DOI: 10.2478/v10025-012-0005-0

JOURNAL OF WATER AND LAND DEVELOPMENT
J. Water Land Dev. 2012, No. 17 (VII–XII): 39–44
PL ISSN 1429–7426
Available (PDF): www.itep.edu.pl/wydawnictwo; http://versita.com/jwld/

Received 03.12.2012
Reviewed 11.12.2012
Accepted 14.12.2012

A – study design
B – data collection
C – statistical analysis
D – data interpretation
E – manuscript preparation
F – literature search

Are fishponds really a trap for nutrients? – a critical comment on some papers presenting such a view

Lech KUFEL ABCDEF

Institute of Biology, Siedlce University of Natural Sciences and Humanities, Prusa 12, 08-110 Siedlce, Poland, e-mail: lech-kufel@tlen.pl

For citation: Kufel L. 2012. Are fishponds really a trap for nutrients? – a critical comment on some papers presenting such a view. Journal of Water and Land Development. No. 17 p. 39–44

Abstract

There is still a controversy about the environmental impact of fishponds, especially on their ability to retain nutrients. This paper presents some basic rules of nutrient cycling in running and stagnant waters and the biotic and abiotic transformation of nutrients delivered to dam reservoirs and fishponds. Based on these common properties of eutrophic stagnant waters, some critical remarks are presented on papers that claim to prove the capacity of fishponds to retain nutrients (mainly nitrogen) during fish production and after pond drainage. Finally, some ways of reducing negative environmental impacts of fishpond effluents are described as an indirect evidence that such impacts really pose a threat to water quality.

Key words: *nitrogen release, nutrient accumulation, nutrient cycling, phosphorus and calcium co-precipitation*

INTRODUCTION

Carp production in fishponds is one of the most common aquaculture worldwide. Known since the ancient times it is still developing due to increasing demand for fish food [KESTEMONT 1995]. Fish production is usually carried out in earthen ponds of different size from less than one to several hundred hectares or often in complexes of several interconnected ponds. Fish rearing may be extensive or intensive and thus differ in the fish stock, in the amount and type of feed given to fish (pelleted high protein feed *versus* cereals or natural feed sources), and in pond management (fertilisation and liming). Pond management may also differ depending on the growth stage of fish (fry, fingerlings or market-size fish). Fish biomass produced in fishpond is usually proportional to the intensity of management [KESTEMONT 1995].

Apart from productive purposes, fishponds may also serve various other functions [KUCZYŃSKI 2007]. They retain water during dry season and, when being filled in spring, may mitigate possible flood waves in adjacent stream or river. Sometimes, fishponds may be used as tourist and recreational sites. In areas otherwise devoid of stagnant water bodies (and these areas concentrate most of fishponds in Poland), fishponds play a role of "habitat islands" and serve as spawning grounds for amphibians or nesting and feeding places for numerous waterfowl. The latter may sometimes arise the conflict of interests between nature protection and fish production, especially when a fishpond complex is populated by a great number of piscivorous bird species like the great cormorant (*Phalacrocorax carbo*) or the great crested grebe (*Podiceps cristatus*). Nevertheless, the overall biological value manifested in species richness and diversity resulted in granting 10 fishpond complexes in Poland the status of nature reserves. Ponds Nowokuźnicki and Smolnik protect sites of a rare macrophyte *Trapa natans*, pond Wydymacz is a landscape reserve and the remaining 7 ponds or pond complexes (Milickie, Łężczak, Przemkowskie, Broszkowskie, Raszyńskie, Siedleckie and Stawinoga) are waterfowl sanctuaries [DOBROWOLSKI 1998]. Still other fishponds function within the Natura 2000 protected areas.

Despite widely acknowledged high non-productive biological values of fishponds, the environmental impact of fish rearing in ponds is still a matter of debate and controversies. Proponents (BARSZCZEWSKI, KACA [this volume], KNÖSCHE *et al.* [2000]) claim that the impact of fishponds on connected surface waters is negligible or even that the ponds may act as nutrient traps decreasing thus the progress of eutrophication of surface waters receiving the effluents from fish production. Opponents (KONNERUP *et al.* [2011], PRĄDZYŃSKA [2004], SARÀ [2007]) are of the opinion that fishponds generate large nutrient loads that are not balanced by fish harvest and eventually reach natural waters posing a threat of advanced eutrophication there. It seems that the controversy stems from some misunderstanding on what and why may and what and why may not be retained in fishponds during carp (or any other fish species) production. Clarifying these misconceptions is the main aim of this paper.

