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Article

Lake Narlay (Jura Mountains) a Paleolimnological Reconstruction Over the Last 1200 Years Based on Algal Pigment and Fossil Diatoms

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Abstract: The overarching aim of this paper is to investigate the lake ecosystem response to different drivers over a long term period by a paleolimnological study in Lake Narlay (46°64N, 5°91E) located in the Jura Mountains of France. It is a small, hard-water lake with a maximum water depth of 40 m and extended anoxic condition of the bottom water. Previous results on sediments analysis have documented a differential response of the lake to the environmental changes that occurred in AD 1600 when major shift in the trophic reliance on methane of the benthic food web were observed. From 1920 with intensification of modern agriculture, animal farming and the construction of a cheese making facility, the lake become eutrophic, with Oscillatoria rubescens bloom. However, the lake showed pronounced changes in an older period that remained unanswered. In this paper we aim at reconstructing in more detail the limnological conditions of this Lake over the last 1200 yrs. using combined analyses of specific algal carotenoids and subfossil diatom remains. A comparison with other proxies (chironomid, pollen, and instrumental climatic reconstruction) will be used to better identify, between the complex combination of climate and anthropogenic pressure, the driving factors that determined the ecological trajectory of Lake Narlay.

Keywords: algal pigment; fossil diatom; sediment core, climate change

1. Introduction

Even if water occurring lake represent a quite small fraction (0.013%) of the water available on Earth, these systems are fundamentally important to the environment and biosphere and, of course, human populations in terms of the ecosystem services they provide[1]. Not only are lakes under increasing stress from anthropogenic impacts, they are also vulnerable to Earth's changing climate. Understanding how freshwater ecosystems change through space and time is crucial to ensuring global-scale resource sustainability at a time when humans increasingly drive environmental change. One of the key challenge is to understanding the onset, and nature, of the 'anthropocene,' especially as human-driven changes and impacts on the environment are time-transgressive4 and regionally and environmentally-specific [2]. While an increasing number of lake systems are monitored in situ, or remotely and in real-time (e.g., as part of programs such as GloboLakes, GLEON, LTER) we are largely monitoring already impacted ecosystems. Furthermore, there is a tendency to direct monitoring efforts towards aquatic systems that are deemed the most impacted or 'at risk' and such assessments are generally based on recent (past few decades) measured or anecdotal data. As a result, possible effects from pre-20th century human activities are unknown, meaning long-term records of environmental change are required to adequately validate ecosystem response to climatic and anthropogenic drivers. The use of lake sediments as ecological archives represents a powerful tool

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for extending the time span of ecological records back in the past (secular-scale environmental reconstruction), for defining reference conditions and restoration targets, and to assess future ecological risk. Pigment proxies are usually well preserved in lake sediment and have been shown to be a powerful tool in paleolimnological studies [3–6]. Photosynthetic pigments (especially carotenoids) of former planktonic and benthic populations as they reflect a number of biological, physical and chemical factors influencing their deposition and abundance pigments are useful indicators of present and past trophic conditions, related to anthropogenic disturbance or climate change. Models based on sedimentary pigment have been established for a quantitative reconstructions of lake water concentration of total phosphorus [7]. Diatom is among the most commonly used to detect changes in the lake ecosystem, and they were used to infer several lake physical and chemical characteristics[8,9].

Previous studies [10,11] on subfossil chironomid remains, total carotenoids and pollen grain has shown significant changes in oxygen conditions at the water/sediment interface, trophic food web as a consequence of increased anthropogenic pressure around Lake Narlay.

Here, we present the results from diatoms and specific photosynthetic pigments analysis, performed on the same core, as an additional tools aimed to reconstruct more clearly the limnological conditions, trophic and ecological evolution at secular scale of Lake Narlay and document the impact of different drivers (climate and/or human activities) of this long-term temporal evolution (the last 1200 years).

