Temporal evolution of lake level fluctuations under flood conditions and impacts on the littoral ecosystems

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ABSTRACT

Lake levels fluctuations are conditioned by seasonal variability, water resources management and above all climate change. Recent studies have shown that global warming potentially affects the risk of flooding and that the decisive factor for flood events is not temperature, but precipitation characteristics and hydrological conditions. Flood events have numerous impacts on social, economic and environmental aspects depending on how humans have altered lands, natural rivers and lake dynamics. Flood protection measures can cause conflicts with conservation measures and with ecosystem services because natural capital is not considered able to control floods and to contribute control floods and that it can contribute to human health and safety. In this paper we analysed the flood events in Lake Maggiore for return time periods of 3 – 5 – 10 – 25 – 50 – 100 – 250 – 500 years, considering the flood frequency in the last ten years using 1868-2021 as a reference period. We discussed the probability distribution of flood peaks, the correlation and linear regression between the lake level fluctuations and macroinvertebrates occurrence. We also presented lake coasts flood hazard mapping. The probability distribution that better describes the annual peak level distribution, is the Gumbel function, while for spring and autumn flood events the better distribution is the Log-Pearson type III. One of the historical flood events in terms of magnitude was in 2000, characterized by a return time of about 50 years. The last flood event in 2020, was characterized by a return period of about 10 years. Considering the seasonal frequency of flood, the autumn magnitude was higher than the spring one, and the differences between seasonal flood events progressively increased. For a return time period of 3 years, a difference of a few cm is expected, while for a return time of 500, years a difference of 1.5 m is feasible. The results suggested a high probability of a flood event every three years and also a forecast of a flood of about 197 m asl (3.14 m above the average lake level) every 10 years. Raising the lake level will affect the reed bed area from 193 m asl, and it will be more effective at 194.5 m (up to a 10% reduction). During flood events, the whole reed bed area is submerged. As regard macroinvertebrates composition and abundance, the first results show significant negative relationships between all sampling stations altogether *vs* the abundance of *Cladotanytarsus* sp. (Chironominae) and nearly significant positive relationships between water levels at Magadino *vs Pscectrocladius sordidellus* (Orthocladiinae) abundances. These few results are perhaps due to the current limited data availability.

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Key words: floods frequency; return period; probability distribution; linear quantile regression; QGIS map; effects on biocoenosis.

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INTRODUCTION

Globally, floods are the most common natural hazard and the third most damaging event after storms and earthquakes (Wilby and Keenan, 2012; Wasko *et al.*, 2021a). Some studies concluded that global warming has potential effects on the risk of flooding, because of the growth capacity of the air to holding water vapour causing extreme events (Swain *et al.*, 2020). However, the decisive factor for flood events is not temperature, but precipitation characteristics and hydrological conditions (Bronstert, 2003; Polade *et al.*, 2014; Pendergrass *et al.*, 2017; Boulange *et al.*, 2021). Indeed, climate and hydrologic cycle influence each other through various driving forces and feedbacks. Superficial or partial knowledge of hydrologic cycle can cause to underestimate the magnitude and the recurrence of flood frequency and would not allow to fully define their evolution (Arnell *et al.*, 2016). The high frequencies of extreme floods from the late 20th century are consequence of the rapid global warming change (Knox, 2000; Swain *et al.*, 2020; Alifu *et al.*, 2022). The hydrological cycle is expected to intensify with global warming, with higher intensity of extreme precipitation events and risk of flooding (Zhou *et al.*, 2012). During recent years extreme rainfall is associated with flash floods in many areas, and studies on the frequency of rainy days, and heavy rainfall days for specific return period showed the impact of climate change on extreme rainfall events and flood risk (Guhathakurta *et al*., 2011; Tabari, 2020). Flood risk can be defined as the combination of the probability of a flood event and its potential adverse consequences on socio-economic aspects and on land. It means that floods and vulnerability are non-stationary events, so that flood risk can be considered a dynamic element of land management (Löschner *et al*., 2017). Rainfall extremes are projected to increase the intensity and frequency of flooding, destroying or degrading aquatic and terrestrial ecosystems, human societies, and the economy (Swain *et al*., 2020; Tabari, 2020). Ecological response to floods depends on how humans will alter the land, natural river and lake dynamics, thus it is essential to understand the ecological implications of climate change (Poff, 2002). Even small changes in climate may have large consequences on ecosystems and economy (Wasko *et al*., 2021b). Hence, the research of potential effects of climate change on flood hazard has made significant progress over the past decade, but the physical causes of changes in flooding and the common methods of design flood estimation, are moving in a context of uncertainty (Gersonius *et al*., 2013; Wasko *et al*., 2021a). Floods, therefore, are influenced by both, the meteo-climatic aspects (precipitation duration and intensity, soil freezing, snow and ice melt), and by drainage soil condition and status (permeability, soil moisture, snow and ice cover, soil urbanization, presence of dikes, dams, reservoirs and their management) (Kundzewicz *et al*., 2014; Tabari, 2020).

