

## Sediment–water phosphorus dynamics in newly created Lake Agmon (Agmon–Hula wetlands), Israel

K. David Hambright and Werner Eckert

### Introduction

The role of sediments in P dynamics is well established for freshwater aquatic systems (BACINI 1985, BOSTRÖM et al. 1988). Sediments can be particularly important in shallow lakes and wetlands as various forms of bioavailable (e.g. iron- and organic-bound) P in the upper sediments can be a major source of P to the water column biota via numerous physically, chemically and biologically mediated processes (REDDY & D'ANGELO 1994, KUFEL et al. 1997).

Lake Agmon is located ca. 20 km north of Lake Kinneret in the Hula Valley, northern Israel within the newly created (1994) Agmon–Hula wetland (Fig. 1). This small (100 ha, mean depth ca. 0.8 m) wetland lake was created as part of the Hula Valley Restoration Project aimed at remediating problems such as underground fires in the peat soils, soil subsidence, and dust storms that have resulted since Lake Hula and its surrounding swamps were drained in the 1950s (HAMBRIGHT & ZOHARY 1998, 1999). Today, this multipurpose lake serves in water table regulation, irrigation supply regulation and ecotourism. Although general water quality has been acceptable for the designed purposes of the lake, it has become increasingly eutrophic since its creation, and is characterized by high summer water-column P concentrations and cyanobacterial blooms. Detailed descriptions of general water chemistry and quality can be found in HAMBRIGHT et al. (1998), MARKEL et al. (1998), and ZOHARY et al. (1998). Here we report results of a study designed to determine the potential importance of biogeochemically mediated release of P from the sediments in the supply of P to the Lake Agmon biota.

### Methods

Intact sediment cores (four to five on each date, 40 cm deep, with 8–15 cm of overlying water) were taken from a central site of the lake in November 1996, March and August 1997 and June 1998 as

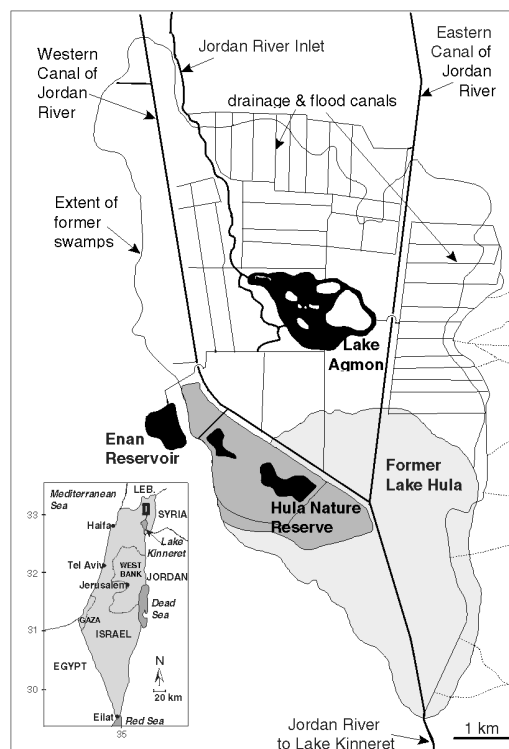


Fig. 1. Map showing location of Lake Agmon in relation to the drained Lake Hula. Rectangle in inset shows location of Hula Valley.

described previously (ECKERT et al. 1997). One core on each date was sectioned into 0.5- (upper slice only) and 1-cm slices (0.5–9.5 cm). Each slice was processed for porewater content (by centrifugation and filtration), porewater SRP and TDP concentrations (APHA 1992) and particulate P fractionation (August and June cores only – modified from HIELTJES & LIJKEMA (1980) and (KARL & TIEN 1992)) to separate metal- and humic acid-bound

fractions (ECKERT unpubl.). The remaining cores were incubated in controlled (20 °C, dark) laboratory conditions for studying the roles of pH, redox and microbial activity on P release from the sediments of Lake Agmon.

In the first experimental series (November, March and August cores), the overlying water of replicate cores were subjected to one of three treatments:

1. microbial activity inhibited, pH ~8 (not regulated);
2. microbial activity inhibited, pH ~6.5 (regulated by automated-feedback CO<sub>2</sub> injection);
3. control.

