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ORIGINAL ARTICLE

Fluctuations of Lake Orta water levels: preliminary analyses

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ABSTRACT
While the effects of past industrial pollution on the chemistry and biology of Lake Orta have been well documented, annual and seasonal fluctuations of lake levels have not yet been studied. Considering their potential impacts on both the ecosystem and on human safety, fluctuations in lake levels are an important aspect of limnological research. In the enormous catchment of Lake Maggiore, there are many rivers and lakes, and the amount of annual precipitation is both high and concentrated in spring and autumn. This has produced major flood events, most recently in November 2014. Flood events are also frequent on Lake Orta, occurring roughly triennially since 1917. The 1926, 1951, 1976 and 2014 floods were severe, with lake levels raised from 2.30 m to 3.46 m above the hydrometric zero. The most important event occurred in 1976, with a maximum level equal to 292.31 m asl and a return period of 147 years. In 2014 the lake level reached 291.89 m asl and its return period was 54 years. In this study, we defined trends and temporal fluctuations in Lake Orta water levels from 1917 to 2014, focusing on extremes. We report both annual maximum and seasonal variations of the lake water levels over this period. Both Mann-Kendall trend tests and simple linear regression were utilized to detect monotonic trends in annual and seasonal extremes, and logistic regression was used to detect trends in the number of flood events. Lake level decreased during winter and summer seasons, and a small but statistically non-significant positive trend was found in the number of flood events over the period. We provide estimations of return period for lake levels, a metric which could be used in planning lake flood protection measures.

Key words: Lake Orta; water level fluctuation; flood event; trend; linear regression; logistic regression; return period.

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INTRODUCTION

The Alps are a dominant feature of the Italian Lake Maggiore, and the upstream Lake Orta watersheds, causing heavy rainfall and, on occasion, extreme flooding events (Frei and Schär, 1998). Both natural climate variability and/or climate change contribute to these events (Saidi *et al*., 2015). Furthermore, regional climatic models forecast both an increase in temperature in alpine regions for the XXI century (European Environment Agency, 2009) and an increase in the number of extreme rainfall events (AUER *et al*., 2007). The frequency of such events are difficult to predict, but their impacts might be severe. These forecast changes could increase erosion and floods, and this would require enhanced attention by managers of water resources and hydraulic infrastructure design. Therefore, it is important to improve our knowledge of the hydrological regime of water bodies, in general, and water level fluctuations of sub-alpine lakes, in particular.

Lake Orta is located in the southwestern part of the larger drainage basin of Lake Maggiore (Bonacina, 2001). The lake drains north via the Niguglia stream, which successively joins Strona River after a stretch of 1 km, and finally Toce River that enters Lake Maggiore. To mitigate problems due to floods events, the bottom of Niguglia channel was excavated in 1602, and again in 1816. In 1882, hydraulic infrastructure, *i.e.*, a dam, was built at the outflow of the lake to control low water levels and to guarantee a constant supply of water for industrial and human needs. In this way, Lake Orta became the first sub-alpine lake in Italy with regulated water levels (De Agostini, 1897). This regulation did not influence high level or flood events. Lake level fluctuations are determined directly by the rainfall regime, which is characterized by two annual maxima, during spring and autumn, and two minima, during winter and summer (Ciampittiello *et al*., 2013). Some hydrological features of Lake Orta are given in Tab. 1.

Understanding relations between climate and lake level variability is critically important in the light of ongoing and future climate change (Hanrahan *et al*., 2014; Changnon, *et al*., 1989). While sophisticated models of lake level fluctuations (Rani and Parekh, 2014; Aksoy *et al*., 2013) can be parameterized using hydrological variables such as evaporation and precipitation driven-components (precipitation, runoff and inflow), such long-term data on precipitation and temperature is not available for the watershed of Lake Orta. Therefore, we were forced to limit our analysis to water levels data. Still, we believe the results of our analysis could be useful for the management of the territory at local scale.

Due to the risk of serious floods and the resulting human and infrastructural costs, it seems important to analyse the lake level variability and trend. In this paper, we quantified the seasonal and long-term fluctuations of Lake Orta water levels, identifying the annual and long-term frequency of flood events.

METHODS

Data

Data of lake levels have been collected from: i) hydrologic annals of the Po Hydrographic Office, from 1917 to 1991; ii) from archive of Omegna municipality from 1992 to 2007; and iii) from Consortium of regulation of Orta-Strona from 2007 to 2014.