In a catchment, the relationship between rainfall and flood is very complex. The response of a catchment area to extreme rainfall depends on the soil antecedent conditions, landslides instability, blockage of bridges and culverts, the rapid urbanisation that decrease the natural capacity of soil to absorb water. All these elements together can increase the flood impacts on the economy and human lives (Kundzewicz *et al*., 2014; Löschner *et al*., 2017). Some floods can be considered a natural consequence of snowmelt or annual monsoon, but others such as heavy rain after long drought periods can cause flash floods with devastating impacts. Recent studies found that the amount of precipitation volume is not increasing as well as the duration of rain peaks is decreasing, revealing an intensification of rainfall events (Wasko *et al*., 2021b). Anthropogenic modifications of the catchment area such as infrastructures, roads and highways, deforestation, altogether changed the runoff characteristics leading to increasing flood risk (Kundzewicz *et al*., 2014), population exposure and vulnerability, damages to infrastructures (Löschner *et al*., 2017; Swain *at al*., 2020; Boulange *et al*., 2021). Often, the effects of climate change on societies are not clearly defined, above all at a local level. Recent studies on natural disasters showed that climate variability and land vulnerability are area-specific, so the local institutions have to develop hazard management and adaptation strategies and to raise awareness of society to climate changes. Urban flooding can cause damage to transportation, electricity supply, civil infrastructures due to the impact of urbanisation on natural runoff, flood volume and urban drainage (Zhou *et al*., 2019). After a flood, frequently, the response at local level is the result of the urgency of the measures whose consequences have not been thoroughly evaluated such as large-scale consequences on ecosystems of some infrastructural intervention decision or intervention. Furthermore, when local political and economic interests coincide with national interests, measures are often implemented without even considering environmental problems (Næss *et al*., 2005). Recent studies showed that flood measures, mainly local, may be in conflict with environmental protection and with biodiversity and ecosystems conservation (Juárez *et al*., 2021). The natural capital could have a role in controlling floods, if enhanced through ecosystem restoration, thereby contributing to human health and safety (Vallecillo *et al*., 2020). At the same time floods cause disturbances and impacts on ecosystems and their services, in particular the availability of these services depends on flood magnitude and impacts depend also on physical, chemical and biological conditions of the ecosystems. In general, the impacts of extreme floods concern ecosystem services such as primary production through nutrient enrichment, soil formation through bank erosion and deposition, drinking water through a sanitation breakdown, disease regulation through microbial proliferation, and tourism through safety risks (Talbot *et al*., 2018). A few studies indicate floods as a cause of the decline in macroinvertebrate density with severe decrease in water quality (Gholizadeh, 2021).

Several researches pointed out that changes in flood and in extreme precipitation are significant and robust when considering climatic regions, because regionalization decreases the noise in extreme precipitation changes occurring at a small scale improving the reliability of results (Tabari, 2020). Therefore, in dry regions, extreme precipitation events are expected to increase and total precipitation to decrease, while in the regions and seasons with high water availability, an increase in spatial water availability is expected (Tabari, 2020). This means that attention must be paid to the amount of water in the atmosphere, but above all to the amount of available water (Tabari, 2020). Furthermore, the profound uncertainty of the effects of climate change on flood events requires a more flexible planning approach and more scientific information in support of a wide range of flood estimation methods (Wasko *et al*., 2021a).

This study aims to analyse the floods event of Lake

Maggiore under conditions of regional climate change, considering: i) the flood frequency during the last ten years, ii) evaluating the return periods, iii) defining the probability distribution of flood peaks, iv) proposing a map of lakeshore flooding and their extent to estimate their impacts on shoreline habitats; v) potential impacts on macroinvertebrate diversity and abundance.

Study area

Lake Maggiore is located in north-western Italy (Fig. 1) and it is the second largest freshwater basin in Italy, with an area of 212.2 km^2, and a watershed of 6599 km^2 divided almost in half between Italy and Swiss, but with 80% of the lake surface in Italian territory and the remaining 20% in the Swiss side. The highest point of the catchment is the Dufour Peak (4634 m asl) and its average altitude is 1270 m asl. Six percent of the catchment is above 2500 m asl. The pluviometric regime is defined as sub-littoral alpine characterised by two maxima in spring and autumn and two minima in winter and summer (Saidi *et al*., 2013). This area is considered an important hot spot of heavy precipitation in the Alps where almost 16% of the intense rainfall comes from this Region. Also, in this Region, extreme precipitation events have increased in the last decade (Saidi *et al*., 2020).

Due to the large hydrographic basin and the historically high amount of rainfall (Saidi et al., 2013), Lake Maggiore is characterized by recurring flood phenomena, of which we have information since 1178. In 1829, the systematic recording of the lake levels began at the Sesto Calende gauge, which observed an exceptional flood in 1868 of which indications and plates of the height reached by the waters remain.

METHODS

Traditionally, in the case of Lake Maggiore, a flood is considered an event in which the lake level equals or exceeds 195.5 m asl.

The maximum lake levels reached by Lake Maggiore every year from 1868 to 2021 were used, considering only the maximum value even if there was more than one flood in the same year, for a total of 154 peaks. Several data sources were used to obtain this long data series.

- data from 1868 to 1911: derived from the Meteorological Observatory of the Italian Alpine Club;
- data from 1912 to 1951: derived from the River Po Hydrographic Office;
- data from 1952 to 2021: derived from the CNR-IRSA gauge (or Verbania Pallanza gauge).

