ORIGINAL ARTICLE

Correlation between *Phragmites australis* growth and seasonal lake level variations in Lake Maggiore (Italy/Switzerland): common reed management guidelines

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ABSTRACT

The present study investigates the impact of water level regulation on the growth of common reed (*Phragmites australis*), a globally widespread helophytic plant. The investigation has been carried out in the Bolle di Magadino (municipalities of Locarno, Gambarogno, Gordola and Tenero; Ticino, Switzerland), a lacustrine-riparian nature reserve in the context of the Lake Maggiore (that stretches between Italy and Switzerland). This is an oligotrophic, artificially regulated lake. Our initial hypothesis was that variation in water table regulation is the most influential factor for explaining observed local reed dieback. To test this, culm height of *P. australis* was measured at each significant change in lake water level (water table height increase greater than 20 cm), or monthly in the case of a relatively constant lake level. The study took place between 2020 and 2022, monitoring 14 plots of 400 m^2, placed at three different relative elevation classes with respect to the level of the lake (5 plots at low elevation, <193.475 m; 7 plots at intermediate elevation, 193.476-193.700 m; 2 plots at high elevation, >193.701 m). The results showed that *P. australis* growth is significantly influenced by the lake water level and thus the relative elevation of the stands, with lower lake levels leading to better growth, especially during the early phases of the growing season. On the other hand, prolonged flooding of shoots significantly impaired common reed growth. The study identifies two relevant relative elevation thresholds for winter mowing, a management practice that enhances reedbeds health. Mowing below 193.20 m elevation is considered risky, as no healthy reedbeds have been observed below this threshold. Mowing below an elevation of 193.50 m was defined as possibly risky, due to observed dieback in some areas as well as healthy reedbeds in other locations at the same or lower elevations. The research also discussed the potential impact of future changes in water level regulation, including the planned change in the spring regulation threshold (+1.50 m above the hydrometric zero in Sesto Calende). This is expected to result in a further rearrangement in lacustrine vegetation, with the growth optimum for *P. australis* becoming higher and an increase in clumping habit. In conclusion, this study provides valuable insights into the impact of water level regulation on the growth of *P. australis* in the Bolle di Magadino nature reserve. The research highlights the need for careful management of water level regulation to preserve the reedbed ecosystem and identifies relevant elevation thresholds for winter mowing to mitigate the risks of reed dieback. The findings can inform future management strategies for the Bolle di Magadino reserve and other similar ecosystems facing the challenges of artificial regulation of water levels.

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Key words: *Phragmites australis*; common reed; dieback; clumping; artificial regulation of lake levels.

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INTRODUCTION

Phragmites australis (Cav.) Steud., known as common reed, forms characteristic wetland communities, playing essential roles in marsh ecology. Indeed, reedbeds provide a habitat for many animals, stabilise shores, and filter pollutants demonstrating an exceptional environmental resilience (Ostendorp, 1989, 1993; Kiviat, 2013, Tòth, 2016). However, since the middle of the last century, reedbeds have begun to show signs of regression (dieback), a phenomenon that has gradually spread in Europe and world-wide (Gigante *et al*., 2011; Ostendorp, 1989; Van der Putten, 1997).

Different reed dieback indicators have been identified: shorter and thinner culms, low flowering rate and clumping habit (Lastrucci *et al*., 2017; Ostendorp, 1989). Clumping (underlined in red in Fig. 1) is observed when *P. australis* is in poor health condition and tends to grow in height rather than horizontally (Armstrong *et al*., 1996). Clumps are much more vulnerable to ground erosion and clumped reedbeds will eventually die (Armstrong *et al*., 1996; Forni and Patocchi, 2015).

Increasing eutrophication and artificially regulated water levels have been identified as primary causes for reed dieback, but the process may be exacerbated by grazing, insect attack, wave action, low genetic diversity, sediment type, algal mats and algal wash and invasive species (Armstrong *et al*., 1996; Gigante *et al*., 2011).

Since the Lake Maggiore is an oligotrophic lake, we discarded eutrophication as a predominant causal factor for local common reed dieback and we focused on the artificial regulation of the lake water level. Especially in spring, at the beginning of the vegetative period, flooding of *P. australis* sprouts may seriously affect their growth (Forni and Patocchi, 2015; Lastrucci *et al.,* 2017; Ostendorp, 1989; Rea, 1996). Indeed, in years when the water level is low during spring (as opposed to normal years when the water level is high during spring because of snow melting and for the climatic region typically heavy rainfall in May), *P. australis* is expected to grow well and expand, while in years when the lake level is high and the growing sprouts are flooded for several days, *P. australis* is expected to grow with difficulty and may die (Gigante *et al*., 2011, 2014; Ostendorp, 1993).

Given the ecological importance of reedbeds and their widespread struggling, conservationists are trying to find ways to promote common reed conservation. One of the most used practices is mowing of dead *P. australis* culms during winter, which speeds up sprouting and growth in the following spring (Tóth, 2018). However, this type of management is risky at places with high flooding risk because *P. australis* may not be able to grow back.

In the context of a possible change in the regulation of the hydrological regime of the Lake Maggiore, we monitored *P. australis* growth in 14 plots placed at different elevations (compared to the lake water levels) in the Bolle di Magadino nature reserve (municipalities of Locarno, Gambarogno, Gordola and Tenero; Ticino, Switzerland) between 2020 and 2022 to test how flooding affects the growth of *P. australis* and to define elevation limits

Fig. 1. Clumping habit of *Phragmites australis*, the most important signal for reeds' poor health condition, and vegetative shoots recruitment after a season of extremely low lake (Bolle di Magadino, 08.09.2022). Clumps are underlined in red, vegetative shoots recruitment in light blue.

below which winter mowing of common reed may become risky for the maintenance of reedbeds.