The first problem to solve was the homogenization of data coming from different sources. Data from the hydrologic annals were reported as annual maximum daily levels. In this case, the altitude of the hydrometric zero was defined using different sources of information and historical reports. Weekly data were stored in the archive of Omegna Municipality. It was possible to extract maximum levels values by combining these data with some existing hydrographs. Most recent data, registered by the Consortium of regulation of Orta-Strona, were collected with modern level sensor in near real-time, and no problems were encountered in defining the altitude of hydrometric zero, and to extract minimum, mean and maximum lake levels. Data from 1942 to 1953 are still missing. In spite of this, the important event of 1951 were reported in the annals.

The traditional and the new water level sensor were placed at the outflow of the lake, near outflow Niguglia (in square Martiri - Omegna). The altitude of the hydrometric zero was not the same during the history of Lake Orta. The following values were used:

- 289.10 m asl for the years 1917 to 1954;
- 288.85 m asl for the years 1955 to 1980;
- 288.99 m asl for the years 1981 to 1991;
- 288.85 m asl for the years 1992 to 2000;
- 288.72 m asl for the years 2001 to 2007;
- 288.86 m asl for the years 2007 to 2014.

The observed average water level is 290 m asl and it ranges from a low of 288.9 m asl in 1972 to a high of 292.3 m asl in 1976. Annual maximum lake levels are reported in Fig. 1. The horizontal line (red line) define the flood threshold level, at a value of 290.67 m asl.

Many flood events occurred on Lake Orta throughout its history. The most important ones occurred in: 1755, 1800-1815 (six events), 1844, 1868 [lake level increased quickly by 3 m and caused serious damage to home and danger to people, and caused road closure of Omegna for >8 days (De Agostini, 1897)], 1872, 1880, 1882, 1907, 1924, 1926, 1934, 1935, 1939, 1940, 1941, 12-13 November 1951 (another historical flood with lake level risen to 3.05 m above hydrometric zero), 1952-1975 (eight events), 1976 (an important historical flood when lake level rose to 3.46 m above hydrometric zero, to the absolute maximum lake level), 1977-2013 [ten, less severe flood events (source: Ministero dei Lavori Pubblici, Annali Idrologici, 1917-1991)]. The most recent flood event occurred in 2014, when lake level increased 3.03 m above the hydrometric zero. This event is ranked third in terms of importance after the 1976 and 1951 floods.

Statistical analysis

In addition to the long-term, climate-driven fluctuations or trend, three other types of fluctuations in lake levels can be distinguished (Changnon, 2004). The first type is a short period fluctuation caused by precipitation associated with extreme storms that can last from a few hours to a few days. The second type is the regular seasonal fluctuation from autumn and spring highs to summer and winter lows in the case of Lake Orta. The third type is the fluctuation that results from the artificial regulation of lake levels by control works at the outflow dam. The seasonal and inter-annual fluctuations of lake level are a normal and essential component of the health of the ecosystem and lake (Leira and Cantonati, 2008).

Monotonic trend analysis - Linear regression and Mann-Kendall test

In order to identify any possible trend in lake levels time series, we adopted the procedure proposed by Salas (1993). Where monotonic time trends may be present, two procedures are recommended: significance tests using i) linear regression with time as predictor; and ii) nonparametric methods such as Mann-Kendall test (MK). Dadaser-Celik and Stefan (2007) proved that the linear regression approach provided meaningful estimates of trends in lake water levels, and provides a good visual representation. The MK test (Mann 1945, Kendall 1975) is a non-parametric test, which has also been widely used for detection of trends in hydrologic data.

First, linear regression equations were fitted to the annual and seasonal maximum lake levels and a test statistic computed to determine if the regression slope was signif-

Tab. 1. Characteristics of Lake Orta.

Mean lake level	290 m asl
Longitudinal length	12.4 km
Maximum width	2.5 km
Mean width	1.4 km
Perimeter	33.5 km
Lake area	18.14 km^2
Maximum depth	143 m
Watershed area	116 km^2
Maximum altitude of the watershed	1643 m asl
Mean altitude of the watershed	650 m asl

icant at the 95% confidence interval during the 1917-2014 period. From these regressions, a linear trend curve was established for each parameter. These curves were then used to estimate the magnitude of the lake level trend. Second, the nonparametric MK test was performed to determine the significance of the trend.