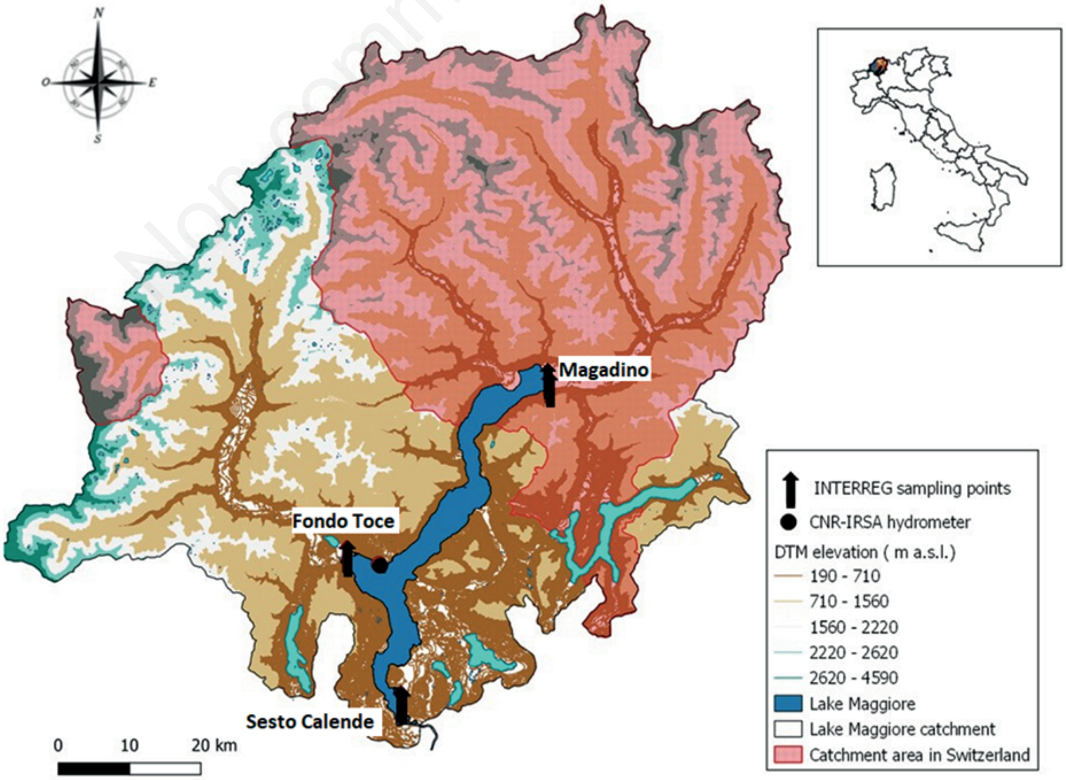

Fig. 1. Lake Maggiore catchment with position of CNR-IRSA hydrometer (Verbania Pallanza gauge).

The data obtained from these different sources were not comparable and useful if they did not refer to a unique reference system. In order to compare the datasets, it becomes necessary to report all data to the same gauge and successively to the sea level. The Verbania Pallanza gauge was selected as reference instrument.

Indeed, given the disparity of the institutions that collected data and considering that they adopted different zero points of the gauge, it was necessary at the beginning to homogenize the dataset (Abdolhay, 2008) and report it, through a regression line (Oosterbaan, 1994), to the zero point of the Verbania Pallanza gauge. Considering the flood events that occurred from 1868 to 1993, it was possible to define the equation that connects the lake level measured to the Verbania Pallanza gauge (Fig. 1), using an overlapping period from 1951 to 1993. This equation was obtained using a regression analysis which made it possible to estimate a value of the "dependent" variable presented by the value of lake level measured at the Verbania Pallanza gauge, on the basis of the value of the "independent" variable presented by the lake level measured in other station as well as explained in Kumari and Yadav (2018).

The equation of the linear regression is:

$$y = mx + c$$

where: y is the dependent variable; x is the independent variable; m and c are parameters function of the dataset.

The correlation coefficient, dimensionless number whose values range between -1 and +1, was calculated. It represents how much variation of y is explained by x. Negative values of r show inverse or negative relationships, positive values show positive relationship (Kumari and Yadav, 2018).

Firstly, we adopted a non-parametric test such as Mann-Kendall (Ahn and Palmer, 2016) to assess the long-term trend of Lake Maggiore water level peaks between 1868 and 2021. Then, a flood frequency analysis was carried out to estimate the magnitude for different return time periods using a probability distribution of annual peaks (Arnell and Gosling, 2016; Wasko *et al*., 2021a). Additionally, the guidelines presented in England *et al*. (2019) helped us to perform seasonal analysis to verify the trend in frequency and magnitude of flood events in different periods of the year.

Floods represent rare events so that they require a probability distribution fitting adequately with the observed data. The choice of the most suitable model to represent a flood event probability was accomplished using the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC) applied to the probability distribution chosen (Laio *et al*., 2009).

In addition, correlations between macroinvertebrate assemblages (α diversity, number of oligochaete and chironomid species, and abundance of major chironomid species) and lake level values were evaluated through the correlation matrix to highlight the most correlated variables (Han and Liu, 2017). The composition and abundance of macroinvertebrate assemblages of Lake Maggiore littorals were analysed at Bolle di Magadino in Switzerland, and Fondo Toce and Sesto Calende in Italy during 2019-2021. In total, 100 samples were collected through the use of a handle-net (250 µm) (see Boggero *et al*., 2022a for method details). Afterwards, in the laboratory, the samples were sorted into the main taxonomic groups without subsampling, identified to the lowest taxonomic level (genus or species) using identification keys specific to each group (chironomids: Andersen *et al*., 2013; oligochaetes: Timm, 2009; other faunistic groups: AA VV, 1977-1985), all specimens counted, and relative abundances used (percentage values). The number of identified taxa (alfa diversity) per sampling site was also included in the analysis. All these data, collected during the INTERREG project Parchi Verbano Ticino (ID 481668) (Boggero *et al*., 2022a) was used to define Kendall's rank correlation. Once the two most correlated variables were selected, we defined the linear correlation between them (Kumari and Yadav, 2018). Linear correlation analysis allows to verify the presence of significant relationships and if potential significant effects of lake levels on littoral macroinvertebrates.