2. Materials and Methods

Site description

Lake Narlay (46°64N, 5°91E) is located in the Jura Mountains (eastern France) as shown in Figure 1. The catchment area is mainly covered by forest (32 % of mixed forest, 13 % of coniferous forest, 16% of hardwood forest) while 34 % is represented by agricultural parcel and only 5 % by urban area (Corine Land Cover, www.stats.environnement.developpement-durable.gouv.fr). The lake has a surface of 41 ha, and 40m as water depth maximum. From the earlier part of the 20th century, Lake Narlay was polluted by wastewater from a piggery and cheese-making factory. The increased nutrient input caused an acceleration of the eutrophication process and the buildup of anoxic zone in the lake deep water. The oxygen concentrations in the deep water reached zero at the end of summer and during the winter stratification. From 1980s a wastewater treatment plan has been set up; however, the deeper water layer remains hypoxic each summer (Figure 1; **[12]**).

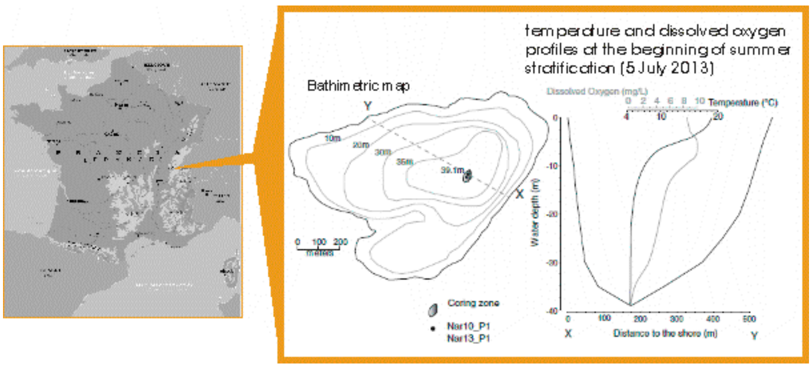

Figure 1. Lake Narlay location, bathymetric map showing the coring site and an example of temperature and dissolved oxygen profiles at the beginning of summer stratification (5 July 2013) showing the presence of anoxic condition in the bottom water column.

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Sediment cores and dating methods

Two sediment cores (Nar10_P1 and Nar13_P1) were collected in the deepest part of the lake using a gravity corer (UWITEC, 63mm of diameter) in summers 2010 and 2013 (Figure 2). Using radiometric methods, sediment dating was performed on Nar10_P1, while the chronology of the core Nar13_P1 has been cross-correlated with the Nar10_P1 signal of the magnetic susceptibility for the upper part of the core (the first 20 cm), see Figure 2c. Moreover, two additional radiocarbon dates have also been obtained (Poznan Radiocarbon Laboratory, Poland; Beta Analytic, USA). Age-depth modeling for the Nar10_P1 and Nar13_P1 core (Figure 2a,b) was performed using a simple linear interpolation (Clam package for R; [13]). For a detailed discussion about chronology see [11].

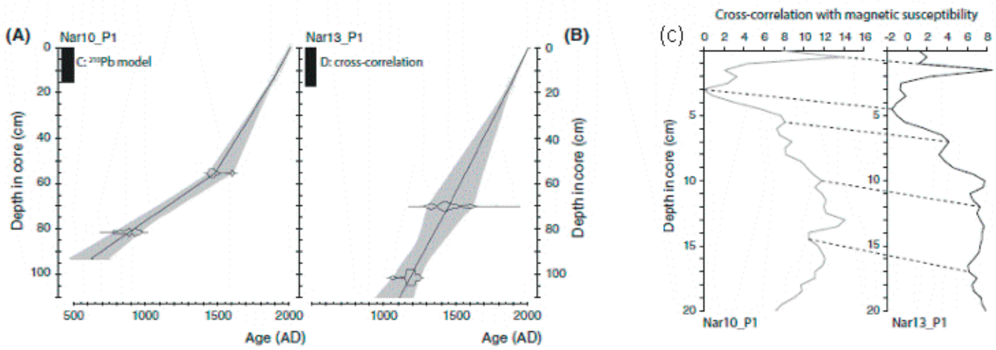

Figure 2. Lake Narlay: Age-depth model derived from 210Pb and 14C dating of the two cores (a) NAR10_1, (b) NAR. The cross-correlation between the two cores is also shown (c).