SOME NOTES ON NUTRIENT CYCLING IN FISHPONDS

Phosphorus and nitrogen are the main elements of concern when discussing environmental impact of fishponds. Both are introduced to the pond with inflowing water, atmospheric precipitation, in fish and their feed and in fertilisers applied to increase the biomass of natural fish feed. Nutrient output from the pond consists of N and P in harvested fish and in outflowing water or that drained at the end of the rearing season. The difference between the former and the latter makes the retention (positive or negative) of nitrogen and phosphorus in the fishpond [KNÖSCHE *et al.* 2000] and the balance may be dealt with as a measure of environmental impact of fish rearing in artificial water bodies. Apart from being accumulated in fish biomass, nitrogen and phosphorus undergo numerous biotic and abiotic transformations in fishpond. One has, however, keep in mind different biogeochemical properties of nitrogen and phosphorus resulting in their different behaviour in aquatic ecosystems.

Phosphorus in its mineral forms is taken up by aquatic primary producers (algae, cyanobacteria and macrophytes) and its part is deposited in bottom sediments in organic debris to undergo slow decomposition there. Intensive algal photosynthesis in hardwater lakes and ponds (and limed fishponds are such water bodies) is often accompanied by decalcification. Rapidly growing plants utilise bicarbonates, increase pH and shift the ionic equilibrium to the formation of carbonate ions. These, together with calcium ions form insoluble calcite which precipitates in a form of tiny settling particles (the so-called lake "whiting") or as an incrustation covering some macrophytes (mainly charophytes). Phosphorus may adsorb on and co-precipitate with calcite particles [MURPHY*et al.* 1983; OTSUKI, WETZEL 1972] or even convert calcite into hydroxyapatite [STUMM, MORGAN 1970]. In general, combination of mineral P with calcite is non-stoichiometric and it is impossible to calculate the amount of immobilised P from phosphate and calcium concentrations. Anyway, the resulting products are stable in bottom sediments unlike e.g. ferric phosphates which liberate dissolved phosphates under anoxic conditions. Immobilisation of calcium-bound phosphates in sediments is thus a second (after P withdrawal with fish biomass) important mechanism of phosphorus retention in fishponds.

Nitrogen cycling and its possible retention in fishponds is of quite different character. There is no single cation on Earth that would precipitate nitrates in a form of hardly soluble mineral compound. Therefore, nitrate ions in fishponds may be either taken up by aquatic biota or denitrified, otherwise they flow through the water body and are released unchanged to the recipient stream. Noteworthy, denitrification, though possible, is unlikely in carp ponds due to burrowing activity of these benthic feeders which, when searching for food, additionally aerate surface layers of bottom sediments – possible sites for denitrification. This situation is similar to that often met in agriculture – excess nitrates from saltpetre fertilisers, if not taken up by crop plants or soil microorganisms, are easily washed out to ground or surface waters. The same is true for ammonium ions both in terrestrial and aquatic habitats.

Because running waters do not provide adequate conditions for the development of phytoplankton, they are usually rich in mineral N forms available for potential primary producers. The situation changes when such waters are discharged to stagnant water bodies like natural lakes, fishponds or dam reservoirs. There, an excess of unused mineral N is immediately taken up by algae and cyanobacteria which start to "bloom" and produce large phytoplankton biomass. Such a mechanism is common for all dam reservoirs fed with apparently clean river waters (see the case of heavily eutrophic Siemianówka Dam Reservoir – GÓRNIAK (ed.) [2006]. The effect may also be illustrated by results of a study made in Siedlce Dam Reservoir and in the Muchawka River [GĄSIOR 2012]. The reservoir is used for recreational purposes and also stocked with fish by the Polish Angling Association for the benefit of numerous anglers. River water is delivered through a side canal to one end of the reservoirs and discharges at the other end to the same river. Water samples were taken several times from the river channel and at the outlet from the reservoir.

As seen in Fig. 1, nitrate concentrations were several times higher in the river than in the reservoir water. When delivered to the reservoir, nitrates were taken up by phytoplankton resulting in mass algal blooms reflected here in high chlorophyll concentrations in reservoir but not in river water.