METHODS

Monitoring of common reed growth at different elevations

To test if the lake level affects common reed growth, 14 plots at different elevations have been chosen in the nature reserve of Bolle di Magadino (Fig. 2). This reserve stretches over about 600 hectares and is created by the delta of two rivers, the Ticino and the Verzasca rivers, which flow into the northern part of Lake Maggiore (Gulf of Locarno). It consists of a mosaic of open and wooded areas and is characterised by marsh and river vegetation. Habitats dominated by *Phragmites australis* formations were chosen for this study. The Bolle di Magadino are listed in the Ramsar Convention since 1982.

8 plots were located in the southern part of the reserve (P1-P8), 2 in the central part (C1 and C2), and 4 in the northern section (S1-S4). Each plot is represented by a square of about 400 m^2 and is marked with a stake (placed approximatively at the centre of the square) to ensure the repeatability of the measurements over time. Monitoring was conducted from 2020 to 2022.

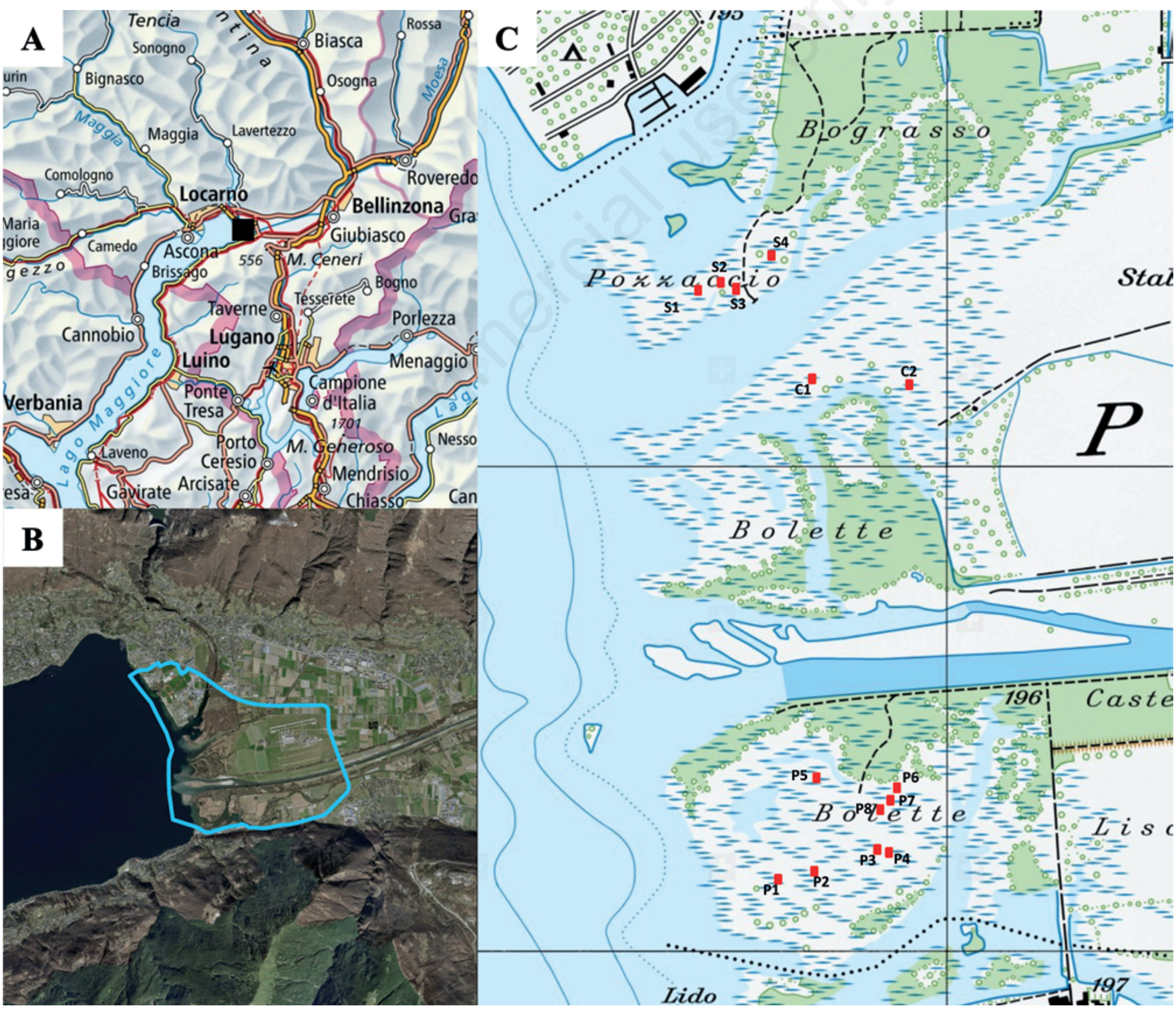

Fig. 2. Location of the study area. A) The black square indicates the location of the Bolle di Magadino nature reserve in Ticino, Switzerland. B) The perimeter of the nature reserve on satellite picture. C) Location of the monitoring plots within the nature reserve. The base maps are retrieved from ©swisstopo.

Plot elevation (respect to sea level)– was measured in the four corners and in the centre of the plot, with a margin of error of 1 cm. The average elevation for each plot was calculated. The plots were then divided into three elevation classes (sorted by increasing relative altitude):

- Low elevation (<193.475 m asl): C2, S1, C1, S4 and P1.
- Intermediate elevation (193.476-193.700 m asl): P8, S3, S2, P7, P5, P3 and P2.
- High elevation (> 93.701 m asl): P4 and P6.

All altitude data, are given in the Swiss scale, shifted by -0.35 m compared to the Italian values.