Proxies analyzed

Photosynthetic pigments were extracted in 90% acetone, overnight in the dark, under nitrogen. The extract obtained was used both to quantify the chlorophylls and their derivatives (Chlorophyll Derivatives Units, CD) and total carotenoids by spectrophotometer. Individual carotenoids were detected by Reversed Phase High-Performance Liquid Chromatography using a Thermo Scientific HPLC. Carotenoid concentrations were expressed in nanomoles per gram of organic carbon (nmol g^{-1} TOC and chlorophyll derivatives in units per gram of organic matter (U g^{-1} TOC).

Diatoms were prepared using standard H_2O_2-HCl digestion and mounted with Naphrax. For each sample, at least 500 valves were identified and enumerated with a light microscope (Zeiss Axiolab).

Data analysis

Statistical analyses were performed using R software[14]. The zones were determined by constrained hierarchical cluster analysis using a Bray-Curtis distance and CONISS linkage method with the Rioja package[15]. The significance of the zone was assessed using the broken-stick model [16]. The probability distribution of age changes for the cores Nar10_P1 and Nar13_P1 was performed using the Clam package for R [13]. Change point package developed for R by Killick and Eckley [17] was used to identify the location of multiple change points within time series. PCA was done with CANOCO[18] and the significance of the axes was tested using the broken-stick model [16].

3. Results

Figure 3 represent the major algal specific carotenoid that have been detected along the core. The temporal evolution of the key photosynthetic algal and bacteria taxa, represented by their specific carotenoid. Car inf-TP is the water TP inferred from total carotenoid as in Guilizzoni et al. [7]. The pigment zones have been identified by CONISS and the results are presented accordingly.

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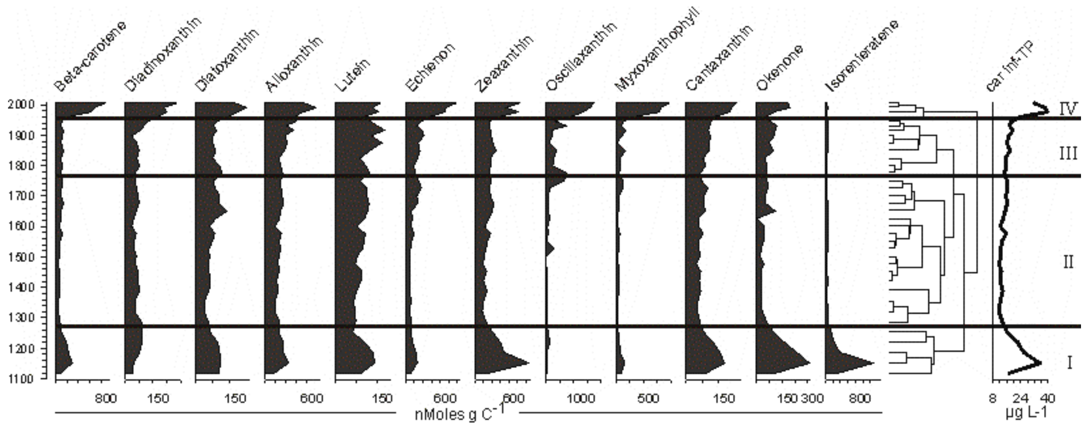

Figure 3. Lake Narlay, core NAR13-P1: Distribution of the most abundant specific carotenoid identified along the core analyzed. The horizontal line represents the boundary between the zone based on the CONISS clustering. The total phosphorus reconstructed from total carotenoid (car-inf TP) is also shown.

P_Z1 (1100-1300 AD): This zone is characterized by a relatively high productivity. Among phytoplankton, cyanobacteria are well-represented (zeaxanthin, cantaxanthin) with chlorophyceae (Lutein) and diatom (diatoxanthin). In this period there is also a high amount of both photosynthetic anaerobic bacteria forms: "red" (okenone) and "green" (isorenieratiene). This suggest the presence of anoxic bottom water, but a good water transparency due to the development of red and green bacteria.

