Fakulta rybářství
a ochrany vod
Faculty of Fisheries
and Protection
of Waters

Jihočeská univerzita
v Českých Budějovicích
University of South Bohemia
in České Budějovice

# Innovative methodology for carp supplementary feeding in ponds using assessment of the nutritional status of the pond ecosystem and selection of appropriate feed

## Inovativní metodika přikrmování kapra v rybnících využívající odhad nutričního stavu rybničního ekosystému a výběr vhodného krmiva

Koushik Roy, Jan Mraz

Edition of Methodics 211

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## 1. Background

Supplementary feeding in European, particularly Czech, ponds are built on decades of valuable knowledge and practical experience. This practice is generally well understood and clearly illustrated through various regional feeding tables and charts. Notable examples can be found in several sources (Woynarovich et al., 2010; Füllner, 2015; Hartman and Regenda, 2016; Schlott et al., 2023). The relative feeding coefficient (RFC) for supplementary feeds in regional ponds typically ranges from 2 to 4 units (kg or tons) of cereal grains applied per unit (kg or tons) of fish produced. To define, RFC is the relative feed conversion ratio of a supplementary feed in presence of natural food in pond; [RFC = supplementary feed fed in $kg.ha^{-1}$ / net fish yield in $kg.ha^{-1}$]. The standard lab-measured absolute FCR (feed conversion ratio), where feed is tested alone in absence of natural food, is generally greater than RFC of that same feed in pond. It is because natural food also contributes to the net fish yield (i.e., denominator in the above formula).

The top three countries within European Union (Czechia, Poland, and Hungary) have kept alive the European pond aquaculture. Their share in EU common carp production is 74% of total European carp production in 2023 (FAO, 2025). Based on reported data in 2023 (FAO, 2025), the annual common carp yield and estimated supplementary feed consumption in European ponds are given in Tab. 1.

***Tab. 1.*** *Supplementary feed usage in European ponds doing common carp aquaculture with RFC between 2.5–3.5.*

| Country | Reported annual yield 2023 ($ton.yr^{-1}$) | Supplementary feed used ($ton.yr^{-1}$) |
|---|---|---|
| Poland | 17,697 | 44,242–61,941 |
| Czech Republic | 15,903 | 39,758–55,661 |
| Hungary | 11,037 | 27,593–38,630 |
| Ukraine | 7,123 | 17,807–24,930 |
| Germany | 4,056 | 10,140–14,196 |

Supplementary feeding usually takes place from May to September, with minor regional adjustments across Czechia, Germany, Poland, and Hungary based on local temperature conditions and the trophic status of ponds (see Tab. 2). Overall, modified-extensive ponds in Czechia, stocked with *Cyprinus carpio* (common carp), produce annual yields ranging from 0.3 to 1.0 tons per hectare. To support this production, between 0.6 and 3 tons of cereal grains

are applied per hectare each year. The most used cereals in the Czech Republic, in order of preference, are wheat/triticale (the most widely used), followed by barley/rye, and corn (the least used). The feeding in the temperate European ponds is connected to the daylight and thermal regime that the pond encounters in the region. For example, the typical Central Eastern European ponds could experience the following degree-days (water temperature x number of days in month): April (386.85), May (614.42), June (689.02), July (723.84), August (679.21), September (519.22) and October (394.63). The daylength is another important feeding cue: April (13.4 hours), May (15.3 hours), June (16.4 hours), July (15.4 hours), August (14.2 hours), September (12.4 hours) and October (10.8 hours). The months June–August, having simultaneously the highest degree days and day length, is the most critical and sensitive window for fish nutrition as well as the pond natural food web. In these months, pond fishes are most hungry and exert tremendous grazing pressure on both food sources (natural food and supplementary feed).

***Tab. 2.*** *Supplementary feeding chart (% of total feed) typical in European carp ponds.*

| Country | Year | March | April# | May | June | July | August | September | October# |
|---|---|---|---|---|---|---|---|---|---|
| **Classic/ Rigid feeding plans** | | | | | | | | | |
| Germany | 1905 | 0 | 0 | 10 | 25 | 30 | 25 | 10 | 0 |
| Bavaria | 1934 | 0 | 0 | 10 | 20 | 30 | 30 | 10 | 0 |
| Germany* | 1979* | | | 5 | 15 | 25 | 40 | 15 | 0 |
| Austria* | 1979* | 0 | 0 | 10 | 20 | 30 | 30 | 10 | 0 |
| Czechia* | 1982* | 0 | 0 | 4 | 13 | 26 | 37 | 20 | 0 |
| UK | 1988 | 0 | 0 | 10 | 15 | 25 | 30 | 20 | 0 |
| Hungary | 1992 | 2 | 5 | 10 | 20 | 25 | 28 | 10 | 0 |
| Czechia | 2004 | 0 | 3 | 11 | 21 | 25 | 22 | 18 | 0 |
| Germany* | 2007* | 0 | 0 | 7 | 19 | 28 | 29 | 17 | 0 |
| Poland* | 2008* | 0 | 0 | 5 | 15 | 25 | 40 | 15 | 0 |
| **Modern/ Adaptive feeding plans** | | | | | | | | | |
| Austria[1] (*demand feeding*) | 2007 | 0 | 0 | 5 | 8 | 10 | 42 | 32 | 3 |
| **Czechia[2] (*balanced feeding*)** | **2023/ 2025** | **0** | **3 Grain** | **7 Grain** | **11 Grain** | **32 Pellet** | **25 Pellet** | **15 Pellet** | **7 Pellet** |

**Popular choice.*
*#15 days or half-month feeding only, to maintain basal metabolism.*
*[1]Schlott et al. (2023)*
*[2]Current project outcome The Ministry of Agriculture of the Czech Republic project no. QK22010177 2021–2025. Roy and Mraz unpublished data.*

## INNOVATIVE METHODOLOGY FOR CARP SUPPLEMENTARY FEEDING IN PONDS USING ASSESSMENT OF THE NUTRITIONAL STATUS OF THE POND ECOSYSTEM AND SELECTION OF APPROPRIATE FEED

More than half of the total supplementary feed (≥50%) is typically applied during two peak feeding months – either July and August or August and September. This timing coincides with the seasonal collapse of natural planktonic and benthic food resources for common carp, effectively compensating for the decline in available natural prey. As a result, the prevailing approach to supplementary feeding in European ponds aligns with the conceptual model illustrated by Füllner (2015) (see Fig. 1). This seasonal collapse of the natural food base is well explained by the PEG (Plankton Ecology Group) model, which describes the dynamics of temperate shallow-lake ecosystems – conditions closely resembling those of Czech ponds. Despite significant supplementation with cereals, critical growth slowdown – or even collapse – of carp growth is inevitable during July and August, when natural food resources are at their lowest. Regardless of year, pond, or research group, this phenomenon has been consistently observed in ponds (Fig. 2). The grains that are applied to supplement low natural food in ponds cannot replace 'nutritionally' the natural food in terms of essential amino and fatty acids, including bioavailable phosphorus (Mraz et al., 2025). If over-supplemented, the grains are not efficiently utilized as food and rather cause water quality deterioration, algal blooms, and long-term eutrophication of water bodies.

