Erschienen in: Water Research ; 180 (2020). - 115849
https://dx.doi.org/10.1016/j.watres.2020.115849

Reply for comment on "on the calculation of lake metabolic rates: Diel O_2 and $^{18/16}O$ technique" by Peeters et al. [Water research 165 2019, 114990]

Frank Peeters*, Jorge Encinas Fernandez, Hilmar Hofmann

Department of Biology, Limnological Institute, University of Konstanz, Germany

Keywords:
Lake metabolism
Production
Respiration
$^{18/16}O$ technique
Diel O_2 technique

1. Clarification of research objective, method and conclusions of Peeters et al. (2019)

Peeters et al. (2019) investigated the uncertainty of daily mean metabolic rates obtained with the steady state isotopic technique. Bogard et al. (2020a) claim, that Peeters et al. (2019) "disregard the steady state isotopic technique based on its inability to detect sub-daily metabolic patterns". This claim is false. The paper by Peeters et al. (2019) is entirely focused on the uncertainty of daily mean metabolic rates. It addresses the question, how strongly the principal assumptions of the steady state isotopic technique affect the reliability of the estimated daily mean metabolic rates. The steady state isotopic technique assumes that dissolved oxygen, DO, and ^{18}O in DO, $^{18}O_{DO}$, are at steady state, which is in contradiction to observations. The diel O_2 technique even utilizes diel changes in DO to estimate metabolic rates. The false assumption that DO and $^{18}O_{DO}$ are at steady state introduces errors in the daily mean metabolic rates obtained with the steady state isotopic technique. These errors are assessed in Peeters et al. (2019) clarifying the limitations of the applicability of the steady state isotopic technique.

* Corresponding author.
E-mail address: frank.peeters@uni-konstanz.de (F. Peeters).

The analysis in Peters et al. (2019) is based on a model study using the parameterization of Bogard et al. (2017). Initial $^{18}O_{DO}$ data were not assigned randomly as suggested by Bogard et al. (2020a). The initial $^{18}O_{DO}$ values were taken from long-term simulations providing the diel cycle of $^{18}O_{DO}$ values assuming the same diel pattern of gross primary production, GPP, and the same values of daily mean GPP, respiration rate, temperature and gas transfer velocity during 1000 days (Peeters et al., 2019). The initial $^{18}O_{DO}$ values are therefore consistent with the assumption of a regular pattern of diel change in GPP, steady state daily mean conditions, and the parameters used in Bogard et al. (2017). $^{18}O_{DO}$ values determined from the mass balance of $^{18}O_{DO}$ (eq. (6) in Peeters et al., 2019) assuming steady state as in the stable isotope technique, are essentially the same as the daily mean $^{18}O_{DO}$ we obtained from the numerical simulations.

The main conclusion of Peeters et al. (2019) is that the steady state isotopic technique may cause errors in the daily mean metabolic rates by up to a factor of 2.5. Estimated metabolic rates deviate from the true metabolic rates because DO and $^{18}O_{DO}$ are not steady but vary at sub-daily time scales and between days. The errors in the estimated metabolic rates due to diel variations of DO and $^{18}O_{DO}$ (i) depend on the time during the day when the point measurement is performed, (ii) are lowest, if measurements are conducted around midday, and (iii) increase with increasing eutrophication with daily maximum errors ranging from 20% in oligotrophic to 500% in eutrophic systems (Peeters et al., 2019). Changes in DO and $^{18}O_{DO}$ between days cause additional uncertainty in the metabolic rates. In the mesotrophic Schwarzenbach reservoir (average GPP ~ 1 mg l^{-1} d^{-1}), true and estimated daily mean GPP differ by up to a factor of 2.5 (Fig. 5 in Peeters et al., 2019). Hence, the claim of Bogard et al. (2020a) that Peeters et al. (2019) emphasized "the most extreme deviance of 250% that only occurred at a single time in the most productive system" is incorrect.