Logistic regression

The statistical analysis of Lake Orta flood events per year (when the lake level is higher than the critical level defined by local authority of 290.67 m asl) require the use of logistic regression which is presented as a special case of Generalized Linear Models (GLM). Frei and Schär (2001) recommended the use of a binomial distribution to model the count, n, of events at a particular time (for example the number of extreme daily precipitation in a year).

The probability for n events in m independent days is given by:

$$B(n;\pi,m)=\binom{m}{n}\times\pi^{n}\times(1-\pi)^{m-n} \qquad \text{(eq. 1)}$$

with

$$\binom{m}{n}=\frac{m!}{n!\times(m-n)!} \qquad \text{(eq. 2)}$$

Where π is the probability for successful trial (in our case the exceedance of lake level threshold of 290.67 m asl).

The logistic regression model expresses a transformed form of the expected value of counts (or equivalently the flood event probability) as a linear function of a time t: α

$$\eta(\pi)=\alpha+\beta\times t \qquad \text{(eq. 3)}$$

Where α and β are the regression intercept and coefficient, respectively to be estimated from the historical data.

This logistic regression approach was adopted to investigate the presence of significant trend in the number of flood events during the period 1917-2014. In this section, our analysis are based on the R software package called trend (Frei, 2010).

Generalized Extreme Value distribution - Return level curve

Return levels for different return periods were estimated and its variation was examined compared to the last 20 years (1995-2014). The T year return level is defined as the value occurring on average once every T years. In