The deltaic sediments of the Bolle di Magadino are sandy gravel, with no clays. For this reason, on the lake shore, the water surface level, taken as a reference in the present study, corresponds to the water table level for at least 1 km towards the shore. By knowing the elevation of the survey stations and that of the lake level, the water table level is also automatically known if the station is not flooded.

All plots were mowed in winter with manual removal of biomass to better observe shoots growth at the beginning of the vegetative season. At each significant change in lake level (increase in water table height greater than 20 cm) during the vegetative season (from March to August), or monthly if no significant changes occurred, the height of *P. australis* in each plot was estimated by measuring around 5 culms from base to top and then calculating the average value. When plots were notably uneven in elevation, two height measures were taken: one for the lowest portion (B) and one for the higher portion (A) of the plot. Once during the season (in May, when all the culms have already sprouted and the density should no longer change), the density of the common reed was also estimated by counting the sprouts in 4 plots of 1 m^2 and then calculating the average value. The lake level was retrieved from official hydrological data (UFAM, no date; https://www.bafu.admin.ch/bafu/it/home/ufficio.html) and flooding, or water table, was calculated directly as the difference between lake level and elevation plots.

The growth performance of *P. australis* was assessed in the field using the following categories: 'no growth', for plots showing an extremely low culm density and 'good growth' for healthy plots that can potentially serve as habitat for a myriad of associated species. Reedbed typology, based on its potential functionality as nesting habitat for reedbed birds, was determined visually. The following reedbeds typologies were defined:

- CPDO1: Healthy dense aquatic reedbed with horizontal structures (not regularly managed); it is normally represented by a monospecific stand of *P. australis*.
- CPDO11: Aquatic reedbed with horizontal structures (not regularly managed) showing obvious clumping.
- CPDV: Dense terrestrial reedbed with vertical structures only (regularly managed); still dominated by *P. australis*, but not represented by a monospecific community.
- CPS-CXD: Scattered common reed mixed with sedges (*Carex*. spp.).
- CPS: Scattered terrestrial reedbed, a plant community dominated by other species.

In addition, we integrated our growth assessment data with data from a similar study conducted in the Fondo Toce nature reserve (Verbania, Piemonte, Italy) between 2020 and 2022 (Canalis *et al*., 2020, 2021, 2022) and an additional monitoring site at the Spiagge d'Oro Monvalle (site 103; Brebbia, Lombardia, Italy). In this case, the purpose was to monitor the effectiveness of conservation measures such as reedbed mowing, but the similar study setup allowed us to use the data and gain perspective on the growth of *P. australis* in another nature reserve on the same lake, namely reedbeds submitted to the same artificial regulation of the lake level. It also provided us with a verification of the critical thresholds of growth or growth impediment of aquatic reed beds, thus allowing us to extrapolate guidelines for reedbed management on all shores of Lake Maggiore. The monitored plots in Fondo Toce were also divided in three elevation classes, each with a representative number of plots. However, the plots in the lowest elevation class were not found in the field and are therefore not represented: we consider A2-Q1, A2-Q2 and A3-Q3 as intermediate elevation and A1-Q2, A1-Q3 and A1-Q1 as high elevation. Since these plots had relatively uniform elevation, only one measurement per plot was taken, which resulted in no elevation variability.

Distribution of clumping

Vegetation mapping is repeated approximately every 20 years for the whole area of the target nature reserve (Bolle di Magadino). The vegetation typologies, compared to a phytosociology survey, take into account the phisiognomy and structure of different dominant facies together with ecological function. This typological approach is simple and intuitive and allows for a common language between botanists and zoologists (Patocchi and Grisoli, 2012). Moreover, clumps are visible on orthophotos and can be reported as map units after *in situ* verification.

The CPDO11 typology was highlighted and its distribution and occupied area in 1992 and in 2021 were compared.

RESULTS

Relationship between *P. australis* growth and lake level

All the three years monitored were characterized by a very dry winter and spring, resulting in a very low lake level at the beginning of the growing season, that is to say from March to mid-May. The annual water level trend of Lake Maggiore is shown in Fig. 3, adapted from the hydrological data of the Federal Office for the Environment (UFAM, n. d.). During the winter of 2021-22, almost no snowfall was recorded in the hydrological basin of the Lake Maggiore, which resulted in an even lower lake level that never reached ground level in any of the monitoring plots during the whole 2022 monitoring season.

All data are reported in Fig. 4, divided into the three elevation classes. In addition, a representative example for each elevation class is shown in detail. In this case, 2021 was chosen, as 2022 was a particularly dry year and therefore not representative and because in 2020 no separate measurements (A and B) were taken for plots of uneven elevation. For the low elevation range, C1 plot was chosen (Fig. 5). Culm height does not differ greatly between the lowest portion (B – 193.13 m) and the highest portion (A – 193.27 m) of the plot, but almost no culms were observed growing in the lowest portion of the plot in all monitoring years (white patch in Fig. 4). Indeed, culm density in 2021 in the highest portion was 30 culms/m^2, while in the lowest portion it was only 5 culms/m^2. With such a low density, the reedbed in question cannot be considered functional in terms of providing habitat and can be taken as an example of common reed dieback at low elevation. C1 plot in the highest portion