Several correlation coefficients to measure the degree of correlation existed, and Kendall's rank correlation, which is more suitable when the sample is small and which is based on the agreement/disagreement between the correlation pairs, were adopted in this study (Chen and Popovich, 2002).

Finally, to display the interactions on littoral ecosystems a map was created using the QGis software, the lake level range of peaks derived by historical analysis, the cross-border Digital Terrain Model (DTM) (Saxena *et al*., 2020) obtained within the INTERREG IT-CH "Heli-DEM" project (Cross-border cooperation program Italy-Switzerland 2007-2013), with a resolution of about 20 m, the Land use information (Mori *et al*., 2021) and the road cartographic map derived from Lombardy, Piedmont and Swiss cartography. Land uses maps, obtained with QGis software, were applied to define land suitability, available habitat for biocoenosis, land exposure to flood events (Malczewski, 2004). Therefore, land use categories (artificial, agricultural and natural areas) affected by different return time flood periods were estimated. Flood maps were created using flood events with different time return periods and the DTM, through the QGis raster calculator and geoprocessing tools (Criss and Nelson, 2022).

RESULTS

Distribution of lake level peaks and seasonal analysis

The linear regression found using peak lake levels is:

$$y = 1.0881x - 16.978$$

where: y represents the lake levels measured at Verbania Pallanza gauge; x represents the historical lake levels measured, with regression coefficient r=0.999.

The first statistical analysis was to estimate peaks distribution, to identify maximum and minimum, mean, median, and first and third quantile (Tab. 1) describing the grouping or the density of the observations (Fig. 2). A generic function of Kernel density was calculated; this is a non-parametric method to estimate the probability density function of a random variable, the lake level peaks (Fig. 2). Mann Kendall test was applied to the time series of peak lake levels to identify any potential trend. The results show τ=-0.0177 and p=0.74638, a slightly negative non-significant trend. Following Laio *et al*. (2009), AIC and BIC criteria were used to define the most suitable model to describe the peak lake level distribution, and the Gumbel function was chosen. The parameters of the Gumbel distribution, its frequency and magnitude with the return time periods for 3, 5, 10, 25, 50, 100, 250, 500 years were found using *fitdistrplus* (Delignette-Muller and Dutang, 2015), *extRemes* (Gilleland and Katz, 2016) and *lmomco* (Asquith, 2022) R-packages (Tab. 2). The results highlighted a high probability of floods, one event every three years: the second historical flood by magnitude was recorded in 2000 with a return time of about 50 years, and 2020, the last event, has a return period of about 10 years. Regarding seasonal analyses, only flood events were considered (*i.e.*, lake levels >195.5 m together with event date). Those flood events occurring between half-March and half-September were considered spring events, those between half-September and half-March were considered autumn events. A generic function of Kernel density was calculated for spring and autumn events (Fig. 3). The summary features of the two distributions are reported in Tab. 3. The absolute frequency of the two distributions was represented by 45 events in autumn and 22 in spring. The two distributions were quite similar: the autumn flood events reached higher values, whereas the spring ones had a higher distribution density. The Mann Kendall test applied to spring events showed a slight non-significant negative trend (τ=-0.161, p=0.309), and for autumn events a slight positive non-significant trend (τ=0.075, p=0.475). The AIC and BIC criteria for spring and autumn flood events identified the Log-Pearson type III as model distribution. The parameters of the distribution, its frequency and magnitude with return time periods of 3, 5, 10, 25, 50, 100, 250, 500 years (Tab. 4) were identified using *lmom* package. Considering the same frequency of flood events in spring and autumn, the autumn magnitude was higher than the spring one, and the differences between seasonal flood events progressively increased. For a return time period of 3 years a difference of a few cm is expected, and a difference of 1.5 m for a return time of 500 years is expected. Floods lake levels for different return time

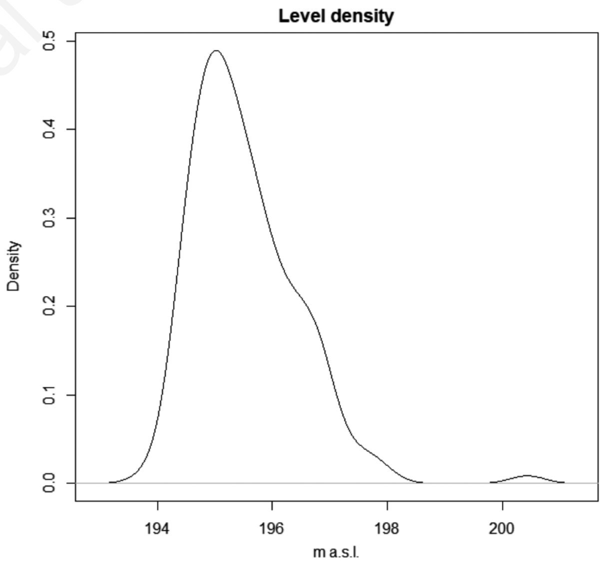

Fig. 2. Probability density function of peak lake levels between 1868 and 2021.

Tab. 1. Main distribution values of the peaks detected between 1868 and 2021 in Lake Maggiore level expressed as m above sea level.

Minimun	1st Quantile	Median	Mean	3rd Quantile	Maximum
193.8	194.8	195.4	195.5	196.1	200.4

Tab. 2. Peak lake levels, expressed as m above sea level, for different return time periods (T in years).