Microbial activity was inhibited by the addition of sodium azide and antibiotics (ECKERT et al. 1997). All cores were then incubated under initially oxic (via aeration), then anoxic conditions while following the accumulation of P (as SRP) released into the overlying water. Anoxic conditions were created artificially by N<sub>2</sub> bubbling and the addition of sodium sulfide (final concentration ca. 100–200 µM) (November and March cores) or naturally by respiration by sealing the cores (August).

In the second experimental series (June 1998), replicate cores were subjected to daily fluctuations between oxic and anoxic conditions as detailed above. One core was regulated to pH ~6.5, while the pH values in three cores were allowed to fluctuate under the experimental conditions. Concentrations of SRP and TDP in the overlying water were monitored for 15 days. Dissolved organic P (DOP) was calculated as TDP – SRP.

## Results and discussion

Total P content of Lake Agmon sediments averaged ( $\pm$ SE) 1041  $\pm$  97  $\mu\text{g g}_{\text{DW}}^{-1}$  in the upper 9.5 cm in cores sampled in August 1997 and June 1998 (Fig. 2). P bound to calcium accounted for the largest fraction (49%). Metal-bound P accounted for ca. 12%, ca. 21% was bound to humic acids, and the remaining 18% was bound to other organic compounds. Loosely bound P was undetectable.

Porewater SRP and TDP concentrations were variable with season and depth (Fig. 3). During November 1996 and March 1997, little SRP was detected in the porewaters and TDP averaged ca. 90  $\mu\text{g P L}^{-1}$  throughout the upper 9.5 cm. However, during the mid-summer 1997 bloom period (August), TDP exceeded 300  $\mu\text{g P L}^{-1}$  in the upper 4.5 cm and SRP ranged between 30 and 100  $\mu\text{g P L}^{-1}$  through-

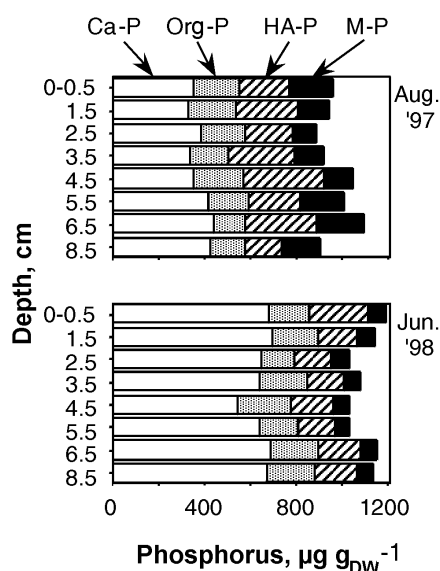


Fig. 2. P fractionation in the upper 9.5 cm of Lake Agmon sediments based on cores sampled in August 1997 and June 1998. Ca-P, calcium-bound; M-P, metal-bound; HA-P, humic acid-bound, Org-P, organic-bound phosphorus.

out the 9.5-cm core. During early summer of 1998 (June) TDP concentrations generally remained below 100  $\mu\text{g P L}^{-1}$  while SRP was similar to that in the August 1997 porewater.

In November 1996, when SRP was undetectable in the porewater, no measurable release was detected for any of the experimental treatments upon shift to anoxia (data not shown). However, substantial P release rates of 9 and 12  $\text{mg P m}^{-2}$ , respectively, were detected in the March and August 1997 cores upon a switch to anoxia indicating P desorption from Fe(III)-bound P at the sediment–water interface (Fig. 4). Measured release was higher in August when porewater concentrations were higher. In the cores lacking microbial activity, P release rates were as much as 6-fold higher, supporting the previous assertion that potential P release from sediments is substantially reduced by microbial activity (ECKERT et al. 1997). The pH effect was most obvious during the summer bloom period (August core) when at pH ~6.5, considerably more P release occurred. This observation can

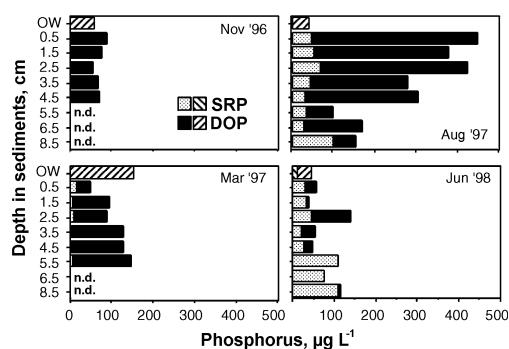


Fig. 3. Concentrations of SRP and other dissolved P (mostly dissolved organic P, DOP) in the porewaters and overlying water (OW) of Lake Agmon cores taken in November 1996, March and August 1997 and June 1998.

be explained by the release of P that was co-precipitated with calcite during elevated algal productivity.