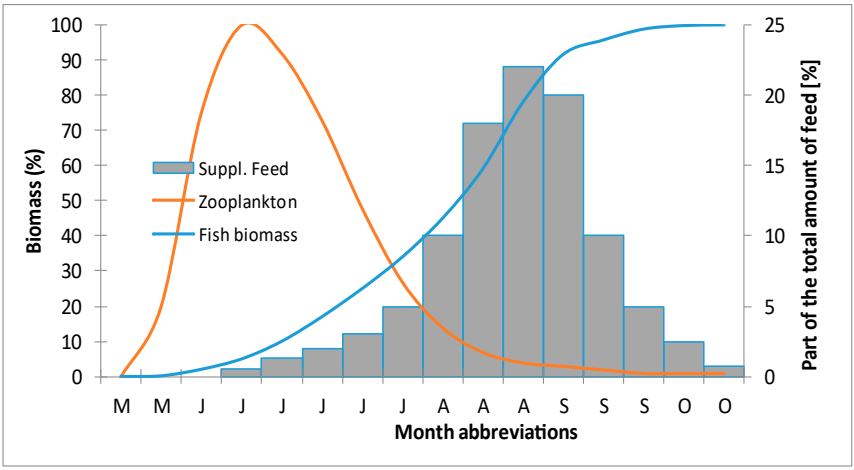


***Fig. 1.*** *Principle of supplementary feeding in European ponds visualized against fish biomass growth, zooplankton population, and supplementary feed input (Fullner, 2015). X-axis: Ten-day periods during the growing season (May = M to October = O) in Central Europe. First three of J implies June. Last three J implies July. Abbreviation could not be expanded due to limited interspacing on x-axis.*

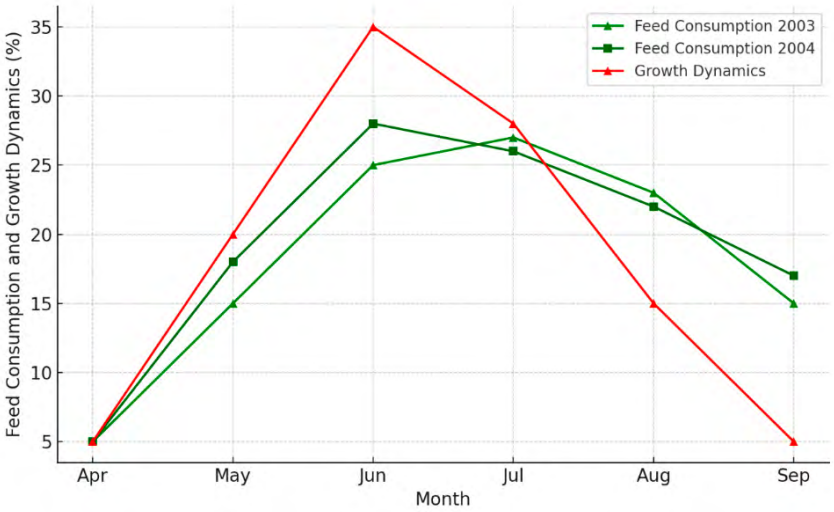


***Fig. 2.*** *Supplementary feeding and growth dynamics of carp in Czech ponds, a typical example from applicable for most ponds (Hartman and Regenda, 2016).*

The important caution that grain can never fully replace natural food (Roy et al., 2022; Mraz et al., 2025), and the equally valid advice to avoid overexploiting natural food resources (Roy et al., 2022; Vrba et al., 2024) – both stem from the challenge of accurately assessing the availability of natural food without significant effort. Since no standardized methods for this assessment exist, the task is left entirely to the pond manager's experience. In this regard, years of hands-on experience can be invaluable, particularly for observant managers who know their ponds well. Nevertheless, it would be highly beneficial for both experienced managers and beginners to have a practical method for roughly estimating the amount of natural food present in a pond and adjusting supplementary feeding accordingly. One approach is often referred to as **demand-oriented feeding with mostly grains.** The commercial extruded feeds (pellets) are only used in certain situations, such as condition feeding. Therefore, the demand-oriented feeding mostly refers to supplemental grain feeding (Schlott et al., 2023); *centered around zooplankton abundance.* The other approach is **balanced pond feeding with seasonal feeds** (Roy et al., 2022); *centered around supply versus demand of nutrition for fish* (Mraz et al., 2025). A nutritional requirement model of European ponds to achieve low and efficient feed use was recently developed (Mraz et al., 2025).

# INNOVATIVE METHODOLOGY FOR CARP SUPPLEMENTARY FEEDING IN PONDS USING ASSESSMENT OF THE NUTRITIONAL STATUS OF THE POND ECOSYSTEM AND SELECTION OF APPROPRIATE FEED

There has been a previous methodology to determine 'proxy markers' in ponds for estimating their supplementary feeding requirement. Schlott and colleagues (Schlott et al., 2023) devised a feeding-requirement scale according to the volume of sedimented zooplankton in 20 L of pond water at temperatures above 14 °C (Tab. 3). *In this methodology, the term proxy marker is defined as a measurable parameter(s) in pond that can indirectly tell the supplementary feed quantity x quality requirement for pond carp, at a given point of time.*

***Tab. 3.*** *Summary of prior methodology developed by Schlott and colleagues using large zooplankton density (>500 µm) as proxy marker of pond supplementary feeding (Schlott et al., 2023).*

| Level | SV* (ml) | Density (ind.$L^{-1}$)# | Feeding recommendation |
|---|---|---|---|
| 1 – Insufficient | ≤0.2 | 20 | Protein mixture at 2% of stock's live weight daily; feed should contain 26–28% protein for K2–3 fish. |
| 2 – Adequate | 0.2–0.55 | 20–55 | Cereals at 2% (up to 4%) of live weight daily when water temperature >15°C and dissolved oxygen >80% saturation. |
| 3 – Above-average | 0.55–0.8 | 55–88 | Cereals at 0.5% of stock's live weight daily or several times a week. |
| 4 – Excessive | ≥0.8 | >88 | Feeding is discontinued. |

**SV= Sedimentation Volume (From 20 L pond water sieved through 500 µm mesh).*
*#SV is converted to zooplankton density multiplying by a factor of 100 (Schlott et al., 2023)*

## 2. Aim of the methodology

This method aims to select a few easily, routinely, and practically measurable in-situ parameters in pond (called "proxy markers") that can be translated into fish nutritional needs (demand vs. supply). The aim of proxy marker(s) is to allow informed decisions on the right timing to switch grains to pellets, quantity, and nutritional composition of supplementary pellets needed to compensate for the gap of nutritional demand (by fish) vs. supply (from natural food) in ponds.

## 3. Novelty of the procedures

The present certified methodology unifies the following three methods of pond feeding:

I. ***Demand oriented feeding mostly with grains (Schlott et al., 2023)***: it is dynamic feeding of pond carps according to level of zooplankton abundance in ponds (Tab. 3).
II. ***Balanced pond feeding with seasonal feeds (Roy et al., 2022):*** it is adaptive feeding strategy to keep a constant state of optimum fish nutrition by switching between energy supplementation (under high natural food) and balanced protein-energy supplementation (under low natural food scenario) (Tab. 4).
III. ***Nutritional requirement model for regional ponds (Mraz et al., 2025):*** it is a model-guided feeding to bridge the gap between nutritional supply (from natural food) and demand (of growing fish) in pond (Tab. 6).

Through a series of comprehensive observations in experimental ponds maintained as living labs, we attempted to filter the most reliable proxy marker of fish nutrition in ponds. The data was synthesized from six carefully prepared experimental ponds maintained over a full vegetative season with a low fish stocking density and sufficient supplementary feeding for fish density to at least quadruple, to allow the following observations to be recorded within such range: (1) water quality parameters (*feeding condition:* water temperature >12 °C, dissolved oxygen >3 $mg.L^{-1}$), (2) growth-adjusted fish density and feed intake, (3) carp natural food density comprising zooplankton (>200 µm, >500 µm mesh) and zoobenthos, (4) nutritional composition of natural food and density-growth adjusted nutritional supply versus demand. Ultimately giving some statistical models to first understand and then predict fish nutrition in ponds. Thus, the present certified methodology builds on and improves the pre-existing methodology (Tab. 3), described in Schlott et al. (2023).