P_Z2 (1300-1790 AD): There is a general decrease among the algal and bacterial pigment suggesting a much lower production. This shift might be associated with colder condition. Among the phytoplankton the reduction seems more evident for cyanobacteria while chlorophycee (Lutein) show a less marked decrease. Among the photosynthetic bacteria the "greens" are much more reduced than "red" ones, this might due to reduction of the anoxic condition ("red" are more tolerant to intermittent break of anoxic condition). From 1550 it should be noted a shift in lake productivity with an increase of oscillaxanthin. These changes are coincident with changes in the catchment usage as documented by pollen remains (Belle et al., 2016)

P_Z3 (1790-1960): This period is characterized by a marked increase oscillaxanthin, among the cyanobacteria carotenoid, and okenone (red phototrophic bacteria). This suggest that the lake ecosystem shift to a higher trophic level.

P_Z4 (1960-2008): There is a general increase of all the pigment and many of them here reach the highest value. This support a further increase of the lake productivity. In the first part of this phase the increment is generalized, while in the second part (last 50yrs) there is a clear shift to the dominance of cyanobacteria (oscillaxanthin, myxoxanthophyll, cantaxanthin). The photosynthetic anaerobic bacteria are still dominated by the "red" ones suggesting the bottom water is anoxic, but with a lower transparency due to a higher primary productivity and then "green" phototrophic bacteria are not able thrive again.

Figure 4 shows the temporal evolution of diatom community that have been dived into 5 major zone. The oldest period (D_Z1: from the bottom of the core to ca. AD 1200) is characterized by the planktonic Cyclotella species dominance. This is in agreement with a period of warm climate conditions and high water transparency indicated by the presence of benthic Staurosira species (mainly S. venter and S. subsalina).

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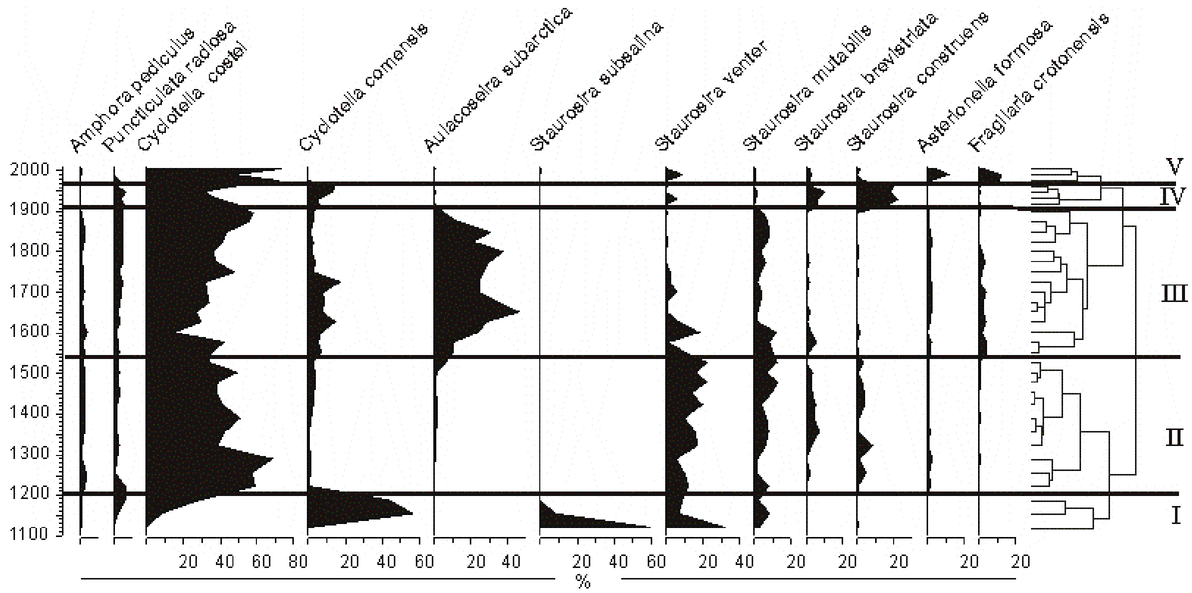

Figure 4. Lake Narlay, core NAR13-P1: Distribution of the most abundant diatoms (filtered at 5% abundance) identified along the core analyzed. The horizontal line represents the boundary between the zone based on the CONISS clustering.