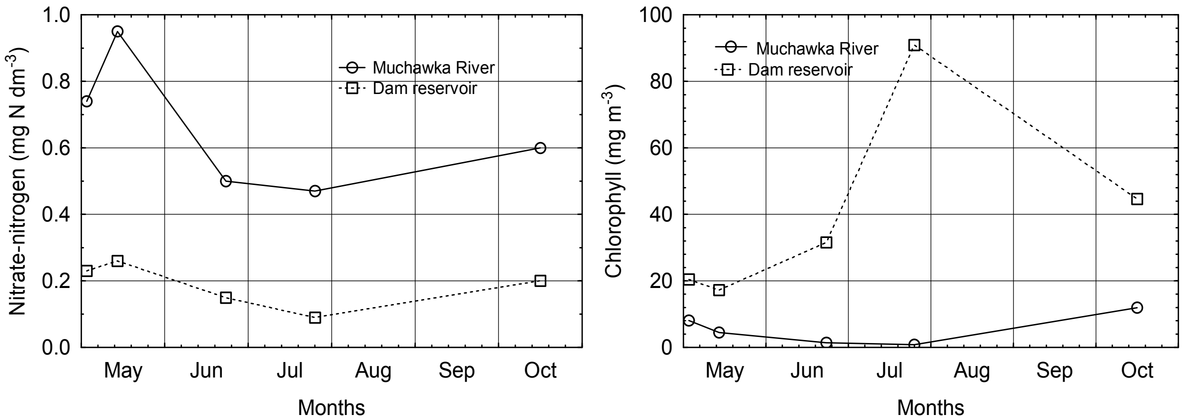

Fig. 1. Concentration of nitrate nitrogen (left) and chlorophyll *a* (right) in river water and in water at the outlet from the dam reservoir; source: GĄSIOR [2012] – modified

If one would like to judge the environmental effect of dam reservoir in Siedlce on the recipient Muchawka River based exclusively on results presented in the left graph of Fig. 1, he/she could convincingly (but wrongly) argue that nitrates are trapped in the reservoir during the whole vegetation season. This simple example of nitrate behaviour in a dam reservoir points to a need of dealing with all nitrogen forms when assessing the environmental impact of fish production. Apart from the external inputs of mineral N forms (inflowing water, fertilisation), nitrates and ammonium ions may be also generated within a fishpond itself. Fish consume on average from 70-90% of given feed, the rest undergoes decomposition followed by the release of nitrogen, mainly in a form of ammonium ions [KIBRIA *et al.* 1997]. Out of all nutrients ingested, fish accumulate about 25% of them [BOYD, LICHTKOPPLER 1979], the rest is excreted in a form of faeces (organic N) or released through gills (ammonium N) [KAUSHIK 1995; QIAN *et al.* 2001]. Fish production increases linearly but the deterioration of water quality increases exponentially with the increase of feeding rate [BOYD, LICHTKOPPLER 1979] due to accumulation of nutrient rich organic matter, both particulate and dissolved. This organic matter is finally drawn down to the recipient when the pond is drained in autumn.

MISUNDERSTANDINGS ABOUT NUTRIENT RETENTION IN FISHPONDS

BARSZCZEWSKI and KACA [this volume] applied the method of "black box" in studying nutrient retention in fishponds. Their calculations are principally based on the difference in concentrations between inlet to and outlet from the pond. This approach may raise some methodological questions, particularly during the fish growth *i.e.* in cases when there is no water flow through the pond. Their results, however, seem to be consistent with the mechanism presented above with respect to phosphorus and calcium. The authors found significant retention of both elements in fishponds during carp growth (Tab. 3 in their paper). There is (not remarked by the authors) a highly significant relationship between these two factors (Fig. 2). Moreover, the regression equation (calculated only from the means since no raw data were available) demonstrates that the P retention variability was explained in 94% by the retention of Ca. So high explanatory power of the regression may additionally suggest that other mechanisms of P removal (like e.g. fish harvest) from the two fishponds were of minor importance. This is in concordance with authors' statement that both ponds were stocked with c. 900 carps and managed in a low-productive system. It