The new improved methodology focuses on four key limiting nutrients for fish growth: protein (Fig. 6), lysine (Fig. 6), methionine (Fig. 6), and digestible non-protein energy (Fig. 8) to give supplementary feed recommendations for carp ponds. A mind-map of the calculation can be found in the associated scientific article (Mraz et al., 2025). The complex calculations are omitted from the methodology for simplification purposes. Please note that the calculation itself is not the methodology, rather the outcome of the calculations presented

in subsequent chapters is the certified methodology – *an improved way of supplementary feeding of European ponds.*

List of proxy markers for ascertaining the status and requirement of pond fish nutrition developed in this methodology:

- *Advanced proxy marker:* Cladocera ≥200 µm (individuals $L^{-1}$)
- Basic proxy marker: Sedimentation volume of zooplankton >500 µm (ml 20 $L^{-1}$ water)

## 4. Methodology of proxy markers in pond fish nutrition – "advanced version"

The advanced version of the methodology is intended for scientists, water protection agencies, and pond managers (if they will use external services for water quality analyses). A simplified version that is farmer friendly (called "basic version") is given separately that can be directly used by the pond managers.

### 4.1. Step 1: Evaluation of nutritional supply

Assess the natural food availability on monthly basis (the first week) by collecting plankton consortia from a known volume of pond water, passing it over a 200 µm mesh, and microscopically count the cladoceran density (i.e., *Daphnia* sp., *Bosmina* sp., *Moina* sp. like structures) from a known volume of the fixed sub-sample, then doing calculations to extrapolate to cladoceran individuals per liter. Copepods can be omitted from counting.

The open-access methodology of plankton collection till fixation can be referred to in Schlott and colleagues, pp. 25–26 pictorial guide (Schlott et al., 2023), with slight modification of using a 200 µm mesh instead of 500 µm mesh and using a better fixative (a mixed sugar-formaldehyde solution at 4.5% weight/volume (Vrba et al., 2024). This better fixative does not dehydrate the cladocerans as much as in 95% ethanol or 4% formaldehyde. It is necessary for their rapid counting under microscope, as deformities slow down the counting process.

The open-access methodology of sub-sampling the fixed sample to its microscopic counting in Sedgewick-Rafter cell, followed by mathematical formulas can be consulted in the protocol by Lepori and Paolo, pp. 3–6 (Lepori and Paolo, 2025). Please note that this step can take up to 4 hours, being the most time-consuming step. If time is an issue and semi-quantitative measurements is enough for the purpose, please refer to the "basic version" of the methodology (another chapter).

The reason for omission of >200 µm mesh fraction of copepods, but selective inclusion of cladocerans only, is grounded on three aspects. First, cladocerans are much heavier in terms of dry matter intake by fish per liter of pond water sieved. Cladocerans have 8–10% dry matter, and dried individuals weigh between 100–300 µg each. Whereas copepods from the same >200 µm mesh fraction is much lighter, having up to 6% dry matter and dried individuals weigh from 30–100 µg each. That means, even if overall zooplankton count in a pond in individuals per liter is the same, and dominated by copepods instead of cladocerans, the dry matter intake by fish per liter of pond water sieved is much lesser. Second, change in copepods count does not correlate significantly with change in nutrient availability for fish. But any change in cladoceran abundance has a significant positive correlation ($r \approx 0.5$, $p<0.05$) with change in nutrient availability for fish. This is visualized by the correlation matrices in Fig. 3. Sometimes cladoceran abundance >500 µm mesh may substitute the correlation for cladoceran >500 µm mesh, but finding the larger fraction is rare in ponds and its absence can lead to false positives of a nutritional deficiency of fish, if there are plenty of smaller cladocerans (200–500 µm mesh) still in the pond. So, we recommend >200 µm mesh cladoceran abundance to be on the safe side.

Therefore, >200 µm mesh cladoceran density in pond water is much more important than the total zooplankton or copepod density. However, this is not always possible to estimate at farm level without involvement of researchers or accredited laboratory service. In such instances, the basic version of this methodology should be used. Based on seasonality of the >200 µm mesh cladoceran abundance in regional ponds, following windows exist from fish nutritional viewpoint:

- **April–June:** Cladocerans exist and did not succumb to top-down pressure. This window food provides surplus protein, indispensable amino acids (lysine, methionine), and phosphorus. However, digestible Non-protein Energy (NPE) and carbohydrates (NFE) are deficient in April due to absence of strong supplementary feeding by grains.
- **July–September:** Cladocerans exist negligibly, after succumbing to top-down pressure. In this window, the availability declines significantly, causing deficiencies in protein (from August), amino acids (from July), phosphorus (from August), and digestible lipid (from June).
- **October:** Cladoceran abundance recovers but is not really needed for fish nutrition at this stage, due to cessation of fishes' feeding activities and their switching to basal metabolism state under low temperature and low appetite (as they stop growing).

The weak but significant relationship (R2 0.3, p≤0.01) between cladoceran abundance (>200 µm mesh) and natural food web derived nutrients for fish show: (a) nutritional deficiencies at ≤250 individual litre$^{-1}$, and (b) nutritional sufficiency at ≥500 individual litre$^{-1}$ (Fig. 4, 5). For pond managers, this has been summarized in a recommendation table (Tab. 4–6).

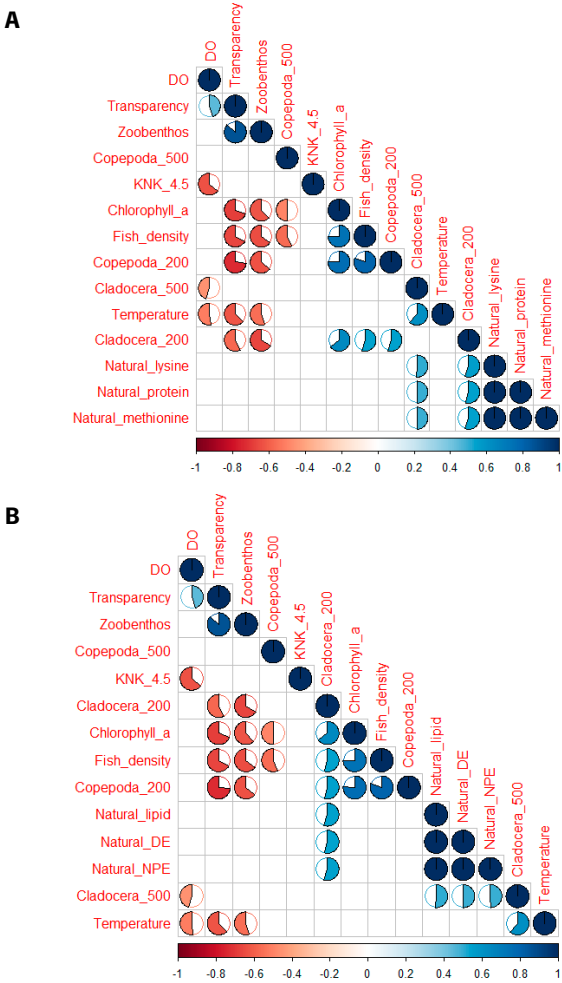


***Fig. 3****. Correlation between pond water quality and natural food web parameters with fish nutrition: A: protein, lysine, methionine. B: lipid, and energy. The variable cladoceran abundance (>200 µm mesh) is highlighted for its consistent and relatively good correlation among others, with the fish nutrition parameters.*