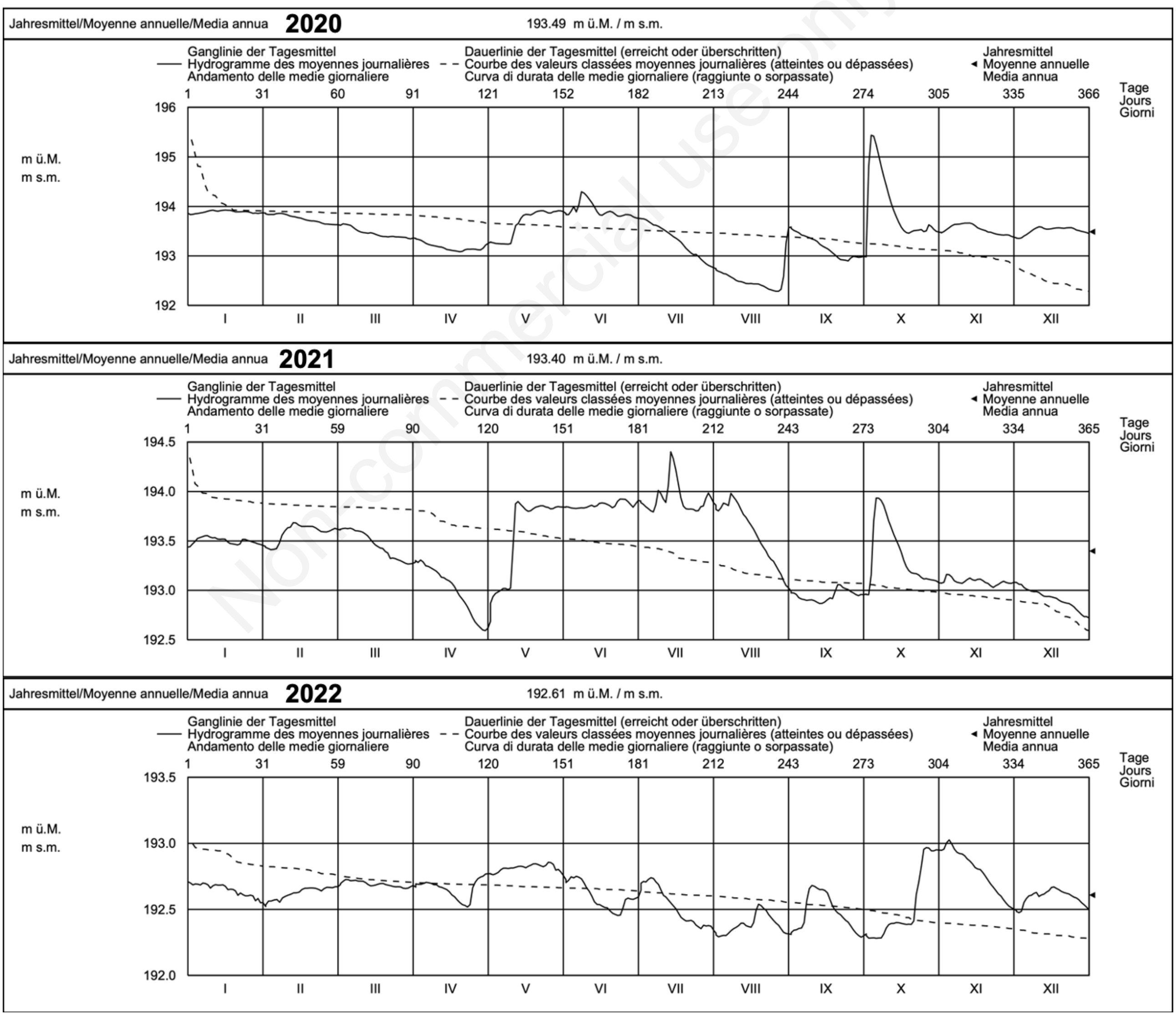

Fig. 3. Annual water level trends in Lake Maggiore for the three years in which this study took place (2020-2022), measured in Locarno (Ticino, Switzerland). Water level is given on the Y-axis as meters above sea level, while time is represented on the X-axis as months in roman numerals. Adapted from: Federal Office for the Environment (FOEN) - Hydrology Division.

can be considered an aquatic reedbed of the CPDO1 typology. For the intermediate elevation range, P5 plot was chosen (Fig. 6). Here, *P. australis* grew into a dense and healthy reedbed with habitat potential in all three monitoring years and this plot can also be considered an aquatic reedbed of the CPDO1 typology. Finally, P4 was chosen for the high elevation range (Fig. 7). Here too the growth was good, but this plot is described as a scattered terrestrial reedbed of the CPS typology.

To sum up the data, we evaluated the growth of common reed respectively to elevation (Fig. 8). The plots are ordered by increasing elevation. Grey lines in the graph highlight the reference thresholds for regulation: the historical regulation level during summer (193.65 m / +1.00 m above the hydrometric zero in Sesto Calende) and the experimental regulation level during summer (193.90 m / +1.25 m above the hydrometric zero in Sesto Calende).

In 5 plots a patch with no or very few culms was observed: P8, C1, C2, S1 and S4. This always occurred in the lowest portion of the plots. In the remaining plots in the Bolle di Magadino nature reserve, in all plots in the Fondo Toce nature reserve (A1-Q1, A1-Q2, A1-Q3, A2-Q1, A2-Q2, A3-Q1) and at the Sabbie d'Oro site plot (site 103), *P. australis* grew into a healthy and functional reedbed.