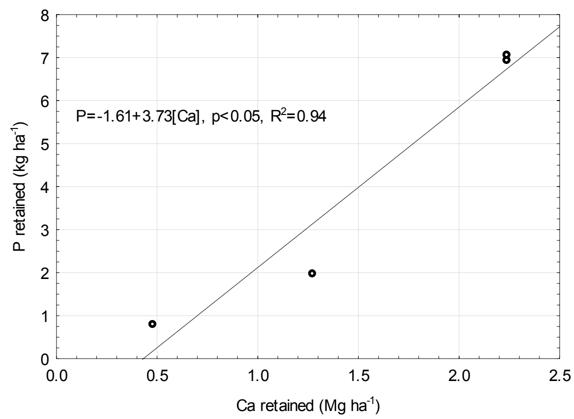

Fig. 2. Phosphorus retention in fishponds during carp growth as a function of Ca retention; source: recalculated from BARSZCZEWSKI and KACA [this volume]

means that P removed in fish biomass (not given in the paper) was relatively small. An indirect evidence of P immobilisation in fishponds by calcium may be also found in KNÖSCHE *et al*. [2000], who noted that P retention in their study was irrespective of the amount of fish harvest.

Conclusions drawn by BARSZCZEWSKI and KACA [this volume] on the retention of nitrates in the two fishponds under study are, however, a kind of over-interpretation. As shown above, the decline of nitrate concentration between the inlet to and outlet from a fishpond does not mean that nitrates are stored in pond water or anywhere else but rather that they are incorporated into algal and/or cyanobacterial biomass and in this form leave the fishpond when the latter is drained at the end of season. KNÖSCHE *et al*. [2000] enlarged their input-output nutrient balance in fishponds by the amounts contained in stocked fish, fertilisers and feed and considered the output of nutrients in fish harvest. Nevertheless, they made the same mistake presenting the retention of nitrates in fishponds and later extending somehow their conclusions over the entire pool of nitrogen. Moreover, KNÖSCHE *et al*. [2000] found the highest efficiency of nitrogen retention in intensively managed fishponds of a fish stock >4000 $kg \cdot ha^{-1}$, probably due to a large nutrient removal with harvested fish biomass. At low productive system like that in StawyRaszyńskie [BARSZCZEWSKI, KACA, this volume] the output of nitrogen in harvested fish is low and overall nitrogen retention is still less possible.

It is also not clear, if and how the accidental spill of 80 thousand m^3 of water from pond 7 (nearly twice the pond's maximum volume) was reflected in calculations of nutrient loads retained in the pond (Tab. 2 and 3 in BARSZCZEWSKI and KACA [this volume]). Nevertheless, the main objection to the conclusions of the cited authors is neglecting the organic forms of nitrogen, both dissolved and particulate, which leads to a false impression that fishponds may trap this nutrient. The discharge of pond water rich in organic matter and nitrogen at the end of the growing season may pose a threat to the recipient. One may imagine the final environmental effect when one compares the volume of water drained from the two study ponds (c. 40 and 80 thousand m^3 from pond 7 and 9, respectively) with the annual mean water flow in the recipient Raszynka River (several dozen litres per second). Both ponds were drained at the end of September. This means that the activity of microbial decomposers is too low to provide appropriate mineralisation of released organic matter (low water temperature) and the absence of primary producers in the river make the uptake of discharged nutrients impossible. All these facts incline to highly possible expectation that the environmental effects of fishponds are profound and far reaching.

OTHER ASPECTS OF NUTRIENT BALANCE IN FISHPONDS

To reliably estimate the environmental effect of carp rearing in fishponds one should have for comparison a reference pond fed with the same water but not subjected to aquaculture. This is unrealistic, but the nutrient balance in such ideal situation should be as follows: N or P in fish at the beginning of the season + N or P in feed + N or P in fertilisers – N or P in fish harvested at the end of season. Literature data on nutrient partitioning in carp ponds (in percent of the total nutrient input) show that 34% of N and 43% of P is accumulated in fish biomass, the remaining amounts are divided among water, bottom sediments and aquatic biota – phyto- and zooplankton and benthic macroinvertebrates [RAHMAN *et al*. 2008]. Many methods have been proposed to deal with these different nutrient pools in order to minimise the environmental impact of fishponds.