T	3	5	10	25	50	100	250	500
Level	195.76	196.18	196.71	197.39	197.88	198.38	199.03	199.52

periods for the three biological sampling areas of the INTERREG Project (Magadino, Fondo Toce and Sesto Calende) are also discussed (Fig. 4). Intersecting the floods maps and the land description, the land use categories affected by floods events were identified. The results of the natural categories most influenced by different flood return time periods are presented in Tab. 5. The three biological sampling areas represented the most vulnerable areas to level fluctuations, not only to flood events (very high lake level) but also to medium and high lake levels. An example of the distribution of medium and high lake levels at Magadino area is presented in Fig. 5. As the lake level increases, a reduction in the reed surface area is observed. The reduction between 192.5 and 193 m asl is around 0.3%, between 193 and 193.5 m asl is around 2%, as well as between 193.5 and 194 m asl. Above 194 m the reduction is more significant, up to 10% at 194.5 m asl. During flood events, above 195.5 m asl, the reed bed is completely

Tab. 3. Main distribution values for spring and autumn flood events between 1868 and 2021 expressed as m above sea level.

	Minimun	1st Quantile	Median	Mean	3rd Quantile	Maximum
Spring	195.6	195.7	196.0	196.1	196.6	197.7
Autumn	195.5	195.8	196.3	196.4	196.8	200.4

Tab. 4. Flood events for spring and autumn seasons (expressed as m asl) for different return time periods (T).

T	3	5	10	25	50	100	250	500
Spring	196.27	196.55	196.91	197.37	197.70	198.03	198.45	198.77
Autumn	196.58	196.98	197.50	198.17	198.67	199.16	199.80	200.29

Tab. 5. Natural land use categories most affected by different time return periods (Tr) flood events, expressed in percentage.

	Tr=3	Tr=5	Tr=10	Tr=25	Tr=50	Tr=100	Tr=250	Tr=500
Deciduous forests	2.42	7.52	12.9	19.07	21.78	24.04	25.89	28
Coniferous woods	0	0.03	0.06	0.09	0.12	0.12	0.12	0.12
Mixed coniferous and deciduous forests	0.06	0.28	0.47	0.74	0.88	0.99	1.06	1.12
Marshes/wetlands and bogs vegetation	0.42	1.23	1.89	2.34	2.49	2.55	2.59	2.79

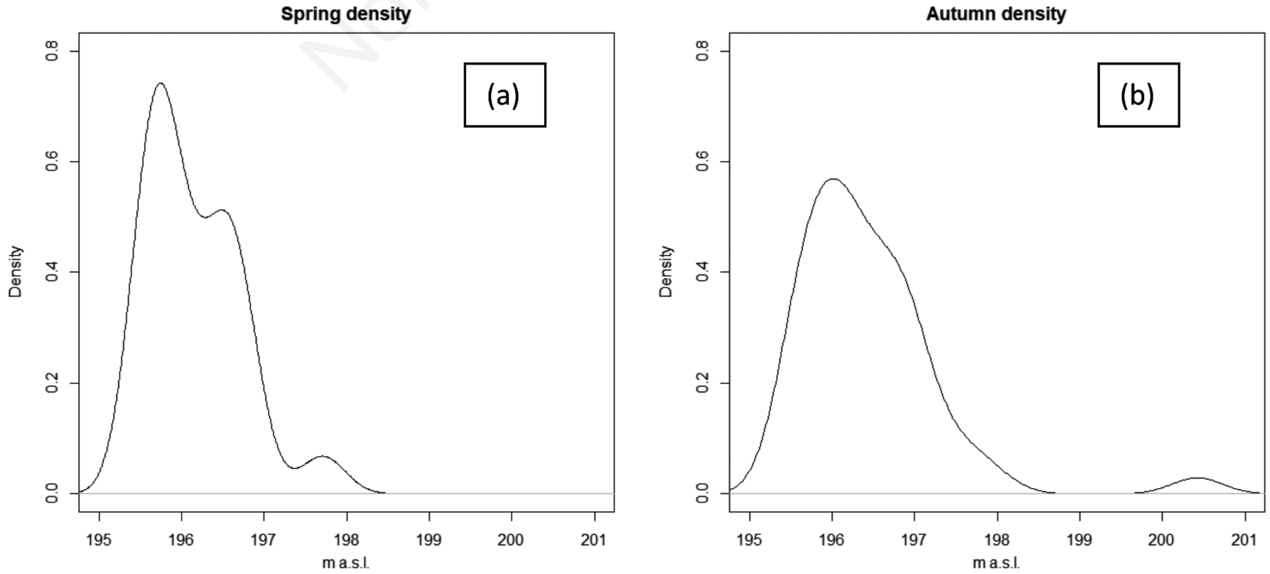

Fig. 3. Probability density function of spring events (a) and of autumn events (b) between 1868 and 2021.

flooded. Some preliminary results of water level fluctuations impact on selected macroinvertebrate parameters (Tab. 6) obtained during the INTERREG Project suggested significant correlations between biological sampling stations taken all together vs the occurrence of *Cladotanytarsus* sp. (chironomid Chironominae) (p=0.004), and just marginally significant findings (p=0.06), but less than 0.10, for Magadino sampling area *vs* the occurrence of *Psectrocladius sordidellus* (chironomid Orthocladiinae).

Tab. 6. Water level control on selected macroinvertebrate assemblage parameters, and significance.