Reedbed typology was assigned to each plot of the Bolle di Magadino nature reserve: P1, P5, P7, P8, C1, C2 and S1 are considered true aquatic reedbeds (CPDO1); P3, P4 and S2 are considered scattered reedbeds because of lower culm density (CPS); P6 is considered terrestrial reedbed (CPDV); S3 and S4 are considered a reedbed mixed with sedges (CPS-CXD); P2 is considered a scattered reedbed dominated by sedges (CXD). The superior limit for aquatic reedbed formation in the Bolle di Maga-

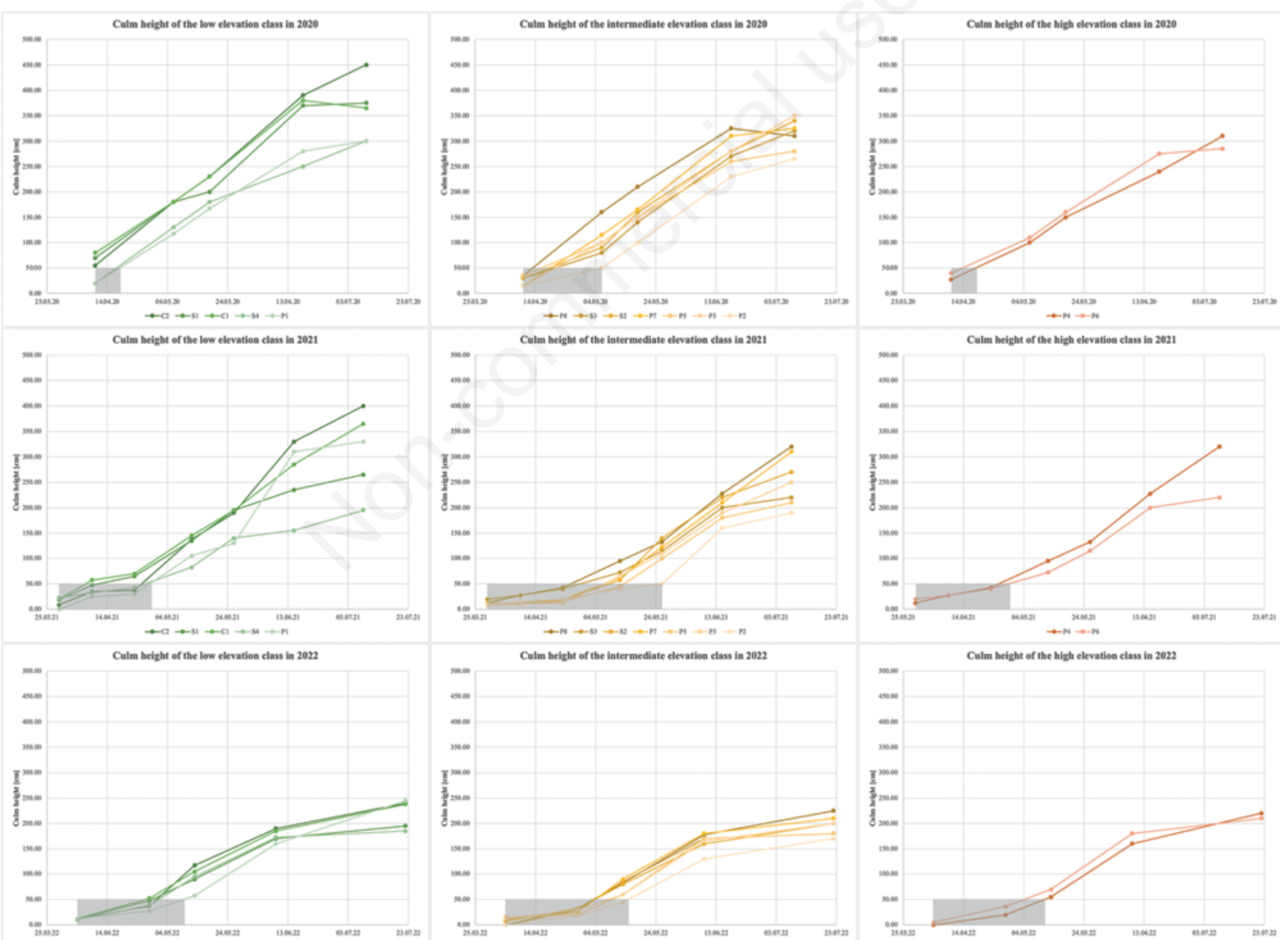

Fig. 4. Culm height for all monitored plots divided in the three elevation classes (low elevation, below 193.475 m asl; intermediate elevation, between 193.476 and 193.700 m asl; high elevation, above 193.701 m asl) for the three study years (2020-2022). The points are displayed on the day the measurement was taken. The plot legend (below each graphic) is ordered by increasing elevation. The grey bands indicate the sprouting period, meaning the time it takes shoots to reach 50 cm.

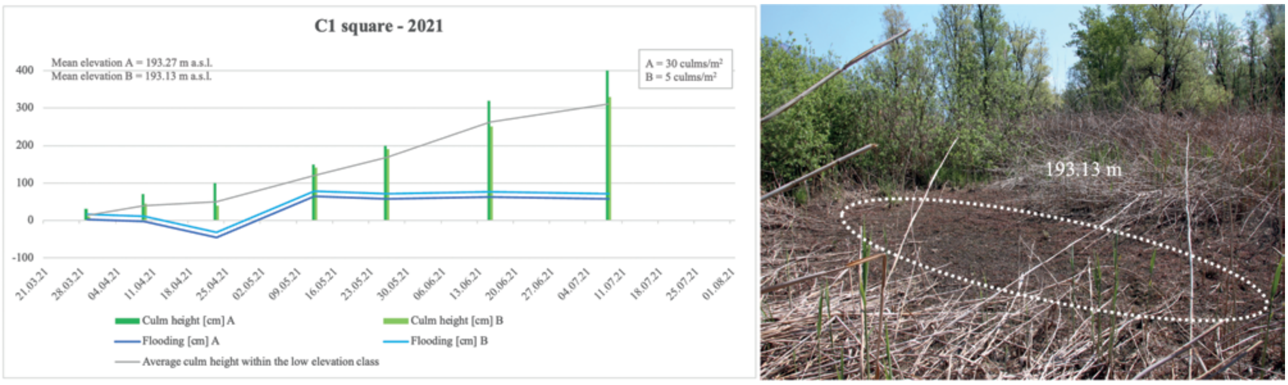

Fig. 5. Culm height in C1 plot (low elevation range) during 2021. Graph on the left shows mean culm height measured during the 2021 vegetative season, both for the lowest portion (B – light green) and the highest portion (A – dark green) of the plot. The blue lines correspond to flooding of the plot (calculated as the difference between lake level and elevation) in the lowest portion (B – light blue) and in the highest portion (A – dark blue). The grey line indicates the average culm height of all plots located in the low elevation range (P1, S1, S4, C1, C2). On the picture on the right (23.04.2021), a patch with almost no *P. australis* culms is highlighted in white, that corresponds to the lowest elevation within the plot. In the higher elevation portion, the common reed grew well and healthy becoming a dense aquatic reedbed.