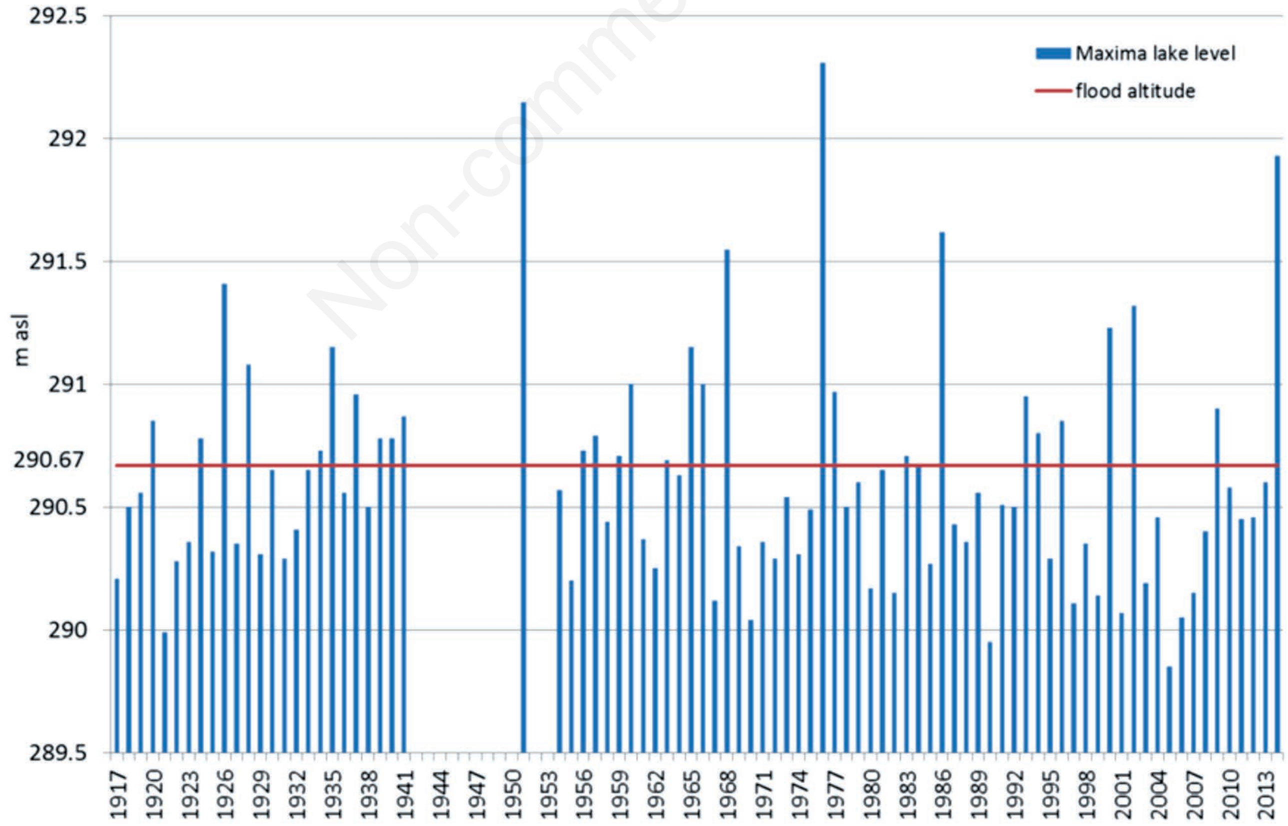

Fig. 1. Annual maximum lake level since 1917 to 2014 and flood threshold level (horizontal line).

our study return levels were predicted by fitting a Generalized Extreme Value distribution (GEV).

The GEV distribution is the generalized form of three commonly applied extreme value distributions: the Gumbel, the Frechet and the Weibull (Coles, 2001). This distribution was chosen for the analysis of annual and seasonal maximum lake levels because of its flexibility and its ability to fit the records of extreme values. L-moments approach (Hosking, 1990) was adopted to estimate parameters when fitting GEV distribution.

The changes in frequency (return period) curves in the last 20 years was investigated comparing the full time series which imply temporal changes in annual maximum lake Orta levels.

RESULTS AND DISCUSSION

It is undeniable that a changing climate is having effects in Lake Orta's water resources. Lake levels have decreased both in the warm-season (June to August) and in the cold-season (December to February).

There was no significant trend in annual maximum lake levels during the period 1917-2014 (Fig. 2; Tab. 2).

Analysing annual and seasonal maximum levels we can say that maximum lake levels decreased slightly in the winter and summer periods (Fig. 3). We believe this trend could be due to drought conditions in these two seasons, *i.e.* to decrease of inflows and increase of water loss by evaporation. The trends during spring and autumn seasons were not significant, although missing 1942-1953 lake level data imply we may have to revisit this result.

The magnitude of the time trend estimated by liner regression was -4.5 cm/decade for summer season and -3 cm/decade for winter season (Figs. 2 and 3).

The analysis of the data using logistic regression indicated that the number of flood events per year had increased in Lake Orta, according to the tendency and the radius of curvature of the red line in Fig. 4. More flood events have been registered during the most recent period. Nonetheless, the trend was very weak and statistically not significant (P>0.05).

The flood event of 2014 has a return period of 54 years and the critical water level given by the local authority (290.67 m asl) has a return period of 3 years based on the GEV distribution (Fig. 5; Tab. 3).

There was no significant change in return period curves (Fig. 6), which implies no temporal change in annual maximum lake levels. However, for high return period events, the curve has steepened and annual maximum of Lake Orta levels have increased.

It is evident from Fig. 7 that the return periods of lake levels during winter spring and summer did not change since 1917, and the curves of the two seasonal periods (1917-1994 and 1995-2014) are close to being parallel.

However, a visual inspection of the return period curves for the autumn season suggests that there have been considerable changes and increase of lake levels for the period 1995-2014. This emerges from the fact that over the last 20 years, there were several flood events in the autumn, *i.e.*

- 18 November 2014: Lake level 291.81 m asl;
- 30 November 2002: Lake level 291.19 m asl;
- 17 October 2000: Lake level 291.23 m asl;
- 22 October 1996: Lake level 290.85 m asl.

CONCLUSIONS

There has been a downward trend in Lake Orta water levels during winter and summer, at a rate of -4.5 cm/decade for summer and -3 cm/decade for winter season. However, the logistic regression provided no evidence of future persistence of observed trend in the number of flood events per year. Nevertheless, these events have been very frequent during the last 20 years. We estimated the return levels corresponding to various return periods and their confidence intervals using the GEV distribution. The comparison of return period curves showed temporal changes in autumn lake levels, which have increased during the last few decades.

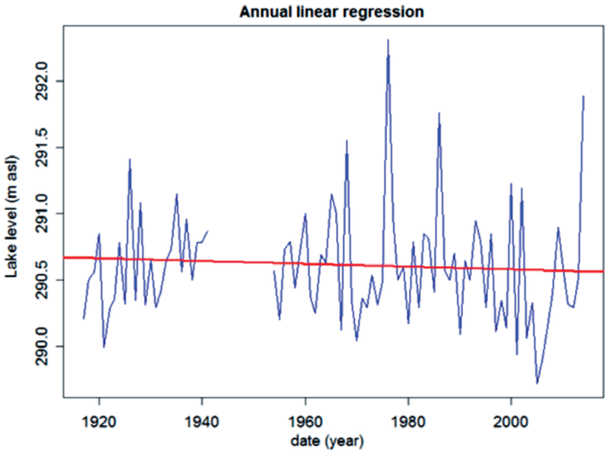

Fig. 2. Linear trend of annual maximum lake levels.