After 1200 AD (Di_Z2) the tycoplactonic Cyclotella costei dominate and the Staurosira species, typical of cold water (S. mutabilis and S. brevistriata), show their highest percentages. This suggest a cold phase with long period of ice cover, which reduce the pelagic, spring-diatom species.

Between 1550 and 1900 AD (Di_Z3) there is a slightly increase of C. comensis, associated with a reduction of Staurosira spp. However, the most striking episode is the abrupt appearance of Aulacoseria subarctica. This planktonic specie have a peculiar autoecology requiring cold and turbulent water, a moderate increase in nutrient and could produce resting cells that survive in the deep layers of Lake Narlay even under anoxic conditions. This suggest that it is a still cold phase, but warmer respect to the previous one, with A. subarctica blooming at the early spring, water mixing.

The early twentieth century (Di_Z4) is characterized by the disappearance of A. subarctica and the other cold-water species and by the increase of oligo-mesotrophic taxa (C. comensis, S.brevistriata, S. construens). This change could be explained by a further enrichment in nutrient that favour the small centric diatoms instead of the large and heavy A. subarctica.

In addition, during the second half of 1900 yrs (Di_Z5) the diatom community show a clear species succession, with oligotraphentic taxa gradually substituted by taxa preferring higher trophic conditions. Indicators of meso-eutrophic conditions (e.g., Fragilaria crotonensis<Asterionella formosa) became abundant in the lakes during the last decade. The temperature increase observed in this latter period is overwritten by the recent anthropogenic impact occurred in the last 50yrs.

4. Discussion

Principal component analysis (PCA) was used to emphasize variation and bring out the common patterns in each of the chironomids, pigments and diatom dataset. For both chironomids and carotenoids only the first axis resulted to be significant, and they explained 44% and 37% respectively of the temporal variability. In the case of diatom up to 4 axis resulted to be significant according to the test, but we considered for the following analysis only the first (31%) and second (23%) axis that explained together up to 54% of the variance among diatoms communities.

Guiot et al. [19] provided a spatially gridded reconstruction of the spring-summer temperature over the last 1400 years. This reconstruction was based on tree-ring analysis for the present area (but also on pollen and ice-core data for the other grids). In the present study, the temperature anomaly from the grid "TAS 2.5° E; 42.5° N" has been used to provide annual climate reconstitution over the time studied. The temporal variations of pigments, diatoms and chironomid sample-scores along the

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PCA axis were compared with long term temperature anomalies and summarized with a scatterplot matrix of the Sperman's rho (Figure 5). The scatter plot with highest correlation are closest to the diagonal and the intensity color mark those with higher correlation p-value. The temporal variation of the scores was also analyzed with the R change-point package to identifying shifts in mean and/or variance of the time series.