Water flowing out of fishponds is rich in nutrients both in particulate and dissolved forms. The construction of additional settling ponds have been proposed to decrease the effect of the former and constructed wetlands – to manage the dissolved nutrients in pond effluents [KONNERUP *et al*. 2011]. Sometimes, aquatic plants (*e.g*. the sea lattuce *Ulva lactuca*) are grown in separate ponds or tanks accompanying fish and abalone aquaculture. Effluents from fishponds are directed to plant culture where they are deprived of nutrients (30% reduction) and photosynthetically aerated to be later re-circulated back to fishponds. Plant biomass produced this way is used as feed for abalones [SCHUENHOFF *et al*. 2003]. Nutrient-rich bottom sediments of fishponds were used in the past (at least in Poland) as fertile soils for growing cereals in a specific, alternating every three-four years, aquaculture-agriculture system [LIRSKI 2007]. Various fish species are often reared in polyculture systems. The common carp (benthic feeder) is kept in the same pond with the silver carp (*Hypophthalmichthys molitrix*) feeding on phytoplankton, the grass carp (*Ctenopharyngodon idella*) feeding on macrophytes and, especially in Southeast Asia, with Chinese and Indian carps: an omnivorous mrigal (*Cirrhinus mrigala*) and zooplanktivorous catla (*Catla catla*). This way all kinds of natural fish food are utilised more economically, nutrient cycling is "tightened" and less nutrients are discharged in effluents [HRYCYNIAK *et al*. 2011; KESTEMONT 1995]. Fish yield in such multi-species aquaculture is usually larger than in monoculture ponds.

It is not the place here to discuss other issues (including *e.g.* legal requirements put on fishpond effluents) of the environmental impact of fishponds (see e.g. O'BRIEN and LEE [2003]). The controversies about the effects of fishpond effluents still seem far from being settled. Both the discussions and practical protective measures undertaken in many places worldwide indicate, however, that the effects of aquaculture on the natural environment are not so beneficial as the proponents would like them to be.

CONCLUSIONS

1. Phosphorus may be retained in substantial amounts in fishponds. The retention mechanism relies on the formation of hardly soluble calcium-bound P compounds and their storage in bottom sediments. The amount of retained phosphorus does not seem to be related to the intensity of fish production.

2. Despite the retention of nitrates recorded in some fishponds, the overall nitrogen balance is probably negative – much of nitrogen may leave fishponds in a form of organic, particulate and/or dissolved form. These may pose a serious threat to the quality of recipient river.

3. Detailed balance of all forms of nutrients are needed to reliably assess the environmental impact of fishpond effluents.

REFERENCES

BARSZCZEWSKI J., KACA E. 2013. Water retention in ponds and the improvement of its quality during carp production. Journal of Water and Land Development. No 17 p. 31–38.

BOYD C. E., LICHTKOPPLER F. 1979. Water quality management in pond fish culture.Research and Development Series. No. 22. Alabama. International Center for Aquaculture, Auburn University pp. 32.

DOBROWOLSKI K.A. 1998. Stawy. W: Ochrona środowisk wodnych i błotnych w Polsce [Ponds. In: Protection of aquatic and wetland habitats in Poland]. Eds K.A. Dobrowolski, K. Lewandowski. Dziekanów Leśny. Ofic. Wydaw. Inst. Ekol. PAN p. 111–132.

GĄSIOR I.K. 2012.Wpływ zbiornika zaporowego na charakter wód rzecznych [The effect of dam reservoir on the characteristics of river waters]. MSc. thesis. Siedlce. UPH pp. 27.

GÓRNIAK A. (ed.) 2006. Ekosystem zbiornika Siemianówka w latach 1990–2004 i jego rekultywacja [Ecosystem of Siemianówka Dam Reservoir in the years 1990–2004 and its restoration]. Białystok. UwB. ISBN 978-83-7431-093-2 pp. 236.

HRYCYNIAK I., JANINOWICZ I., GRYNŻEWSKI N., WĘGLARZY K. 2011. Uzyskiwanie dodatkowej produkcji ryb poprzez racjonalne wykorzystanie pasz naturalnych w stawach [Additional fish production through efficient use of natural feeds in ponds]. Wiadomości Zootechniczne. No 49 p. 53–60.

KAUSHIK S.J. 1995. Nutrient requirements, supply and utilization in the context of carp culture. Aquaculture. Vol. 129 p. 225–241.

KESTEMONT P. 1995. Different systems of carp production and their impacts on the environment. Aquaculture. Vol. 129 p. 347–372.

KIBRIA G., NUGEGODA D., FAIRCLOUGH R., LAM P. 1997. The nutrient content and the release of nutrients from fish food and faeces. Hydrobiologia. No 357 p. 165–171.

KNÖSCHE R., SCHRECKENBACH K., PFEIFER M., WEISSENBACH H. 2000. Balances of phosphorus and nitrogen in carp ponds. Fisheries Management and Ecology. Vol. 7. Iss. 1–2 p. 15–22.