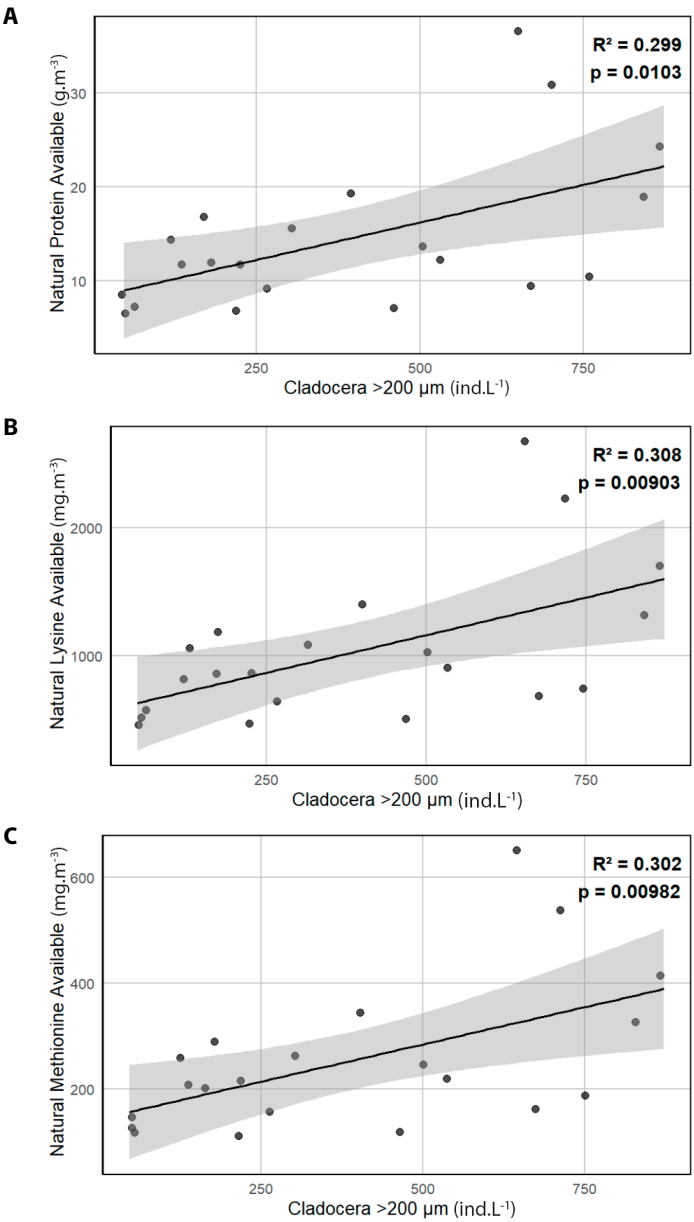


***Fig. 4.*** *Relationship between abundance of >200 µm mesh cladocerans in pond water with (A) protein, (B) lysine, and (C) methionine. Bivariate linear regression.*

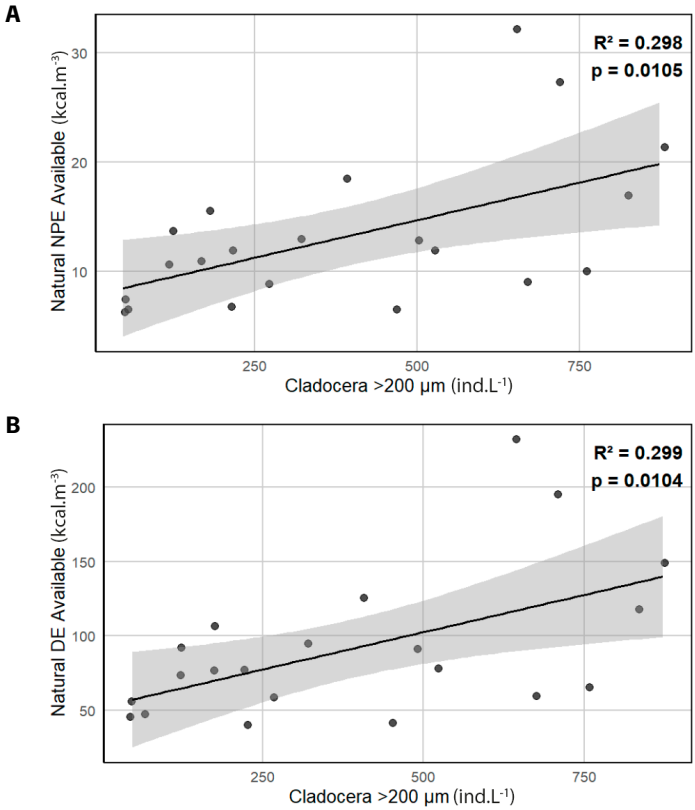


***Fig. 5.*** *Relationship between abundance of >200 µm mesh cladocerans in pond water with (A) non-protein energy (NPE) excluding protein and fibre, (B) digestible energy (DE) including protein and excluding fibre. Bivariate linear regression.*

### 4.2. Step 2: Nutrient supply and gap model for European ponds

The following estimations are aimed to satisfy nutritional requirement of temperate European carp ponds falling within a stocking range of 300–500 kg.ha$^{-1}$ with 300–400 g initial body weight common carp individuals for grow-out from April (stocking) to October/November (harvesting). Please note that all values given below are readily extrapolatable to three-dimensional carp grazing space in a pond, comprising of gill filterable plankton recorded in water column (grams dry weight in litres or 1,000 m$^3$) in 3D-space, and benthic macro-zoobenthos usually in 2D space (grams dry weight per m2 quadrant of

pond bottom). Both pelagic and benthic food web components are summed up on monthly basis, assuming a 1 $m^3$ cubical cross-section of typical European pond receiving grains as supplementary feeding in a traditional way. For further details, see the mind map of calculations presented in Mraz and colleagues (Mraz et al., 2025).

Therefore, the units below are given in $m^3$ (instead of per hectare) so that it can be easily recalculated to hectares area (100x100 m) assuming average 1 m depth and then adjusting/correcting it for the real pond depth also. The values of pelagic natural food nutrients would depend on the pond's depth too, and it needs to be factored into the fish nutrition supply versus gap modelling for ponds.

*Digestible Protein* ***(Fig. 6)***

- Natural food is sufficient until July; supplemental digestible protein is needed in August (3.3±0.9 $g.m^{-3}$) and September (8.0±5.2 $g.m^{-3}$).

*Digestible Lysine and Methionine* ***(Fig. 6)***

- Natural food sufficiently provides these amino acids until June. Deficiencies appear from July onward.
- Supplemental digestible lysine required: August (852.2±69.9 $mg.m^{-3}$), September (814.3±376.5 $mg.m^{-3}$).
- Supplemental digestible methionine required: August (217.6±15.2 $mg.m^{-3}$), September (277.5±93.2 $mg.m^{-3}$).

*Digestible Lipid* ***(Fig. 7)***

- Lipid supply constraints begin in June but are not limited due to compensatory NPE oversupply.
- Focus remains on overall energy rather than lipid specifically.

*Digestible NFE/ Carbohydrates* ***(Fig. 7)***

- Cereals adequately meet NFE requirements throughout the active feeding season.
- No supplementation is recommended; consider reducing cereal inputs and replacing it with compound pellets (protein feed, 30% protein) to balance macronutrient proportions.

*Digestible Energy (DE) and Non-Protein Energy (NPE)* ***(Fig. 8)***

- Surplus DE/NPE provided by cereals between May and September.
- Minimal supplementary cereal feeding in April (6.7±0.7 kcal NPE $m^{-3}$) and October (57.1±4.3 kcal NPE $m^{-3}$) recommended for basal NPE needs.