	All sampling sites	Magadino	Fondo Toce	Sesto Calende
alfa.diversity	-0.12	0.07	-0.47	0.20
N oligochaete species	0.05	0.47	0.14	0.00
N chironomid species	-0.17	0.14	-0.36	0.21
Psectrocladius sordidellus	-0.04	0.47*	0.15	-0.26
Cladotanytarsus sp.	-0.43**	0.28	-0.33	-0.47
Stictochironomus sp.	0.14	-0.55	0.47	0.14
Cryptochironomus sp.	0.41	0.47	0.07	0.60

**Marginally significant p=0.06; **p=0.004.*

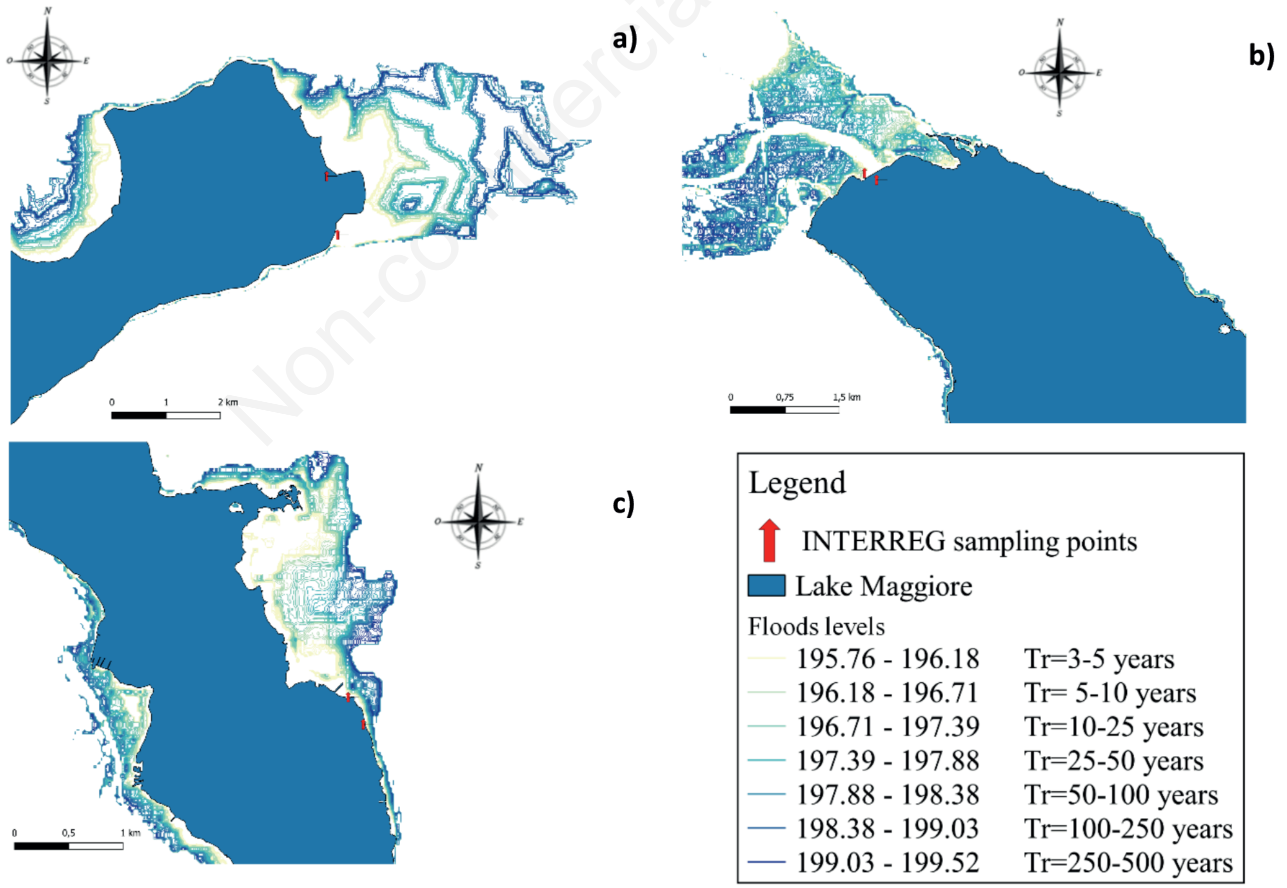

Fig. 4. Floods lake levels (m asl) for different return time periods (Tr) for a) Magadino, b) Fondo Toce and c) Sesto Calende biological sampling areas, and relative legend.