KONNERUP D., TRANG N.T.D., BRIX H. 2011. Treatment of fishpond water by recirculating horizontal and vertical flow constructed wetlands in the tropics. Aquaculture. Vol. 313 p. 57–64.

KUCZYŃSKI M. 2007. Pozaprodukcyjne walory stawów karpiowych. W: Wybrane zagadnienia dobrostanu karpia [Non-productive values of carp ponds. In: Selected problems of carp welfare]. Eds A. Lirski, A.K. Siwicki, J. Wolnicki. Olsztyn. Wydaw. IRŚ p. 43–54.

LIRSKI A. 2007. Wybrane informacje o karpiu i historii jego chowu na ziemiach polskich. W: Wybrane zagadnienia dobrostanu karpia [Selected information regarding carp and the history of its cultivation in Poland. In: Selected problems of carp welfare]. Eds A. Lirski, A.K. Siwicki, J. Wolnicki. Olsztyn. Wydaw. IRŚ p. 11–24.

MURPHY T.P., HALI K.J.,YESAKI I. 1983. Coprecipitation of phosphate with calcite in a naturally eutrophic lake. Limnology and Oceanography. Vol. 28. Iss. 1 p. 56–69.

OTSUKI A., WETZEL R.G. 1972. Coprecipitation of phosphate with carbonates in a marl lake. Limnology and Oceanography. Vol. 17. Iss. 5 p. 763–767.

PRĄDZYŃSKA B. 2004. Próba oceny oddziaływania stawów hodowlanych na środowisko przyrodnicze (na przykładzie gminy Malechowo). Studia ekologiczno-krajobrazowe w programowaniu rozwoju zrównoważonego. Przegląd polskich doświadczeń u progu integracji z Unią Europejską [An attempt to assess the effect of fishponds on the natural environment (an example of Malechowo commune). In: Ecological-landscape studies in programming sustainable development. An overview of Polish experience before integration with the European Union]. Ed. M. Kistowski. Problemy Ekologii Krajobrazu. T. 13 p. 221–226.

QIAN P-Y., WU M.C.S., NI I-H. 2001. Comparison of nutrients release among some maricultured animals. Aquaculture. Vol. 200 p. 305–316.

RAHMAN M.M., JOA Q., GONG Y.G., MILLER S.A., HOSSAIN M.Y. 2008. A comparative study of common carp (*Cyprinus carpio* L.) and calbasu (*Labeo calbasu* Hamilton) on bottom soil resuspension, water quality, nutrient accumulations, food intake and growth of fish in simulated rohu (*Labeo rohita* Hamilton) ponds. Aquaculture. Vol. 285 p. 78–83.

SARÀ G. 2007. A meta-analysis on the ecological effects of aquaculture on the water column: Dissolved nutrients. Marine Environmental Research. Vol. 63. Iss. 4 p. 390–408.

SCHUENHOFF A., SHPIGEL M., LUPATSCH I., ASHKENAZI A., MSUYA F.E., NEORI A. 2003. A semi-recirculating, integrated system for the culture of fish and seaweed. Aquaculture.Vol. 221 p. 167–181.

STUMM W., MORGAN J.J. 1970. Aquatic chemistry. An introduction emphasizing chemical equilibria in natural waters. New York. Wiley pp. 583.

Lech KUFEL

Czy stawy rybne są rzeczywiście pułapką dla pierwiastków biogennych? – krytyczny komentarz do pewnych prac prezentujących taki pogląd

STRESZCZENIE

Słowa kluczowe: *obieg i akumulacja pierwiastków biogennych, uwalnianie azotu, współstrącanie fosforu i wapnia*

Nadal nierozstrzygnięty pozostaje spór o środowiskowe oddziaływanie stawów rybnych, szczególnie w odniesieniu do ich zdolności zatrzymywania pierwiastków biogennych. W artykule przedstawiono podstawowe zasady obiegu pierwiastków biogennych w wodach płynących i stojących oraz biotyczne i abiotyczne przemiany, którym podlegają te pierwiastki w wodach zbiorników zaporowych czy stawów rybnych. Odwołując się do tych zasad, przedstawiono uwagi krytyczne wobec pewnych badań, których autorzy dowodzą retencyjnych zdolności stawów rybnych, zwłaszcza zdolności do retencji azotu. Jako pośredni dowód potencjalnych zagrożeń, w końcowej części artykułu przedstawiono różne zabiegi i sposoby, które są podejmowane, by te zagrożenia minimalizować.