2. Confirmation of numerical results of Peeters et al. (2019) by observations

Observations in lakes and mesocosms confirm the conclusions from the numerical simulations of Peeters et al. (2019). E.g. the

measurements of Bocaniov et al. (2012) show that GPP determined with the incubation technique can be ~35% smaller but also up to 4 times larger than GPP obtained with the isotope technique (Peeters et al., 2019). Bogard et al. (2020a) comment that "results from the isotopic technique also align more closely with other free water metabolic datasets than traditional incubation approaches (Bogard et al., 2017, 2019a,b, 2020b)". However, in the mesocosm experiment conducted by Bogard et al. (2017) to validate the steady state isotope technique, GPP determined from the steady state isotopic technique, GPP_{18O}, and from the free water diel O_2 technique, GPP_{O2}, are not correlated and deviate by up to an order of magnitude (Peeters et al., 2019). Bogard et al. (2020a) argue that "such deviation is more likely attributable to unreliability of high frequency data, for which it is more difficult to accurately capture physical conditions and rates of gas exchange at sub-daily time scales in mesocosm experiments … than daily averages of gas exchange in natural systems". However, GPP_{18O} and GPP_{O2} deviate substantially not only in the mesocosm experiment but also in the lakes sampled by Bogard et al. (2017), i.e. GPP_{18O} and GPP_{O2} differ by up to a factor of 2.5 in Lake Simoncouche and by up to a factor of 3 in Lac Croche (Peeters et al., 2019). Furthermore, GPP_{O2} is typically rather insensitive to gas exchange (Peeters et al., 2016), whereas GPP_{18O} is proportional to v_{gas}/Z_{mix}, v_{gas} being the gas transfer velocity and Z_{mix} the depth of the surface mixed layer (Bogard et al., 2017; Peeters et al., 2019). Especially in lakes with a shallow surface mixed layer the error of GPP_{18O} introduced by the uncertainty in Z_{mix} can be substantial (see e. g. Lac Croche in Bogard et al., 2017). In the diel O_2 technique gas exchange is only one of two terms determining metabolic rates and GPP_{O2} depends on the difference between daily mean gas exchange and the mean gas exchange during daytime (Peeters et al., 2016). Hence, as long as O_2 is oversaturated during the entire day, GPP_{O2} is less sensitive to errors in v_{gas} and Z_{mix} than GPP_{18O}.

Bogard et al. (2019a) did not compare rates measured with different techniques at the same time in the same system and Bogard et al. (2020b) compared estimates of net production, NEP, from the isotopic technique with NEP determined from DO (Bogard and Giorgio, 2016) which were calculated with an erroneous equation:

$$DO\text{-}DO_{sat} = \mathrm{NEP} - v_{gas}\,(DO\text{-}DO_{sat}) \,/\, Z_{\mathrm{mix}} \text{ (Bogard and Giorgio, 2016)} \quad (1)$$

DO_{sat} is the saturation concentration of DO. Note that equ. 1 has incorrect dimensions. The left hand side should correctly be the rate of change of DO, dDO/dt. Bogard and Giorgio (2016) claim that equ. 1 describes steady state conditions, but the steady state assumption implies that daily mean NEP is equal to the daily mean loss of oxygen to the atmosphere divided by Z_{mix} (Peeters et al., 2019), thus $0 = \mathrm{NEP} - v_{gas}\,(DO\text{-}DO_{sat})/Z_{\mathrm{mix}}$. The steady state isotope technique uses exactly this equation to determine daily mean NEP and a correlation with results obtained from equ. 1 cannot serve as a test of the validity of the steady state isotope technique.

Note that NEP is proportional to the gas loss to the atmosphere. The steady state isotope technique can therefore not be applied to assess metabolic rates in waters without connection to the atmosphere, i.e. in the thermocline or below.

3. Accuracy of metabolic rates estimated with the stable isotope technique

Bogard et al. (2020a) state: "the isotopic method delivers metabolic estimates that are generally robust and within the same order of magnitude as those obtained by other techniques". The modelling results of Peeters et al. (2019) are consistent with this statement: In the oligo-to mesotrophic systems Schwarzenbach and Großer Brombachsee, the eutrophic Kleiner Brombachsee, and the numerical experiments with daily mean GPP ranging from 0.25 to 10 mg L^{-1} d^{-1}, the estimates with the isotopic technique and the "true" metabolic rates are within the same order of magnitude (Figs. 2, 3, 5 in Peeters et al., 2019). The model results suggest that the metabolic rates determined with the isotopic technique may deviate by a factor of up to 2.5 from the true metabolic rates in mesotrophic systems and deviate even more in eutrophic systems (Peeters et al., 2019). Because the deviations between GPP_{18O} and GPP_{O2} are smallest during midday, which is confirmed by Bogard et al. (2020a), the findings of Peeters et al. (2019) recommend sampling around midday and suggest caution in highly eutrophic systems in applications of the steady state isotopic technique.