The above measured release rates represent static pictures of the transition between oxic and anoxic conditions at the sediment–water interface and as a “one-time” event cannot explain the observed rate of increase in water column P in Lake Agmon (Table 1). However, Lake Agmon is polymictic and experiences large daily fluctuations in DO content, with bottom waters approaching anoxia on a nightly basis during summer (HAMBRIGHT et al. 1998, MARKEL et al. 1998). Under such conditions, we would expect a nightly surge in P release from the sediments. Results from the June 1998 core experiment verify this possibility (Fig. 5). Each shift to anoxic conditions led to a pulse in water column SRP concentrations, with a mean release rate of  $6 \text{ mg P m}^{-2} \text{ day}^{-1}$ . Compared with the observed increase rates of P in the Lake Agmon water column (Table 1), this measured release rate of SRP can readily account for the high summer P concentrations in Lake Agmon with as little as one night per week of anoxia during the summer, especially considering that there is simultaneous loss of P from the water column via overflow and sedimentation. Moreover, DOP accumulated in the overlying water of the experimental systems at a mean rate of

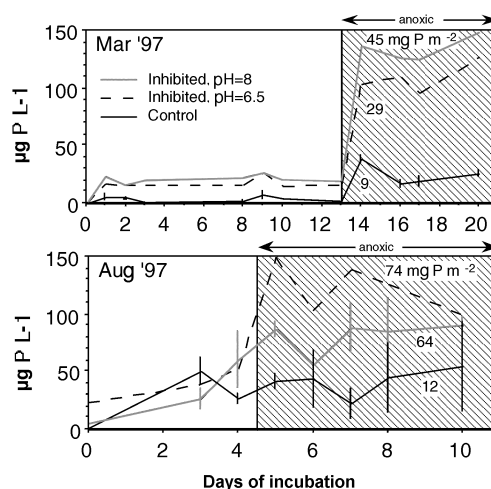


Fig. 4. Accumulation of SRP in the overlying water in experimental cores incubated initially under oxic, then anoxic (gray hatched area) conditions. Gray line – microbial activity inhibited, pH ~8; dashed line – microbial activity inhibited, pH ~6.5; solid line – control. For lines with error bars (SE),  $n = 2$ . Calculated release rates ( $\text{mg P m}^{-2}$ ) under anoxic conditions, relative to oxic conditions, indicated for each treatment.

Table 1. Maximum TP concentrations and rate of TP accumulation in the water column of Lake Agmon during 1995–1997. TP accumulation rates were calculated by linear regression of 5-point running averages of TP on time during the summer increase period.

Year	Max. TP ( $\mu\text{g L}^{-1}$ )	Water column accumulation rate ( $\text{mg P m}^{-2} \text{ day}^{-1}$ )
1995	223	1.3
1996	345	0.9
1997	284	0.4

$3 \text{ mg P m}^{-2} \text{ day}^{-1}$  (Fig. 5), suggesting this form of bioavailable P could also contribute substantially to the high summer water column P concentrations in Lake Agmon. Unfortunately, we did not measure DOP release in the August core when TDP concentrations in the porewater were ca. 3–4 times higher than in the June 1998 experiment.

Our experiments were of batch design and much of the P released into the water column

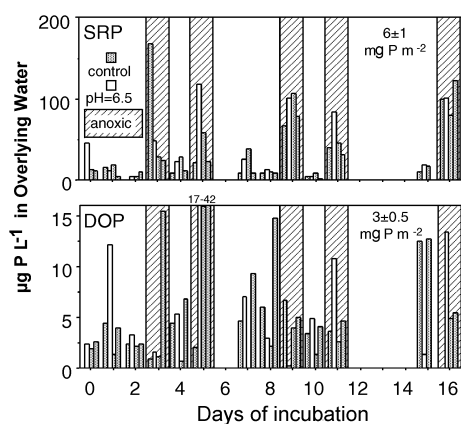


Fig. 5. Accumulation of SRP and TDP in the overlying water in experimental cores ( $n = 4$ ) incubated under alternating oxic and anoxic (gray hatched area) conditions. The pH in one core (open bar) was regulated to 6.5. Numbers in upper right corner of each panel indicates mean release rates ( $\text{mg P m}^{-2} \text{ day}^{-1}$ ) calculated for the anoxic periods.

during anoxia likely reprecipitated to the sediments under oxic conditions. Under more natural conditions (e.g. a chemostat with a natural light–dark cycle), we would expect the released P to be taken up readily by water column biota (CARLTON & WETZEL 1988). Thus additional P could be released in pulses in subsequent nightly anoxic shifts and thereby contribute to the observed high level of eutrophy in Lake Agmon.