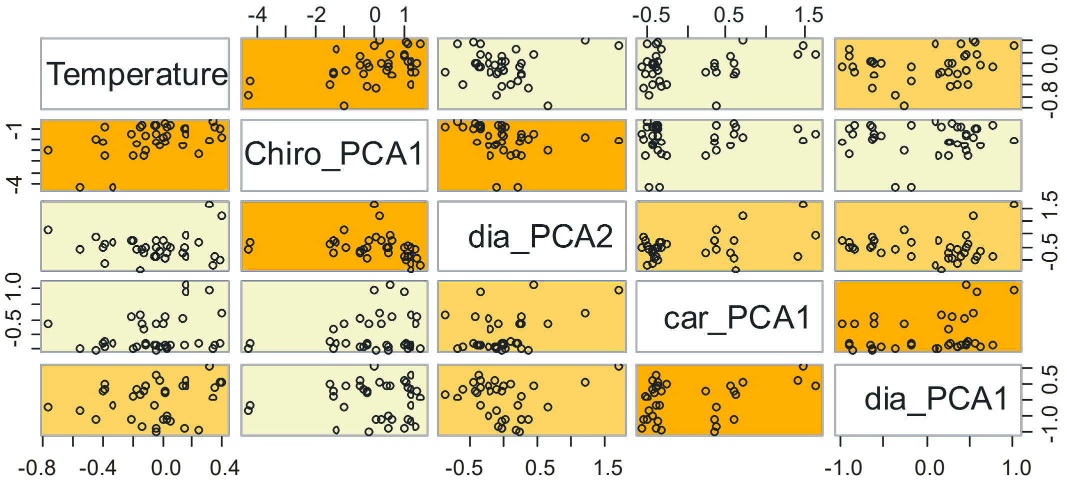

Figure 5. Lake Narlay: Scatter plots of the pigments, diatoms and chironomid sample-scores on the first PCA axis against long term temperature anomalies from Guiot et al. [19]. The scatter plot with highest correlation are closest to the diagonal; the two color tone highlight those where p-value is minor of 0.5 and 0.1 respectively.

Based on this analysis, the chiro-PCA scores are more strongly related to temperature, while carotenoid and diatoms show a weaker relation between PCA scores and climate and evident changes in the recent section of the core that should be imputed to other driving factors, such as the human impact documented by the increase of cultivated plant pollen remains.

Sediment records provide a detailed reconstruction of the trophic and ecological evolution of Lake Narlay during the last ca. 1200 years, which confirm the historical data and is highly coherent with the recent trophic evolution of several other EU temperate lakes.

A complex combination of climate and anthropogenic pressure explain the 1200 years of ecological trajectory of Lake Narlay. Major changes could be found in the sediment records in relation to climatic variability, because the colder event of the Little Ice Age (LIA) induces a significant impact on diatom assemblage, and lake productivity. The effect of the LIA on the lake productivity has already been highlighted by several studies [20,21]. The reconstruction of land use history in the catchment area of Lake Narlay has revealed an intensification of the agro-pastoral practices at ca. AD 1550 (Figure 6). These anthropogenic activities are the cause of an increase in allochtonous organic matter input into the lake and in combination with a little warming event during the LIA occurred at AD 1600 (Figure 6) may be responsible for the change observed in this phase.

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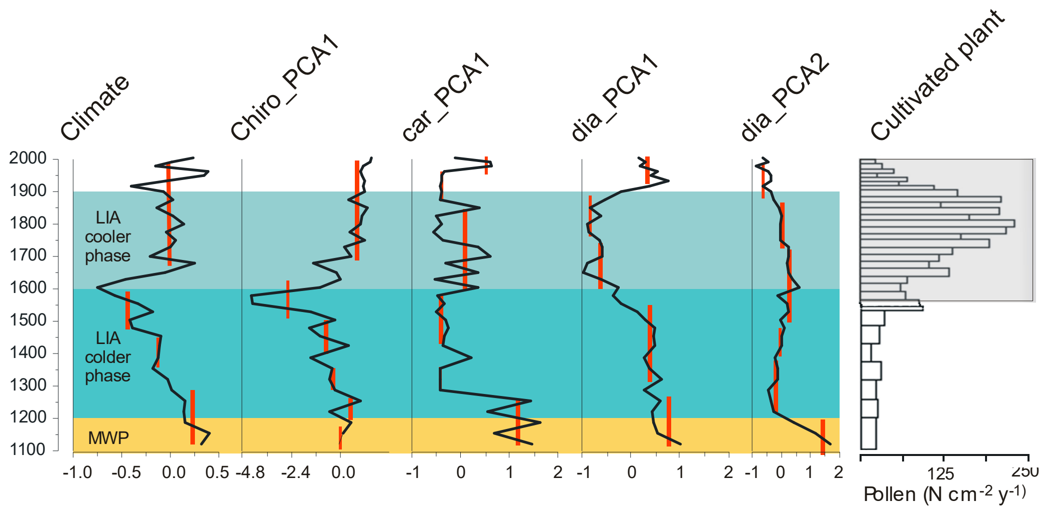

Figure 6. Lake Narlay: Results of the change point detection analysis obtained from the R package "Changepoint detection package [17]. The grey zones are drawn according to the know climatic condition. The cultivated plant pollen abundance documents the increase anthropogenic pressure on the lake.