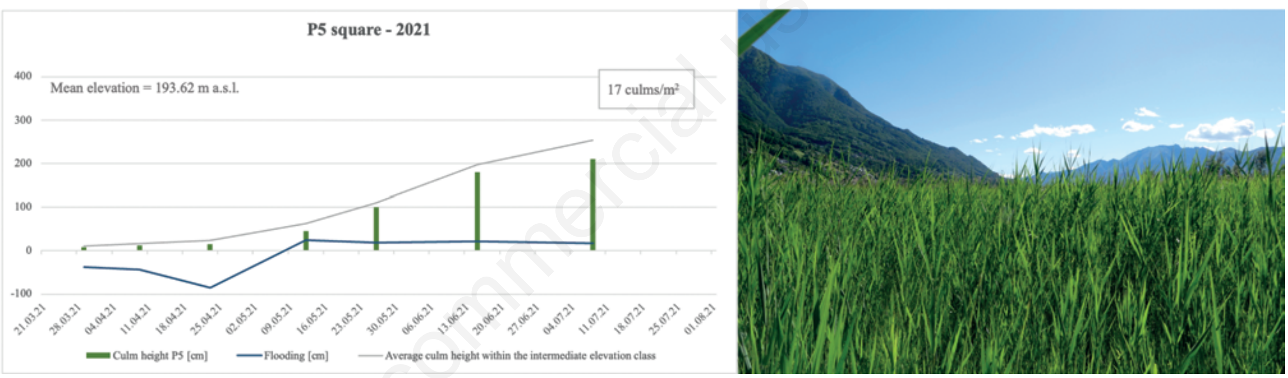

Fig. 6. Culm height in P5 plot (intermediate elevation range) during 2021. Graph on the left shows mean culm height measured during the 2021 vegetative season, the blue line corresponds to flooding of the plot (calculated as the difference between lake level and elevation). The grey line indicates the average culm height of all plots placed in the intermediate elevation range (P2, P3, P5, P7, P8, S2, S3). Image on the right (09.06.2022) shows a healthy and dense aquatic reedbed with no empty patches.

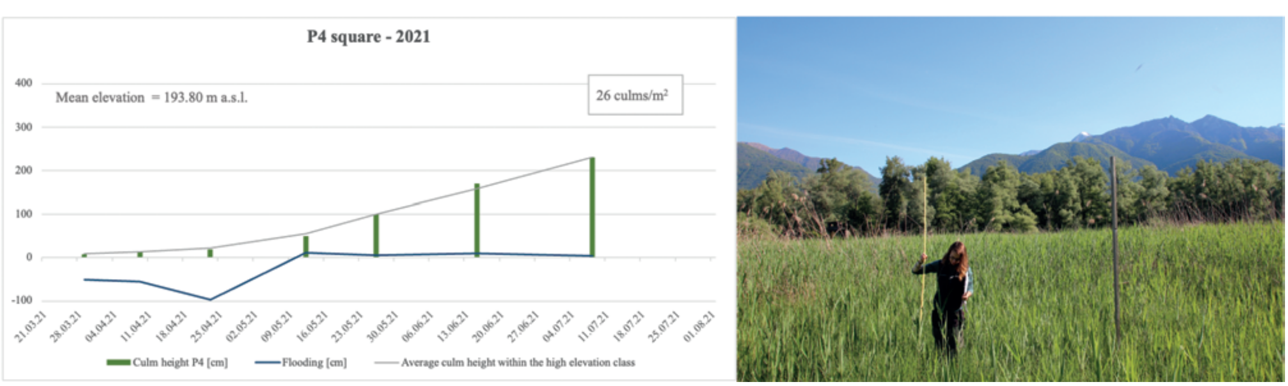

Fig. 7. Culm height in P4 plot (high elevation range) during 2021. Graph on the left shows mean culm height measured during the 2021 vegetative season, the blue line corresponds to flooding of the plot (calculated as the difference between lake level and elevation). The grey line indicates the average culm height of all plots placed in the high elevation range (P4, P6). Picture on the right (26.05.2021) shows a rather scattered terrestrial reedbed, characteristic of higher elevations.

dino was placed at 193.70 m, corresponding to the highest elevation where CPDO1 typology was observed during the present study (highest measured elevation of plot P5). The well-structured aquatic reed beds observed in Fondo Toce and in Spiagge d'Oro (site 103) can reach slightly higher elevations (194.00 m) than those observed in the Bolle di Magadino. Above 194.00 m the observed reedbeds were described as terrestrial reed beds and especially in Fondo Toce are subject to invasion by exotic species (Canalis *et al*., 2020, 2021, 2022).

Distribution of clumping

Over the 19 years monitored, the distribution of clumped reedbeds (CPDO11) almost doubled, getting from 33.256 m^2 in 1992 to 56.322 m^2 in 2021 (Fig. 9). In the Bolle di Magadino nature reserve, the 99% of this type of clumping reed beds are located below 193.65 m, and 83% of which are concentrated in the 192.75-193.00 m elevation range (dark yellow band in Fig. 8).