We are yet unable to speculate on the relative importance of sedimentary P release to overall P dynamics in Lake Agmon compared with alternative mechanisms, such as resuspension by wind and macrophyte “pumping”. Nevertheless, our results provide strong evidence that biogeochemically mediated P release at the sediment–water interface could contribute substantially to the observed high summer concentrations of P in Lake Agmon.

### Acknowledgments

We thank J. EASTON for collecting sediment cores, E. URI and S. SCHWARTZ for assistance with chemical analyses and T. ZOHARY and S. SCHWARTZ for commenting on this manuscript.

### References

- AMERICAN PUBLIC HEALTH ASSOCIATION (APHA), 1992: *Standard methods for the examination of water and waste water. 18th edition.* – American Public Health Association, Washington, D.C.
- BACINI, P., 1985: Phosphate interactions at the sediment water interface. – In: STUMM, W. (ed.): *Chemical Processes in Lakes* 189–205. – Wiley, New York.
- BOSTRÖM, B., ANDERSEN, J. M., FLEISCHER, S. & JANSSON, M., 1988: Exchange of phosphorus across the sediment–water interface. – *Hydrobiologia* **170**: 229–244.
- CARLTON, R. G. & WETZEL, R. G., 1988: Phosphorus flux from sediments: effect of epipellic algal oxygen production. – *Limnol. Oceanogr.* **33**: 562–570.
- ECKERT, W., NISHRI, A. & PARPAROVA, R., 1997: Factors regulating the flux of phosphate at the sediment–water interface of a subtropical calcareous lake: a simulation study with intact sediment cores. – *Water Air Soil Pollut.* **99**: 401–409.
- HAMBRIGHT, K. D. & ZOHARY, T., 1998: Lakes Hula and Agmon: destruction and creation of wetland ecosystems in northern Israel. – *Wetlands Ecol. Manage.* **6**: 83–89.
- HAMBRIGHT, K. D. & ZOHARY, T., 1999: The Hula Valley (Northern Israel) Wetlands Restoration Project. – In: W. STREEVER, (ed.): *Wetlands Rehabilitation: an International Perspective.* 173–180. – Kluwer Academic Press. The Hague.
- HAMBRIGHT, K. D., BAR-ILAN, I. & ECKERT, W., 1998: General water chemistry and quality in a newly-created subtropical wetland lake. – *Wetlands Ecol. Manage.* **6**: 121–132.
- HIJLTJES, A. H. & LIJKLEMA, M. L., 1980: Fractionation of inorganic phosphates in calcareous sediments. – *J. Environ. Qual.* **9**: 405–407.
- KARL, D. M. & TIEN, G., 1992: MAGIC: a sensitive and precise method for measuring dissolved phosphorus in aquatic environments. – *Limnol. Oceanogr.* **37**: 105–116.
- KUFEL, L., PREIS, A. & RYBAK, J. I., (eds), 1997: Shallow lakes '95. – *Hydrobiologia* **342/343**: 1–416.
- MARKEL, D., SASS, E., LAZAR, B. & BEIN, A., 1998: Biogeochemical evolution of a sulfur-iron rich aquatic system in a reflooded wetland environment (Lake Agmon, northern Israel). – *Wetlands Ecol. Manage.* **6**: 103–120.
- REDDY, K. R. & D'ANGELO, E. M., 1994. Soil processes regulating water quality in wetlands. – In: MITSCH, W. J. (ed.): *Global Wetlands: Old World and New.* 309–324. – Elsevier, Amsterdam.
- ZOHARY, T., FISHBEIN, T., KAPLAN, B., & POLLINGER, U., 1998: Phytoplankton-metaphyton seasonal dynamics in a newly-created subtropical wetland. – *Wetlands Ecol. Manage.* **6**: 133–142.

### Authors' address:

K. DAVID HAMBRIGHT, WERNER ECKERT, Israel Oceanographic & Limnological Research, The Yigal Allon Kinneret Limnological Laboratory, Tiberias, Israel.