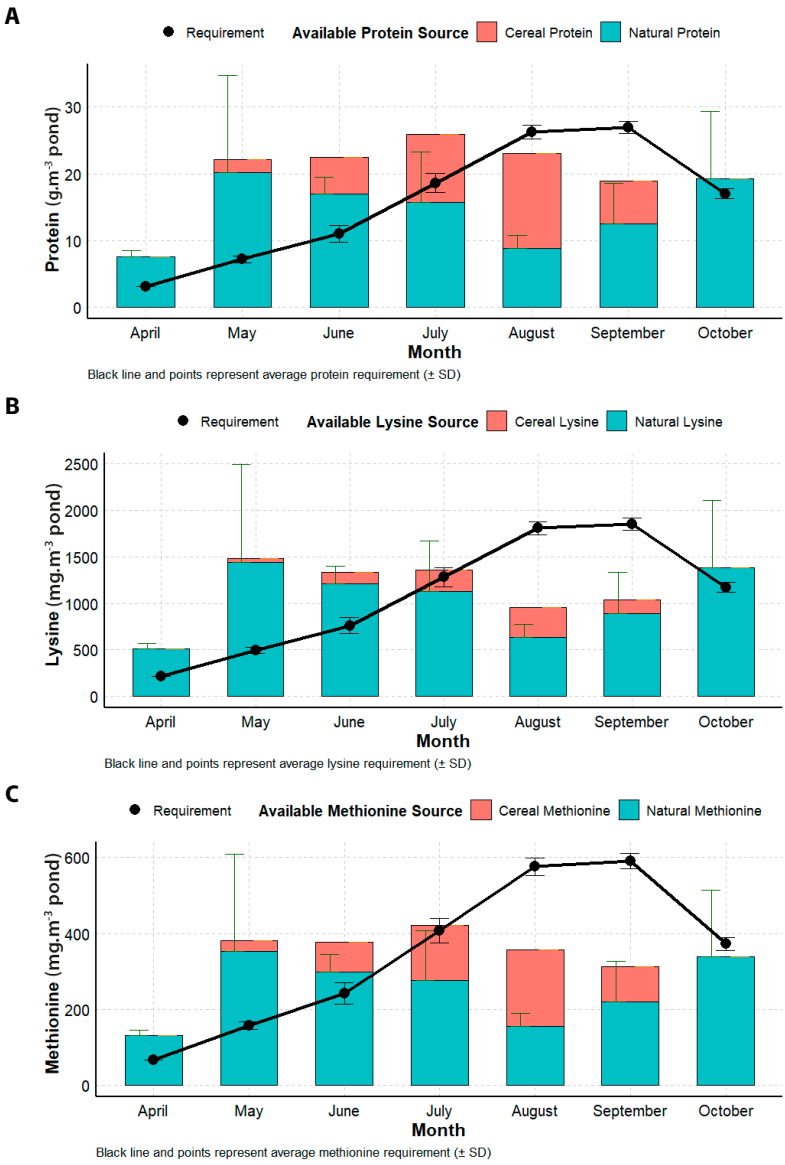


***Fig. 6.*** *Dynamics of supply (bar plot) and requirement (line plot) of (A) protein, (B) lysine, and (C) methionine over vegetative season in the carp ponds. Note: lysine and methionine models are more important to consider from pond fish nutrition point of view (Mraz et al., 2025).*

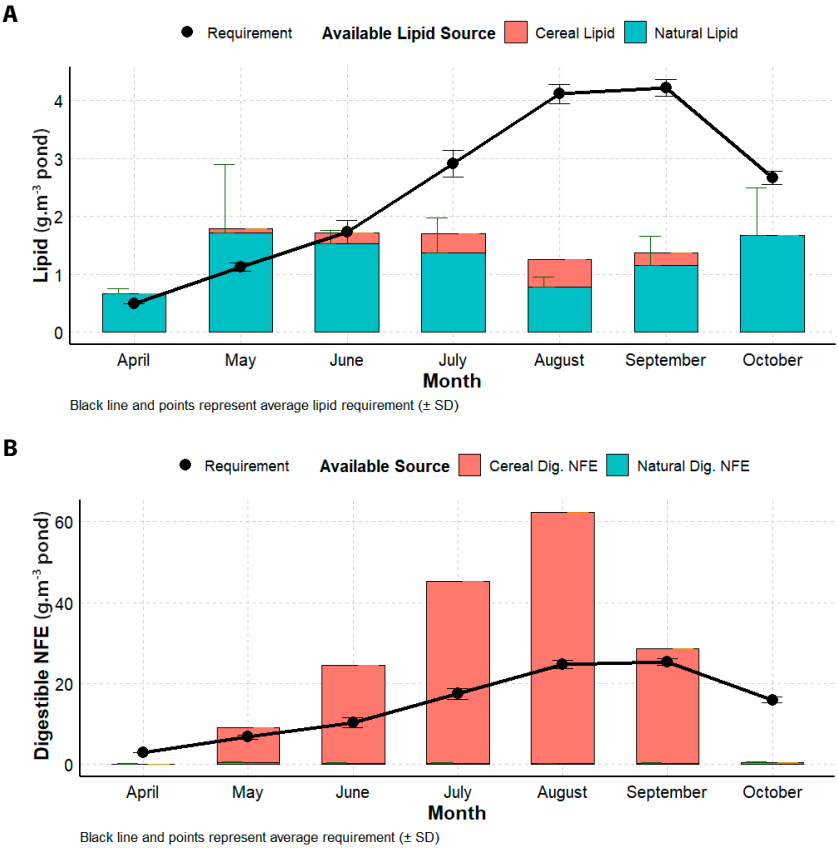


***Fig. 7.*** *Dynamics of supply (bar plot) and requirement (line plot) of non-protein energy fractions, (A) lipid and (B) digestible carbohydrate/ nitrogen-free extract, NFE excluding fibres over vegetative season in the carp ponds. Note: Digestible NFE and lipid compensate interchangeably for the non-protein energy (NPE) demand of pond fish, therefore, NPE model (Fig. 8) is more important to consider from pond fish nutrition point of view (Mraz et al., 2025).*

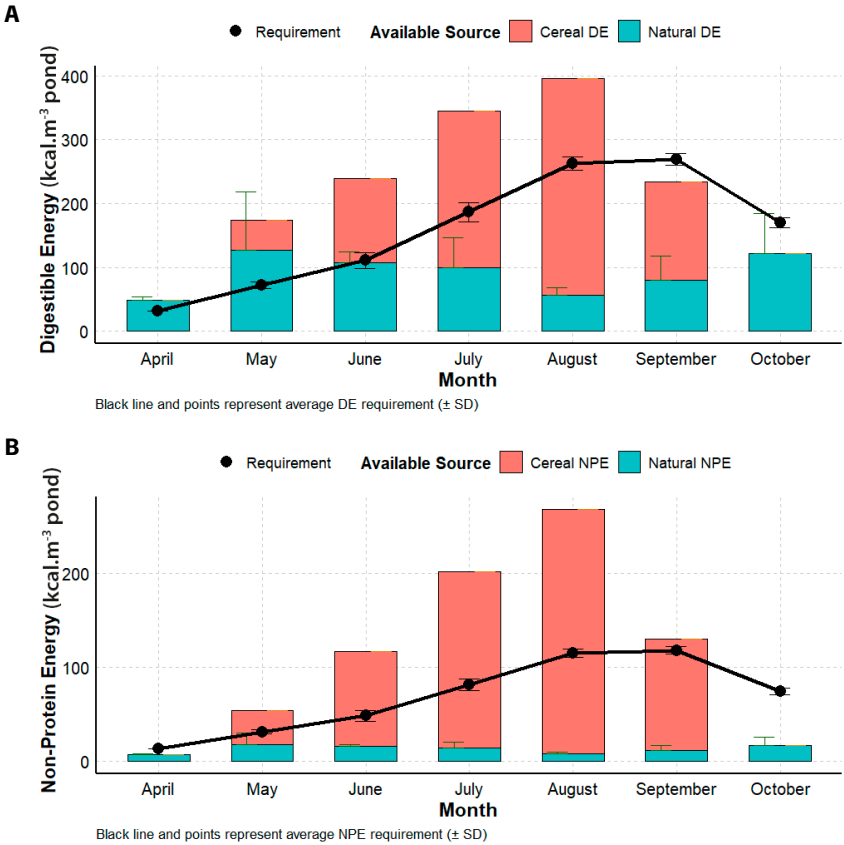


***Fig. 8.*** *Dynamics of supply (bar plot) and requirement (line plot) of (A) digestible energy and (B) non-protein energy over vegetative season in the carp ponds. Note: Non-protein energy is the more important model to consider for pond fish nutrition point of view (Mraz et al., 2025).*