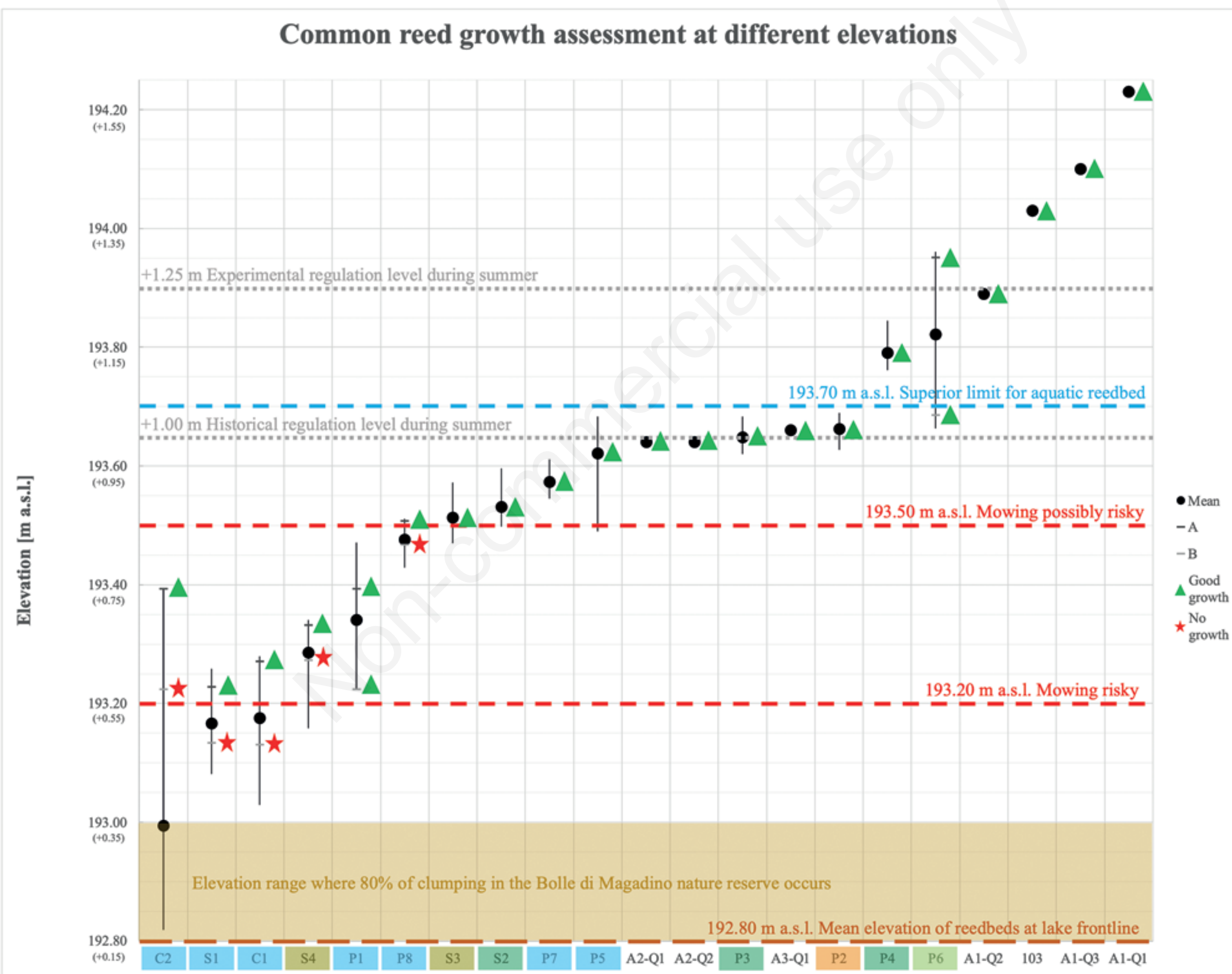

Fig. 8. Common reed growth assessment at different elevations. Plots are ordered for increasing elevation (m asl). For the plots in the Bolle di Magadino nature reserve, the reedbed typology is given: light blue, CPDO1; light green, CPDV; dark green, CPS; olive green, CPS-CXD; orange, CXD. Symbols for growth evaluation are placed next to the mean elevation for the lowest (B) and highest (A) portion of the plot for uneven plots, next to the mean elevation for even plots. Vertical lines represent elevation variability (if absent only one measurement was taken). Number in brackets on the y-axis give the elevation compared to the hydrometric zero in Sesto Calende. Grey lines represent regulation levels, the blue line gives the superior limit for aquatic reedbeds, red lines signalise elevations relevant for reedbed management, the orange line indicates the mean elevation of reedbeds at the lake frontline. Finally, the dark yellow horizontal bar shows the elevation range where 80% of clumping occurs within the Bolle di Magadino nature reserve.

DISCUSSION

The most evident result from our study is that with a low lake level, especially in spring, *P. australis* grows well. Further evidence of good growth under low lake level is the fact that in 2022, when the lake level remained very low throughout the growing season, an incredibly high number of seedlings was observed (Fig. 10). In addition, a recruitment of vegetative shoots was observed around clumps (underlined in light blue in Fig. 2).