Tab. 2. Mann-Kendall statistics of annual and seasonal lake levels. Underlined values: significant level lower than 5%.

Parameter	Kandall's tau statistic
Annual maximum level	-0.07
Winter maximum level	-0.257
Spring maximum level	-0.082
Summer maximum level	-0.331
Autumn maximum level	-0.1

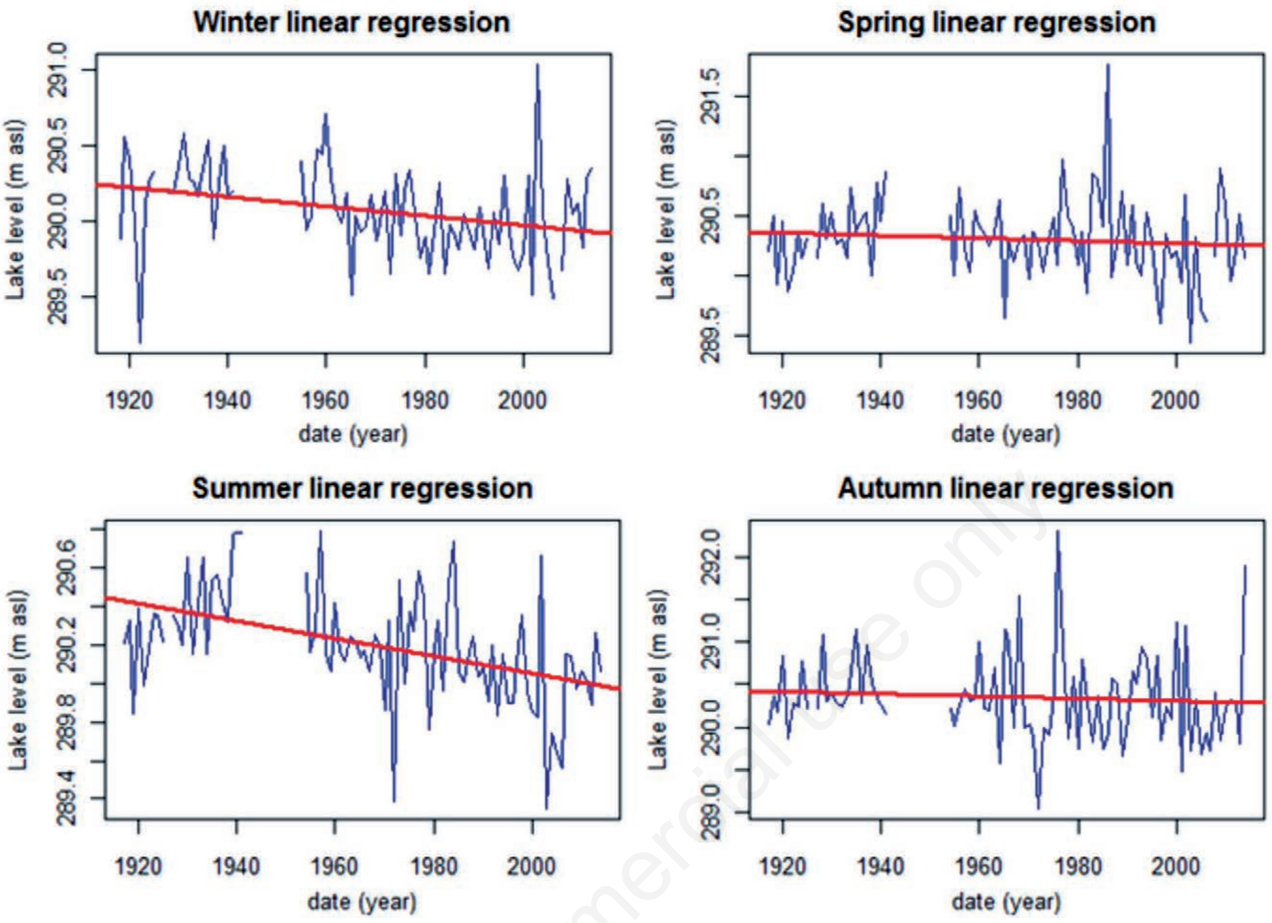

Fig. 3. Linear trend of seasonal maximum lake levels.