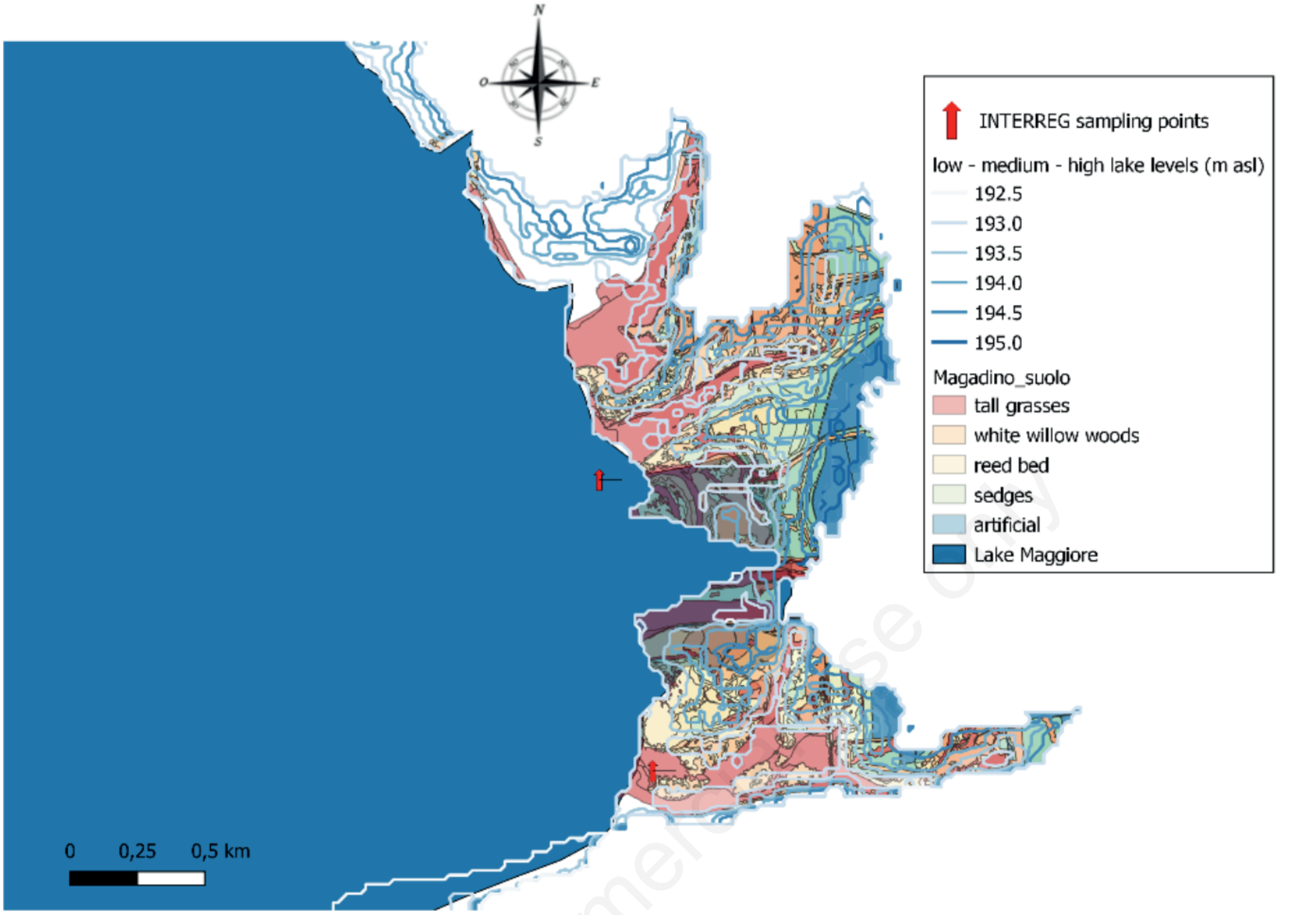

Fig. 5. Lake level fluctuations between 192.5 and 195 m asl over the Magadino area.

DISCUSSION

Linear regression analysis allowed to define a relationship between lake level values historically measured and those measured at Verbania Pallanza gauge. The same equation allowed to also define better lake level management during flood events, usually based only on lake incile measurements representing a low water level than the north and central ones, as demonstrated by the regression equation.

Noteworthy is that during flood events the lake has a lamination effect and lake level management needed to take it into account. In the northern and central part of the lake, during floods, the level is higher than at the lake incile so that littoral infrastructures and above all littoral ecosystems (Leira and Cantonati, 2008) are highly impacted.

Flood events analysis on Lake Maggiore was performed considering the historical flood data and not the precipitation temporal trend. This choice was based on the vast complexity of Lake Maggiore catchment and on a non-dependent relationship between precipitation amount and lake levels. Several studies showed that an increase in extreme rainfall events did not always manifest a clear indication of flood events (Madsen *et al*., 2014). Moreover, the availability of long-time series of lake level peaks allowed to define their potential temporal trend, their flood frequency and magnitude for several return time periods, and for two significant seasons for Lake Maggiore (Luino *et al*., 2018). The application of Mann Kendall test showed a negative trend for annual peaks and spring floods, and a positive trend for autumn floods, all of them statistically not significant.

The lake levels were not directly influenced by precipitations and high temperatures, above all during floods, and therefore become arduous to identify significant changes (Mewded *et al*., 2022). The probability distribution of annual peaks, and of spring and autumn flood events was estimated, showing two different distributions characterized by annual peaks on the one hand, and seasonal flood events on the other. The differences between the two seasonal flood events quantification were probably related to different vegetation status (Guo *et al*., 2008), mainly because spring floods usually occur in May or June (rarely in July or August), and autumn floods in October and November (sometimes in the second half of September) near growing season end. Moreover, the warmer Mediterranean Sea conditions and the global circulation of air masses can lead to an increase in autumn floods intensity in the southern Alpine area caused by significant increase in river runoff and more intense rainfall events (Wirth *et al*., 2013). The return time period was estimate both for the annual lake level peaks, and for the spring and autumn floods. The results suggested a high probability of a flood event every three years and also a forecast of a flood of about 197 m asl (3.14 m above the average lake level) every 10 years. Floods exceeding 197.7 m asl will be less likely, whereas lake levels of about 198 m could have a return period of 50 years, and between 1868 and 2021, four events around 198 m asl were observed. The use of the return time periods to predict the flood intensity and the affected areas, is widely used and can lead to improvement in land uses, water management and risk awareness (Choubin *et al*., 2023). The results of the flood intensity estimated over the return time period allowed to define different lake levels with impacts on the riparian and littoral areas used by humans or characterized by different ecosystems.