## 5. Methodology of proxy markers in pond fish nutrition – "basic version"

In practice, this basic version can be directly applied by pond managers through a simple field observation: measuring the sedimentation volume (SV) after sieving 20 liters of pond water using a 500 µm plankton net. The relationship between >500 µm mesh SV (in ml) and zooplankton abundance (individuals per liter) has been statistically validated by Schlott et al. (2023), reporting a strong Spearman correlation of 0.9. According to their findings, SV

multiplied by 10 provides an empirical estimate of zooplankton abundance. This conversion is based on Schlott et al. (2023) and is not further elaborated here.

*The SV of >500 µm zooplankton fraction (in ml) is quite easy to determine according to open-access protocol of Schlott and colleagues, pp. 25–26 pictorial guide (Schlott et al., 2023). The >500 µm mesh zooplankton abundance (individuals $L^{-1}$) can be then re-calculated multiplying SV in ml by 10. This makes the basic version more practically implementable – measuring directly on-site and decide on the type of pond feed to be used as supplementary feed accordingly* ***(see, Fig. 9, Tab. 4).*** The basic version of methodology is directly accessible to pond managers who may not have the necessary scientific equipment or taxonomic expertise to count cladocerans.

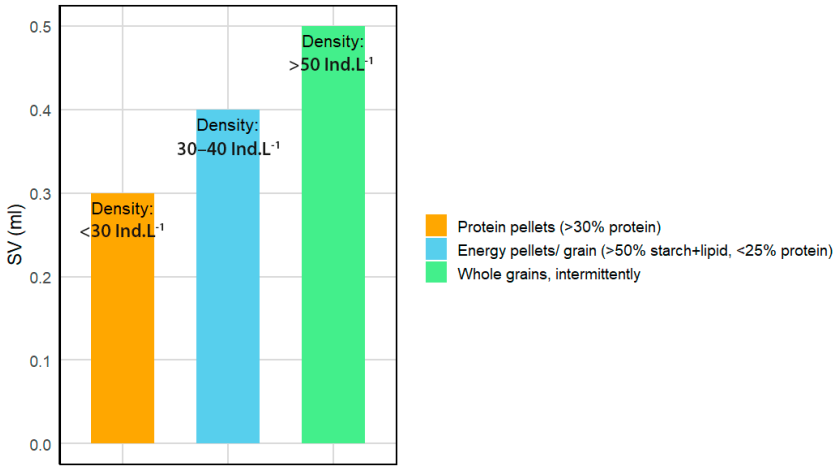


***Fig. 9.*** *Decision tree for sedimentation volume (SV) of ≥500 µm mesh plankton consortia (from 20 L pond water) and corresponding pond feed type to be applied. Refer to Table 4 for more specifications.*

By directly linking the nutritional composition (in g or kcal 100 $g^{-1}$ dry matter) of ≥500 µm mesh plankton consortia with measured zooplankton density (>500 µm, individuals $L^{-1}$), the graphical 3D contour models **(Fig. 10, 11)** validate the robustness of SV guided pond feed choice. The focus is narrowed down to three essential pillars of fish growth: (1) total amino acids or protein **(Fig. 10)**; (2) most limiting indispensable amino acids, lysine and methionine **(Fig. 10)**; (3) digestible energy, including its balance with total amino acids (called energy-protein balance, Fig. 11).

For example, when >500 µm mesh zooplankton is <30 individuals $L^{-1}$ (equivalent to SV <0.3), the total amino acids, lysine, and methionine concentrations begin deteriorating (Fig. 10), as the ponds become increasingly rich in colonial or filamentous algae dominated. To an extent that there is only energy (carbohydrate and/or lipid energy) but not enough amino acids for growth (Fig. 11).

When >500 µm mesh zooplankton is >50 individuals $L^{-1}$ (equivalent to SV>0.5), the total amino acids, lysine and methionine is quite high (Fig. 10), as the ponds are zooplankton-dominated and stays in the so-called clear-water state exerting top-down control on algal population. But this state is poor in energy to amino acids balance by not having enough energy to balance/ spare the high total amino acids, lysine, and methionine intake by the fish (Fig. 11).

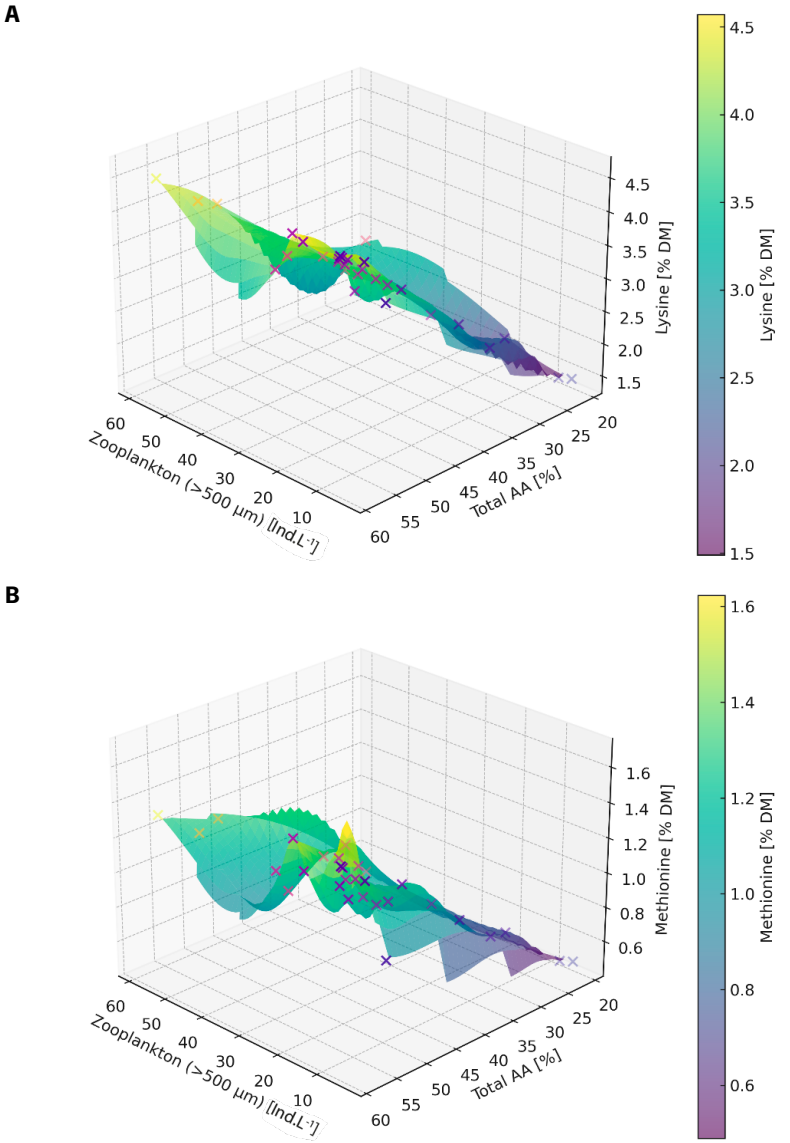


***Fig. 10.*** *The inter-relationship between zooplankton (>500 µm) density with total amino acids (protein), (A) lysine, and (B) methionine contents per unit of gill-sieved natural food. Zooplankton Ind.l$^{-1}$ can be converted to sedimentation volume (SV) by dividing with 10 (i.e., read zooplankton axis as 0.1, 0.2, 0.3, 0.4, 0.5., 0.6 SV).*