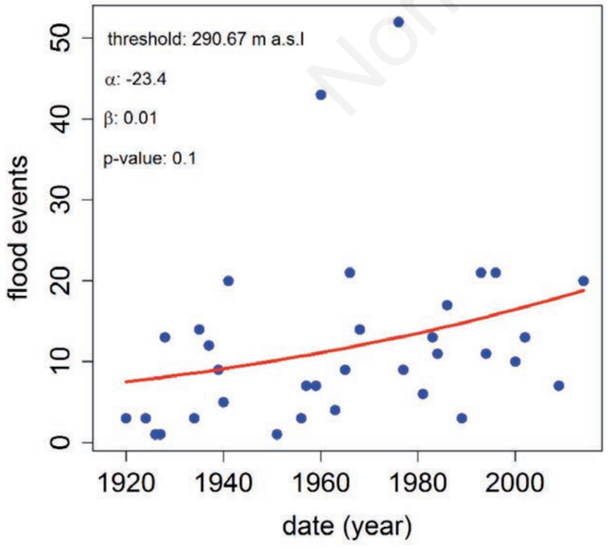

Fig. 4. Logistic regression of flood events.

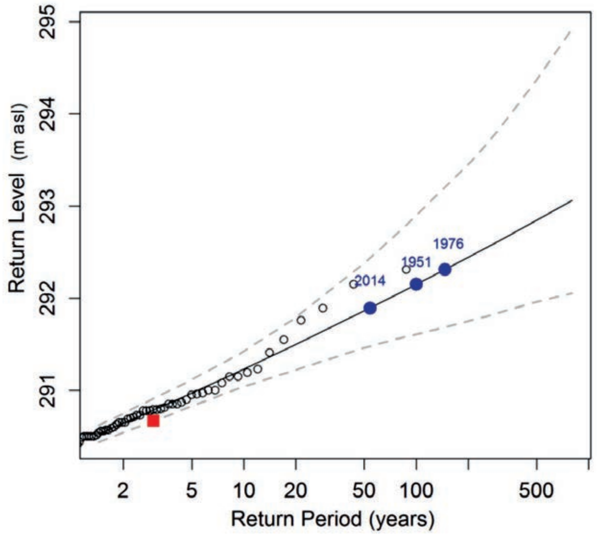

Fig. 5. Lake Orta return levels with 95% confidence intervals. Solid circle: extreme values (1976, 1951 and 2014). Filled square: critical value of 290.67 m asl.

Tab. 3. GEV estimated parameters for annual and seasonal maximum lake levels.

	Location	Scale	Shape
Annual level	290.40	0.34	0.04
Winter level (1917-1994)	290.01	0.28	-0.36
Winter level (1995-2014)	289.84	0.31	-0.04
Spring level (1917-1994)	290.21	0.27	-0.10
Spring level (1995-2014)	289.99	0.40	-0.30
Summer level (1917-1994)	290.15	0.26	-0.23
Summer level (1995-2014)	289.85	0.28	-0.23
Autumn level (1917-1994)	290.17	0.42	-0.09
Autumn level (1995-2014)	289.98	0.41	0.14

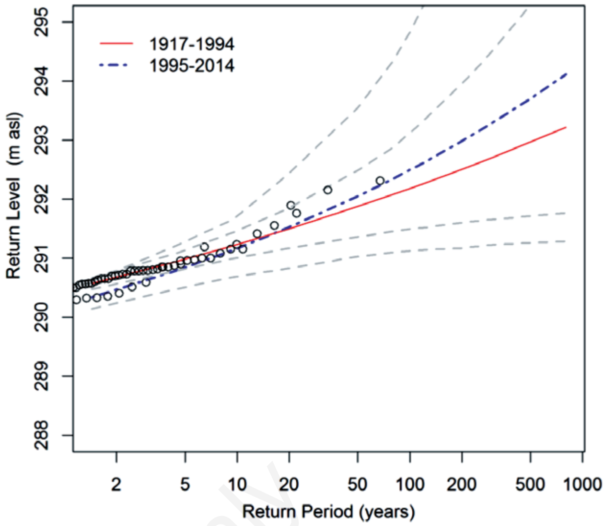

Fig. 6. Changes in return levels at annual scale with 95% confidence intervals.