When shoots are flooded early in the growing season, their growth is critically impaired. Indeed, the four plots placed at lowest elevation showed patches with almost no new culms. In these patches, culm height did not differ much from the surrounding, well-growing reedbeds, but density was clearly lower, and the few remaining culms did not form a true reedbed that could be considered functional as habitat. It is important to bear in mind that dieback is a natural process and that not all *P. australis*

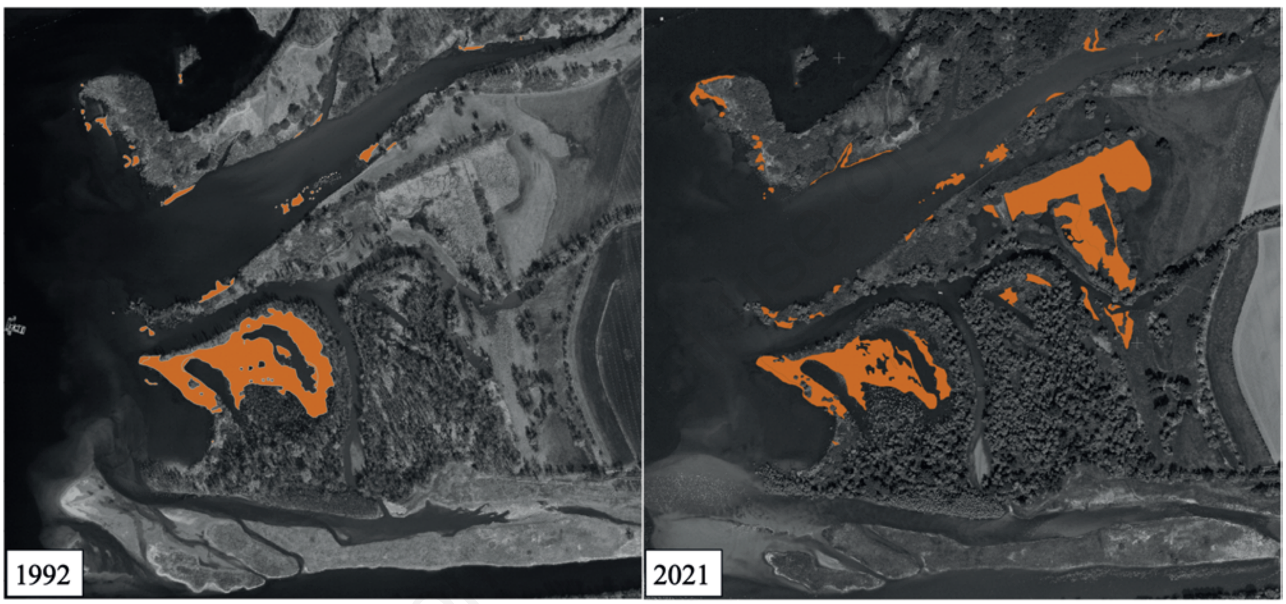

Fig. 9. Distribution of clumped reedbeds (CPDO11 typology) in the central part of the nature reserve Bolle di Magadino at lakefront in 1992 and in 2021.

Fig. 10. New growth of common reed seedlings. In the back, the old reedbeds with dry culms is visible. Picture taken on 08.09.2022.

individuals react at the same time, especially since their rhizomes act as buffer and may delay death (Ostendorp, 1989). Even in areas with dead reedbeds, some culms have managed to grow to near-normal height, but they will probably die in the next years if no action is taken. Therefore, culm height alone is not a good indicator of reed dieback. Indeed, in Fig. 3, it is not possible to find growth trends for the different elevation classes returning over the three study years.

It is however possible to derive sprouting period, defined as the time it takes the shoots to reach about 50 cm in height and shown in Fig. 3 as a grey band. This is the time when *P. australis* shoots are most at risk of flooding and thus impaired growth. In many plots, the sprouting period lasted until May and beyond, when the summer regulation threshold already came into effect. Therefore, as the lake regulation threshold increases, the risk that shoots being completely submerged at the beginning of the growing season increases, which may significantly affect their ability to grow.

Prolonged submersion of shoots has already been found to be a critical factor affecting *P. australis* growth (Gigante *et al*., 2011; Lastrucci *et al*., 2017; Schmieder *et al*., 2014). Moreover, previous studies on the Italian shores of the Lake Maggiore found that lake level affects reed's growth, especially if between mid-March and the third week of April the shoots are submersed for a prolonged period (G.R.A.I.A. Srl, 2018).

Reedbeds are a complex system that responds to changes in the water level regulation. Currently, the reedbeds in the Bolle di Magadino seem to have adapted to the spring water level regulation (+1.00 m) in effect for the Lake Maggiore since the 1943 (year in which the dam in Sesto Calende has been built). However, we are already seeing some signs of change due to changes in the lake regulation: in 2007 the first experiments with higher lake level were made and since 2015 the +1.25 m experimental threshold has been in effect.

A first signal of vegetation rearrangement in the Bolle di Magadino resulting from the changes in lake level regulation has already been observed by Haritz *et al*. (2017): compared to 1992, in 2015 the optimum for aquatic reedbed stands was 20 cm higher than in the previous period (1943-2007). This is especially problematic in a nature reserve such as the Bolle di Magadino, which is rather small and directly bordering with agricultural areas and several human infrastructures. In a such context, the establishment of clear thresholds for reedbed management is important for its conservation. We have defined two relevant elevations for winter mowing: below 193.50 m mowing can possibly be risky; while below 193.20 m mowing is risky because no healthy reedbeds were observed below this threshold.

CONCLUSIONS

We confirm that *P. australis* growth is clearly affected by the ground elevation and thus lake level, validating our initial hypothesis. In all likelihood a further change in the regulation of the water levels of the Lake Maggiore will result in a new displacement of the lacustrine vegetation: the optimum for *P. australis* will be higher, clumping at the lakeside will increase and the reedbed frontline at lakeside will retreat further. The spring regulation threshold can be defined as the determining factor to which the entire system adapts over time, directly linked to the regulation of the reedbed's growth optimum. Thus, it is possible to predict the future distribution of reedbed typologies following the foreseen modification in the spring regulation threshold (+1.50 m above the hydrometric zero in Sesto Calende).

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