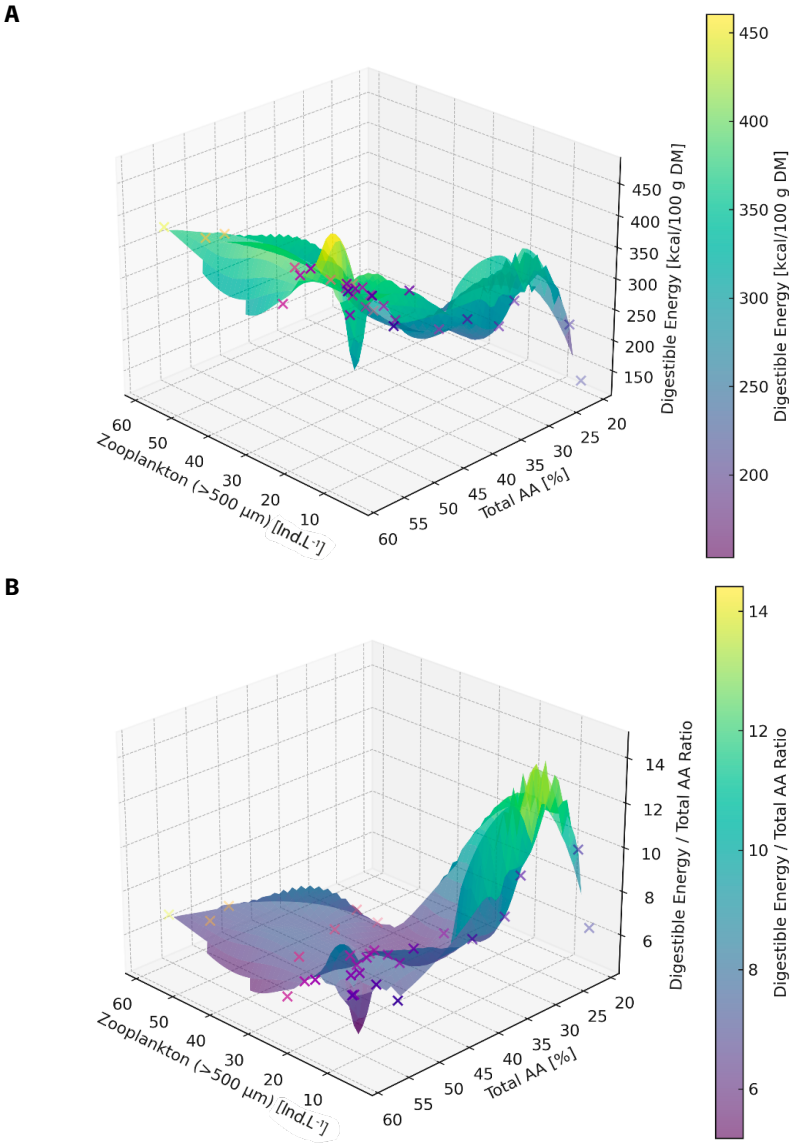


***Fig. 11.*** *The inter-relationship between zooplankton (>500 µm) density with (A) digestible energy, and (B) energy to amino acids ratio per unit of gill-sieved natural food. Zooplankton Ind./L can be converted to sedimentation volume (SV) by dividing with 10 (i.e., read zooplankton axis as 0.1, 0.2, 0.3, 0.4, 0.5., 0.6 SV).*

## 6. Application of methodology, significance, and target audience

The target audience of this methodology are extension agents, farm managers, and researchers working around European pond aquaculture. Unlike the rigid, pre-defined feeding plans outlined earlier (Tab. 2, Tab. 3), our method focuses on actively aligning feeding strategies with the real-time availability of natural food resources in the pond (Tab. 4, Tab. 5). The primary objectives of this approach are to maximize the utilization of natural food, enhance fish yields, and reduce nutrient loading in the pond environment. Although the concept may appear simple, its practical implementation is challenging and represents one of the greatest hurdles in effective pond management. In this context, the certified methodology we propose becomes highly valuable, providing a structured framework that simplifies decision-making. This methodology relies on using zooplankton counts as reliable proxy markers of natural food availability in the pond ecosystem. It involves two key steps:

1. Regular monitoring of carp gill-filterable zooplankton using a ≥500 µm mesh plankton net, which mimics the average branchial sieving capacity of >300 g common carp (Sibbing, 1988).
2. Estimating zooplankton sedimentation volume or individual density ($Ind.L^{-1}$) following the protocols described by Schlott and colleagues (Schlott et al., 2023).

### 6.1. Field guide for application of basic version of methodology

For an on-field application of the basic version of the methodology, a simplified decision tree is given as Fig. 12. The equipment needed for this is described in detail in the open-access document (Schlott et al., 2023). It involves a 500 µm mesh plankton net, buckets, water bottles with pipe (for flushing), and formaldehyde/ethanol. Together which will cost about €400–500, as an initial investment cost. For precision, minimum 3 to 6 repetitions are recommended, from different locations of the pond.

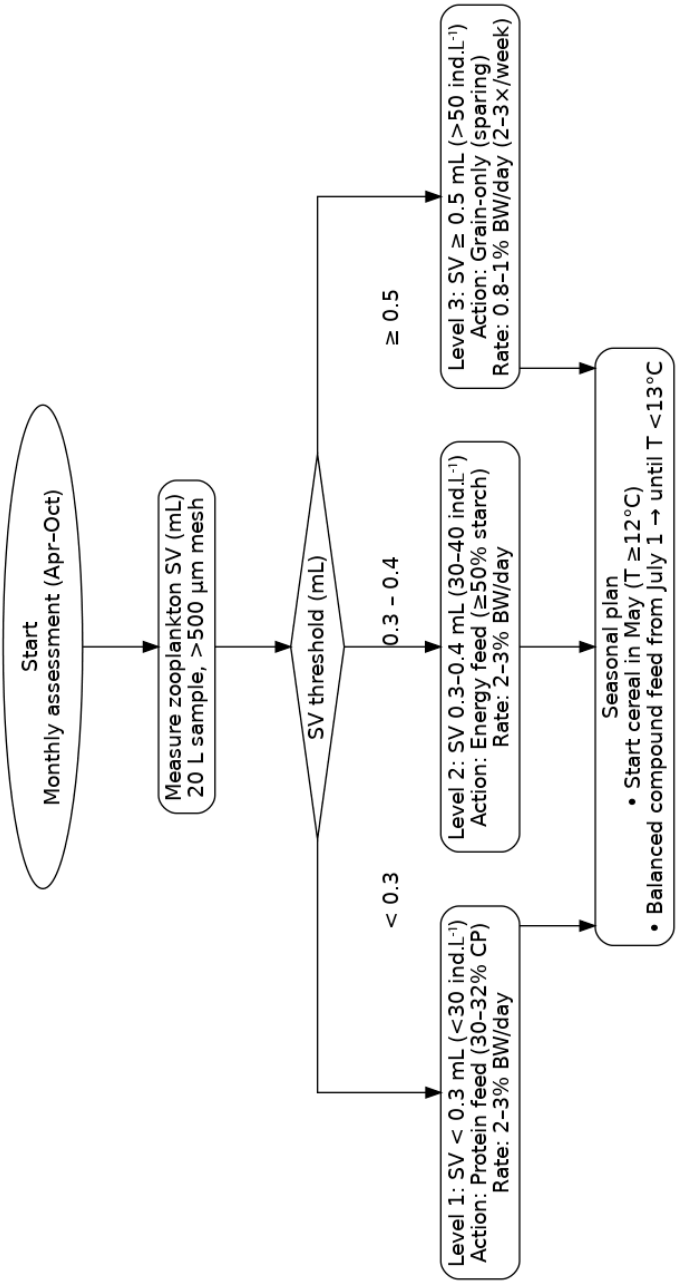


***Fig. 12**. A simplified decision-tree for deciding pond feed application on field. SV: sedimentation volume, BW: body weight/ biomass, T: temperature.*

