of rivers and streams, and the economical goals of several constructing companies in order to obtain aggregates of high quality and high economical value (Mori, 2008). In-stream gravel extraction has many deterious effects on geomorphology and hydrology of the river channel, as well as on riverine and riparian biota.

c) Invasive alien species:

Invasive alien fish species in Soča River Basin are common roach (*Rutilus rutilus*), common rudd (*Scardinius erythrophthalmus*), common chub (*Squalius cephalus*), wels catfish (*Silurus glanis*), common perch (*Perca fluviatilis*), zander (*Sander lucioperca*), common nase (*Chondrostoma nasus*), and brown trout (*Salmo trutta*) (Jogan et al., 2013).

d) Fishery tourism:

In the Soča and its tributaries fishery tourism is wide spread and a very popular sport. Fly fishing is the only permitted method of fishing in the Soča Valley. The famous marble trout, grayling and rainbow trout are the fly fishers' favourites.

e) Sport tourism

In the Soča Valley sport tourism is very well developed with sailing activities on the Soča River such as rafting, and kayaking. The negative impacts of sport tourism are due to spatial interventions such as arrangement of parking spaces and trails, access and exit points for boats, ramps for lowering and raising boats, cable cars, and walkways; interventions in vegetation (removal of trees and shrubs, destruction of undergrowth); interventions in fauna (movement restrictons for wild animals); interventions on watercourses (changes in river cross-sections, arrangements of anchors, boat spikes, etc.) (Golja, 2012).

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River Steyr

General description

The Steyr River raises in the “Toten Gebirge” (Limestone Alps) in Upper Austria at 850 meter above sea level and has a catchment area of about 917 km². The total length of the river is 68 km, 14.9 km are dammed, 5.7 km are residual flow stretches. A total of about 66% of the river stretch is still free flowing. The altitude difference from source to mouth is 560 m. The longitudinal profile is interrupted by a natural gradient (waterfall: drop height 11 m) and numerous weirs. There are 10 hydroelectric power stations along the course of the Steyr.

The water network of the Austrian / Upper Danube, to which the Steyr belongs, was formed in the course of the alpine orogeny about 100 million years ago. Before the Mindel glaciation (600,000 to 300,000 years ago), the Steyr used to flow through today's Krems valley. Since the end of the Würm Ice Age about 10,000 years ago the current course of the river has been created. Due to incision into the gravel body (remainings of the glacier) impressive canyons were created. The canyons of the Steyr and its main tributaries Teichl, Steyrling and Krumme Steyrling are characterized by 30 to 40 meter high, partly overhanging, conglomerate rock walls (Maier & Maier 1997).

Existing monitoring programs

Within the monitoring program for water chemistry, samples are collected every month. Parameters which are analyzed are: Chlorid, DOC, NO3-N, O2 %, BSB5, pH, PO4-P und T. According to these parameters, the Steyr has a high to good status. However, according to the Water Framework Directive, also biological quality elements (fish, phytobenthos, macrozoobenthos) need to be sampled and considered for the ecological status assessment. These assessments, which are carried out in 3-year intervals, take place at different, defined sampling sites (WFD sites) for each BQE.

The overall ecological status (including BQE and hydro-morphological assessments) according to the water framework directive ranges from good to bad for different river stretches (WISA).

Past, emerging and potential threats

The river stretches from km 34,5 to 38,5 and 40 to 49 are considered as heavily influenced waterbodies due to hydropower production, resulting in a partially bad hydro-morphological status.

Due to impoundments, important spawning habitats for fish species have been destroyed. According to the Fish Index Austria (FIA) the Steyr is in a moderate status. During the last three BQE-fish assessments, only 1 native fish species (out of 4) was detected.

Increasing water temperature, increasing number and intensity of flood events and changes in the species composition may be caused climate change.

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