The most impacted land use categories were residential areas with discontinuous and sparse fabrics (41.3%), followed by deciduous forests and agricultural crops (30.9%) and natural landscapes (27.8%). Despite of highly anthropized riparian and shore zones of Lake Maggiore, semi-natural and natural terrestrial and aquatic vegetation are frequent. Natural and semi-natural ecosystems need to be preserved because they could support mitigation and reduce flood risks and damages when relatively unchanged or undisturbed because are often more resilient to natural disturbances (Osawa *et al*., 2020). The conservation and the renaturation of the riparian, shore and littoral zones are extremely important even for 3, 5, and 10 flood return time periods that represent altogether more than 50 % of the areas affected by floods. The more vulnerable biocoenosis is littoral vegetation such as reed bed with a significant reduction of about 10% of the area with lake levels of 194.5 m asl, however not included in flood levels. Human infrastructures and activities could modify the ecosystem's capacity to absorb flood impacts and provide flood control. Littoral and riparian structures change with different water levels along the shore gradient, in relation to human infrastructures, with variable consequences on the assemblage structure and the functionality of biocoenosis at a local scale (Evtimova and Donohue, 2016). The possibility of the biocoenosis to adapt to high and very high water levels depends on the shore slope and the occurrence of natural habitats giving them the possibility to retreat or escape water peaks. Artificial shores and artificialities in littoral zones, or human infrastructures prevent this adaptation.

Expected high water levels in the near future are predicted to reduce spatial variability and habitats, causing habitat homogenization and biodiversity loss (Thomaz *et al*., 2007). As a cascading effect, WLFs also impacted the chironomid assemblages in terms of species distribution, evenness (distribution of individuals among species) and growth (Kamburska *et al*., 2023; Boggero *et al*., 2022b). These results act as a mirror of what could happen to the macroinvertebrate fauna as a whole. Indeed, the first results obtained on the relationships between macroinvertebrate assemblage structure and water levels showed significant negative values only when considering sampling stations all together vs the occurrence of *Cladotanytarsus* sp. (-0.43; p=0.004) with decreasing abundances of this small-sized taxon from low to higher water levels. Just marginally significant findings were obtained between Magadino sampling area vs the occurrence of *Pscectrocladius sordidellus* (+0.47; p=0.06): higher water levels could contribute to the species increase in abundance.

Cautiously, the three sampling stations seemed to show different situations and water level impacts, mainly on the food web structure and functioning with a shift in species distribution and abundance from low to high water levels. At high water levels, higher abundances of chironomid Orthocladiinae (mainly, the ubiquitous *Psectrocladius sordidellus*) are counterbalanced by lower abundances of chironomid Chironominae (mainly, *Cladotanytarsus* sp.). In Lake Maggiore, therefore, rapid changes in water level modify the littoral macrofauna assemblage and function as a result of the creation of more uniform (high water levels) or more diversified (low water levels) temporary habitats found only for short periods (Boggero *et al*., 2022b).

Therefore, two factors become important for further and more in-depth considerations: more data are needed to further investigate water level/species abundance relationships, as well as sustainable management to mitigate the possible impacts of lake level fluctuations to counteract changes in macroinvertebrate assemblage structure. These should include adjusting level fluctuations to the requirements of aquatic organisms, increasing shoreline shading to reduce evaporation and extending the aquatic vegetation to expand aquatic refuge habitats (Heino, 2000, Cereghino *et al*., 2008). To ensure the effectiveness of this strategy, monitoring of aquatic ecosystems under Water Framework Directive to keep good quantitative status unaltered over the long-term is needed.

Water level fluctuations induce a different functioning of lake ecosystems, above all in the riparian, littoral and semi-aquatic areas. The frequency and duration of high levels together with the artificial modification of the hydro-morphological features of lakes, including water level, can cause severe impacts on physical processes, biological productivity with cascading effects on the health and integrity of ecosystems (Leira and Cantonati, 2008; Evtimova and Donohue, 2016). Finally, high water levels decrease the resilience and increase the vulnerability of the structure and function of lake ecosystems (You *et al*., 2022). Hydrological extremes as floods events, play an important role in water resources management (Ahn and Palmer, 2016) and accurate estimates of flood frequency and magnitude are basic components for flood risk management, flood damage plan (England *et al*., 2019) and for understanding their impacts on lacustrine ecosystems.

CONCLUSIONS

Flood events within Lake Maggiore catchment are more frequent in autumn than in spring. Non-significant positive trend was observed in autumn with a probability of flood events every three years. Disastrous floods characterized by lake levels of about 198 m asl (just above that occurred in 2000) showed a 50-years probability of occurrence.

The three INTERREG biological sampling areas (Bolle di Magadino, Fondo Toce, Sesto Calende) seemed to be among the most vulnerable areas to lake level fluctuations and not only to flood events (very high lake level) but also to medium and high lake levels. The first results, while showing only significant relationships between water levels and Chironominae abundances (mainly, *Cladotanytarsus* sp.), showed also nearly significant relationships between water level and Orthocladiinae (mainly *Psectrocladius sordidellus*), maybe due to the current scarce data availability. This allowed to presume a not-so-weak impact on littoral assemblages, including the food web structure and function. Therefore, a more suitable water level management strategy (considering also aquatic organism requirements) has to be considered for Lake Maggiore, because the probability of flood events is high, and the riparian and littoral ecosystems are highly and negatively affected by these events, as demonstrated in this work by the restructuring of chironomid assemblages at different water levels. These negative effects are more related to the presence of riparian and littoral artificializations that decrease the resilience of the littoral ecosystems and the quality and quantity of their services.

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