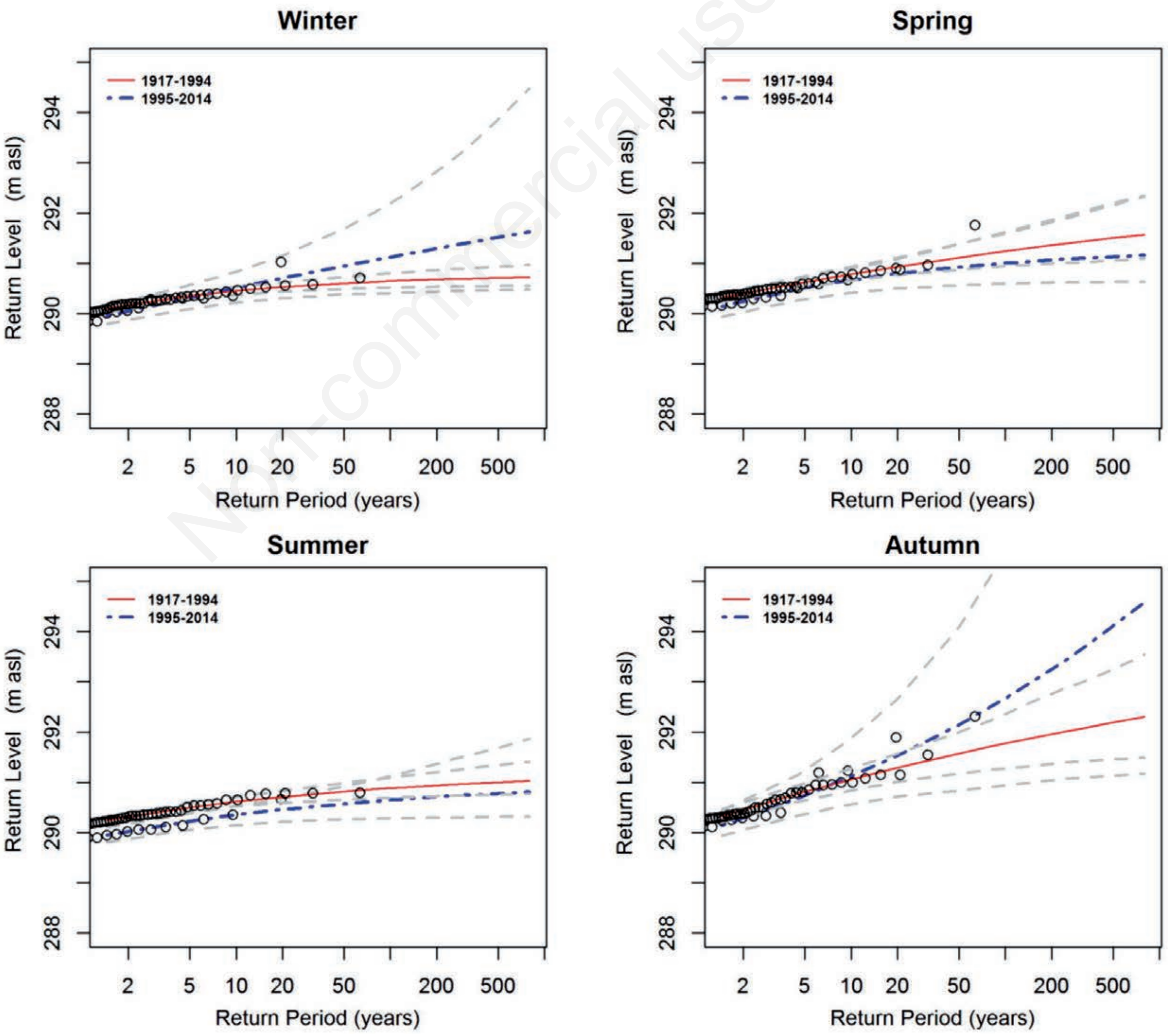

Fig. 7. Changes in return levels at seasonal scale with 95% confidence intervals.

It is undeniable that the water levels of Lake Orta vary on daily, seasonal and annual time scales, and predicting their extreme values for urban planning has proven problematic. For this reason, it will be very useful for future management to create a model forecasting maximum daily lake levels, with additional in-depth analysis.

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