The last change at the beginning of 20th century corresponds to an increase in the trophic status and the degradation of oxygen concentrations to reach probability the current state of Lake Narlay. Despite the reduction in cultivated pollen in the core top section (Figure 6), historic archives reveal deep modifications of the local activities from extensive to intensive exploitation, inducing a shift between diffuse to point source input. The strong modification of agro-pastoral practices and human intensification pressure in the watershed of Lake Narlay seems to be the main cause of the major change in influx of nutrients and induced a significant increase in the trophic status and organic matter sedimentation to reach unprecedented values.

Our data show that all the proxies have responded with a clear shift to the pressure climatic or anthropogenic. The evolution of agricultural practices (from intensification to modernization or industrialization) induces various impacts on trophic functioning. We believe that these kind of results will be help to interpret the interplay between current global warming and the anthropogenic pressures on the lake trophic functioning.

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Author Contributions: AL and SM originally formulated the idea; SB and LM developed the age-depth model of Lake Narlay; SM, AL performed analysis on diatom, sedimentary pigments, while chirononids was done by SB and LM; Al performed statistical analyses and wrote the manuscript with substantial contributions from all co-authors.

Conflicts of Interest: The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

Figure captions

Figure 1. Lake Narlay location, bathymetric map showing the coring site and an example of temperature and dissolved oxygen profiles at the beginning of summer stratification (5 July 2013) showing the presence of anoxic condition-P1n in the bottom water column.

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References

1. Wetzel, R. G. *Limnology.*; Sauders College Publ., Philadelphia: Philadelphia (USA), 1970;
2. Foley, S. F.; Gronenborn, D.; Andreae, M. O.; Kadereit, J. W.; Esper, J.; Scholz, D.; Pöschl, U.; Jacob, D. E.; Schöne, B. R.; Schreg, R.; Vött, A.; Jordan, D.; Lelieveld, J.; Weller, C. G.; Alt, K. W.; Gaudzinski-Windheuser, S.; Bruhn, K.-C.; Tost, H.; Sirocko, F.; Crutzen, P. J. The Palaeoanthropocene – The beginnings of anthropogenic environmental change. *Anthropocene* **2013**, *3*, 83–88, doi:10.1016/j.ancene.2013.11.002.
3. Guilizzoni, P.; Lami, A. Paleolimnology: Use of Algal Pigments as Indicators. In *Encyclopedia of Environmental Microbiology*; John Wiley & Sons, Inc., 2003 ISBN 978-0-471-26339-5.
4. McGowan, S. PALEOLIMNOLOGY | Pigment Studies. In *Encyclopedia of Quaternary Science (Second Edition)*; Mock, S. A. E. J., Ed.; Elsevier: Amsterdam, 2013; pp. 326–338 ISBN 978-0-444-53642-6.
5. Dubois, N.; Saulnier-Talbot, É.; Mills, K.; Gell, P.; Battarbee, R.; Bennion, H.; Chawchai, S.; Dong, X.; Francus, P.; Flower, R. First human impacts and responses of aquatic systems: A review of palaeolimnological records from around the world. *Anthr. Rev.* **2017**, 2053019617740365.
6. Mills, K.; Schillereff, D.; Saulnier-Talbot, É.; Gell, P.; Anderson, N. J.; Arnaud, F.; Dong, X.; Jones, M.; McGowan, S.; Massaferro, J.; Moorhouse, H.; Perez, L.; Ryves, D. B. Deciphering long-term records of natural variability and human impact as recorded in lake sediments: a palaeolimnological puzzle. *Wiley Interdiscip. Rev. Water* **2017**, *4*, n/a-n/a, doi:10.1002/wat2.1195.
7. Guilizzoni, P.; Marchetto, A.; Lami, A.; Gerli, S.; Musazzi, S. Use of sedimentary pigments to infer past phosphorus concentration in lakes. *J. Paleolimnol.* **2011**, *45*, 433–445, doi:10.1007/s10933-010-9421-9.
8. Battarbee, R.; Jones, V.; Flower, R.; Cameron, N.; Bennion, H.; Carvalho, L.; Juggins, S. Diatoms. In *Tracking Environmental Change Using Lake Sediments*; Smol, J., Birks, H. J., Last, W., Bradley, R., Alverson, K., Eds.; Developments in Paleoenvironmental Research; Springer Netherlands, 2002; Vol. 3, pp. 155–202 ISBN 978-1-4020-0681-4.
9. Battarbee, R. W.; Anderson, J. N.; Bennion, H.; Simpson, G. L. Combining limnological and palaeolimnological data to disentangle the effects of nutrient pollution and climate change on lake ecosystems: problems and potential. *Freshw. Biol.* **2012**, *57*, 2091–2106, doi:10.1111/j.1365-2427.2012.02860.x.
10. Belle, S.; Millet, L.; Verneaux, V.; Lami, A.; David, E.; Murgia, L.; Parent, C.; Musazzi, S.; Gauthier, E.; Bichet, V.; Magny, M. 20th century human pressures drive reductions in deepwater oxygen leading to losses of benthic methane-based food webs. *Quat. Sci. Rev.* **2016**, *137*, 209–220, doi:10.1016/j.quascirev.2016.02.019.