4. Concluding remarks

We agree with Bogard et al. (2020a) that the stable isotope technique is sufficient to address research questions that can be answered, if daily mean metabolic rates are known within an order of magnitude. However, in investigations requiring metabolic rates to be known better than a factor of two, e.g. in studies testing the hypothesis that the increase in atmospheric CO_2 leads to higher primary production, the stable isotope technique may provide unreliable conclusions. Note further, that the stable isotope technique is limited to the surface mixed layer and cannot be employed to assess net-production within the thermocline or below. Thus, comparison of metabolic rates between systems is restricted to surface waters and may miss substantial production in deeper waters. Finally, because vertical mixing and transport is not considered, estimates of metabolic rates based on the steady state isotope technique are likely to be unreliable during spring and fall overturn. The reliability of all open water techniques is affected by uncertainties in vertical transport and gas exchange. Selection between the different open water and incubation techniques, which all have their specific merits, needs careful consideration of their limitations with respect to temporal resolution and accuracy of estimated metabolic rates required for the research question addressed.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The study was financially supported by the Ministry of Science, Research and the Arts of the Federal State Baden-Württemberg, Germany (grant: Water Research Network project: Challenges of Reservoir Management - Meeting Environmental and Social Requirements) and by a grant from the Limnology Center at Ecole Polytechnique Federale de Lausanne (EPFL), Switzerland under the project "Primary Production in Large Lakes".

References

Bocaniov, S.A., Schiff, S.L., Smith, R.E.H., 2012. Plankton metabolism and physical forcing in a productive embayment of a large oligotrophic lake: insights from stable oxygen isotopes. Freshw. Biol. 57, 481–496. https://doi.org/10.1111/j.1365-2427.2011.02715.x.

Bogard, M.J., Butman, D.E., del Giorgio, P.A., 2020a. Comment on "On the calculation of lake metabolic rates: Diel O_2 and $^{18/16}O$ technique" by Peeters et al. Water Res [Water Research 165 2019, 114990].

Bogard, M.J., Giorgio, P.A., 2016. The role of metabolism in modulating CO2 fluxes in boreal lakes. Global Biogeochem. https://doi.org/10.1002/2016GB005463. Cycles 1509–1525.

Bogard, M.J., Johnston, S.E., Dornblaser, M.M., Spencer, R.G.M., Striegl, R.G., Butman, D.E., 2019a. Extreme rates and diel variability of planktonic respiration in a shallow sub - arctic lake. Aquat. Sci. 81, 1–9. https://doi.org/10.1007/s00027-019-0657-9.

Bogard, M.J., Kuhn, C.D., Johnston, S.E., Striegl, R.G., Holtgrieve, G.W., Dornblaser, M.M., Spencer, R.G.M., Wickland, K.P., Butman, D.E., 2019b. Negligible cycling of terrestrial carbon in many lakes of the arid circumpolar landscape. Nat. Geosci. 12, 180–185. https://doi.org/10.1038/s41561-019-0299-5.

Bogard, M.J., St-Gelais, N.F., Vachon, D., Giorgio, P.A., 2020b. Patterns of spring/summer open-water metabolism across boreal lakes. Ecosystems. https://doi.org/10.1007/s10021-020-00487-7.

Bogard, M.J., Vachon, D., St-Gelais, N.F., del Giorgio, P.A., 2017. Using oxygen stable isotopes to quantify ecosystem metabolism in northern lakes. Biogeochemistry 133, 347–364. https://doi.org/10.1007/s10533-017-0338-5.

Peeters, F., Atamanchuk, D., Tengberg, A., Encinas-Fernandez, J., 2016. Lake Metabolism : Comparison of Lake Metabolic Rates Estimated from a Diel CO_2 - and the Common Diel O_2 - Technique 1–24. https://doi.org/10.1371/journal.pone.0168393.

Peeters, F., Hofmann, H., Encinas Fernandez, J., 2019. On the calculation of lake metabolic rates: diel O_2 and $^{18/16}O$ technique. Water Res. 165, 1–12. https://doi.org/10.1016/j.watres.2019.114990.