 doi:10.20944/preprints201801.0014.v1

11. Belle, S.; Verneaux, V.; Millet, L.; Etienne, D.; Lami, A.; Musazzi, S.; Reyss, J.-L.; Magny, M. Climate and human land-use as a driver of Lake Narlay (Eastern France, Jura Mountains) evolution over the last 1200 years: implication for methane cycle. *J. Paleolimnol.* **2016**, *55*, 83–96, doi:10.1007/s10933-015-9864-0.
12. Belle, S.; Parent, C.; Frossard, V.; Verneaux, V.; Millet, L.; Chronopoulou, P.-M.; Sabatier, P.; Magny, M. Temporal changes in the contribution of methane-oxidizing bacteria to the biomass of chironomid larvae determined using stable carbon isotopes and ancient DNA. *J. Paleolimnol.* **2014**, *52*, 215–228, doi:10.1007/s10933-014-9789-z.
13. Blaauw, M. Methods and code for 'classical' age-modelling of radiocarbon sequences. *Quat. Geochronol.* **2010**, *5*, 512–518, doi:10.1016/j.quageo.2010.01.002.
14. *R Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing*; Vienna, Austria, 2017;
15. Juggins, S. *Rioja. An R package for the analysis of Quaternary science data*; New Castle, UK, 2009;
16. Bennett, K. D. Determination of the number of zones in a biostratigraphical sequence. *New Phytol.* **1996**, *132*, 155–170.
17. Killick, R.; Eckley, I. changepoint: An R package for changepoint analysis. *J. Stat. Softw.* **2014**, *58*, 1–19.
18. ter Braak, C. J. F.; Šmilauer, P. *CANOCO Reference Manual and CanoDraw for Windows User's Guide: Software for Canonical Community Ordination (version 4.5).*; Microcomputer Power (Ithaca NY, USA), 2002;
19. Guiot, J.; Corona, C.; ESCARSEL members Growing Season Temperatures in Europe and Climate Forcings Over the Past 1400 Years. *PLoS ONE* **2010**, *5*, e9972, doi:10.1371/journal.pone.0009972.
20. Coianiz, L.; Ariztegui, D.; Piovano, E.; Lami, A.; Guilizzoni, P.; Gerli, S.; Waldmann, N. Environmental change in subtropical South America for the last two millennia as shown by lacustrine pigments. *J. Paleolimnol.* **2015**, *53*, 233–250, doi:10.1007/s10933-014-9822-2.
21. Zawiska, I.; Luoto, T. P.; Nevalainen, L.; Tylmann, W.; Jensen, T. C.; Obremska, M.; Słowiński, M.; Woszczyk, M.; Schartau, A. K.; Walseng, B. Climate variability and lake ecosystem responses in western Scandinavia (Norway) during the last Millennium. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **2017**, *466*, 231–239, doi:10.1016/j.palaeo.2016.11.034.