## 6.2. Field guide for application of advanced version of methodology

For application of the advanced version of the methodology, the user needs to use an extensive mind map for modelling. The mind map is given in Fig. 13, adopted from the published study (Mraz et al., 2025). It involves monthly measurement of zooplankton abundance (especially cladocerans >200 µm mesh) and mean fish biomass density (based on monthly average body weight and stocked headcount) per cubical cross section of pond. The setup requires laboratory precision balances, microscopy, and field equipment for plankton and fish collection costing up to €8,000. This is mostly the initial investment cost.

- *Estimation of nutritional supply from natural food*

**Plan-A:** The monthly cladoceran abundance measured in individuals $L^{-1}$ need to be converted to dry matter (DM) using the following monthly adjusted coefficients for cladoceran population quality (supplementary appendix S1). Then the cladoceran DM.$L^{-1}$ needs to be converted to nutritional value $l^{-1}$ using their DM nutritional concentration coefficients (supplementary appendix S2). The user can similarly convert copepods (individuals $L^{-1}$) to copepods DM.$L^{-1}$ and nutritional value $L^{-1}$ using supplementary appendices S1 and S2. The sampling can be done from the surface layer using a van Dorn sampler (0.5 m length, 3.2 L volume). The combined sample to be transferred into a pre-washed 50 L plastic barrel. Subsamples for zooplankton samples to be taken from this sample. A total of 30 L of water is filtered through plankton net for zooplankton collection in a receiving tube at the end of the net and fixation by 4% formaldehyde solution (see section 4.1 for further details). T*his entire process (plan-A) can be replaced by a simpler plan-B given below.*

**Plan-B:** If collecting and weighing >200 µm plankton consortia directly (wet weight, mg.$L^{-1}$), this sample must be devoid of any debris, by passing the samples through a 2,500 µm mesh sieve. The wet weight can be converted to plankton consortia DM (mg.$L^{-1}$) using monthly adjusted coefficients (supplementary appendix S1). Then it could be converted to nutritional value $L^{-1}$ using their DM nutritional concentration coefficients (supplementary appendix S2). Sieving 300 L pond water is enough for this purpose.

Additionally, if the user can manage to sample, segregate and weigh zoobenthos biomass in g $m^{-2}$ (wet weight) of pond bottom, that can be converted to DM assuming a standard 15% dry matter value for zoobenthos

(supplementary appendix S1). The sampling of zoobenthos can be performed using an Eckman grab sampler (25×25 cm area). Then passed through a steel sieve (500 µm mesh).

- *Estimation of nutritional demand by fish stock*

Monthly carp biomass density ($g.m^{-3}$) is determined as follows: [(stocked headcount × average body weight of 20 carp in month) ÷ (pond length x breadth x depth in m)]. It is multiplied with water temperature and body size corrected daily DM intake factors (in % of biomass) for common carp (supplementary appendix S3). It gives daily DM-fed ($g.DM.m^{-3}$) which is multiplied with nutritional requirement factors in DM-fed according to carp requirements, given below.

The nutritional requirement of common carp in DM-fed is adopted from the NRC recommendations (NRC, 2011). The nutritional requirement factors in DM-fed ($g.m^{-3}$) are as follows: protein (32% DM), lipid (5% DM), lysine (2.2% DM), methionine (0.7% DM), phosphorus (0.65% DM), NFE excluding fibre (30% DM), DE (320 kcal 100 $g.DM^{-1}$), and minimum NPE for protein sparing (140 kcal 100 $g.DM^{-1}$). Standard calorific values used in fish nutrition (Bureau et al., 2003) is assigned to protein (5.41 $kcal.g^{-1}$), lipid (9.44 $kcal.g^{-1}$), and NFE excluding fibers (4.11 $kcal.g^{-1}$) to estimate digestible energy. For non-protein energy (NPE), only lipid and NFE calorific values are used.

- *Estimation of nutritional supply-demand gap*

After the nutritional demand ($g.m^{-3}$) is estimated, and the nutritional supply from natural food ($g.m^{-3}$) is estimated too, a simple subtraction [gap = demand – supply] reveals the nutritional gap in $g.m^{-3}$ to be fulfilled by supplementary feeding.

Please note that this is the monthly estimation and cannot be used as daily feeding. To avoid the problem of overfeeding, the value obtained above must be divided by the number of days in a month (or a fixed 30) to calculate the daily supplementary feed nutrient required ($g.m^{-3}$).

***Supplementary Appendix S1.*** *Median individual dry weight of cladocerans, copepods or dry matter (DM) of plankton consortia in ponds.*

| Month | Cladocerans >200 µm (µg ind.$^{-1}$) | Copepods >200 µm (µg ind.$^{-1}$) | Plankton consortia >200 µm (% DM)* |
|---|---|---|---|
| April | 200 | 30 | 10 |
| May | 100 | 30 | 10 |
| June | 100 | 30 | 10 |
| July | 60 | 15 | 8 |
| August | 31 | 10 | 8 |
| September | 50 | 18 | 8 |
| October | 100 | 20 | 8 |
| *Zoobenthos has a fixed 15% DM. | | | |

***Supplementary Appendix S2.*** *Digestible nutrient composition in dry matter basis of zooplankton and zoobenthos.*

| Nutrient (%) | Cladocerans | Copepods | Zoobenthos | Plankton consortia |
|---|---|---|---|---|
| Protein | 49.79 | 46.28 | 42.11 | 50 |
| Lipid | 4.07 | 9.27 | 3.32 | 10 |
| NFE (excl. fibre) | 1 | 1 | 1 | 1 |
| Lysine | 3.58 | 3.23 | 2.44 | 3.6 |
| Methionine | 0.87 | 0.9 | 0.68 | 1.2 |
| Phosphorus | 1.38 | 1.18 | 0.36 | 1.28 |

***Supplementary Appendix S3.*** *Monthly water temperature (WT) and body weight (BW) corrected dry matter (DM) intake to satiation by common carp in grow-out ponds. The assumptions for correction were based on standard carp nutrition literature (Woynarovich et al., 2010; NRC, 2011; Roy et al., 2019; Roy and Mráz, 2021).*

| Month | Daytime surface WT (°C) | Mean BW (g) | Corrected DM intake (% BW) |
|---|---|---|---|
| April | 13.1 | 350 | 1.6 |
| May | 20.1 | 500 | 3 |
| June | 22.8 | 700 | 3 |
| July | 22.9 | 1,000 | 3 |
| August | 22.1 | 1,500 | 3 |
| September | 16.2 | 2,000 | 2.5 |
| October | 12.5 | 2,200 | 1.6 |

The user should avoid supplementary feeding (***i.e.,* 0% of BW**) when water temperature extremes <10 °C or >29 °C, or dissolved oxygen (DO) extremes ≤2 $mg.L^{-1}$ are recorded.

At temperatures around 12 °C and DO around 3 $mg.L^{-1}$, some caution is suggested, and the feeding may be at basal level or minimum maintenance level (i.e., 1% of BW).

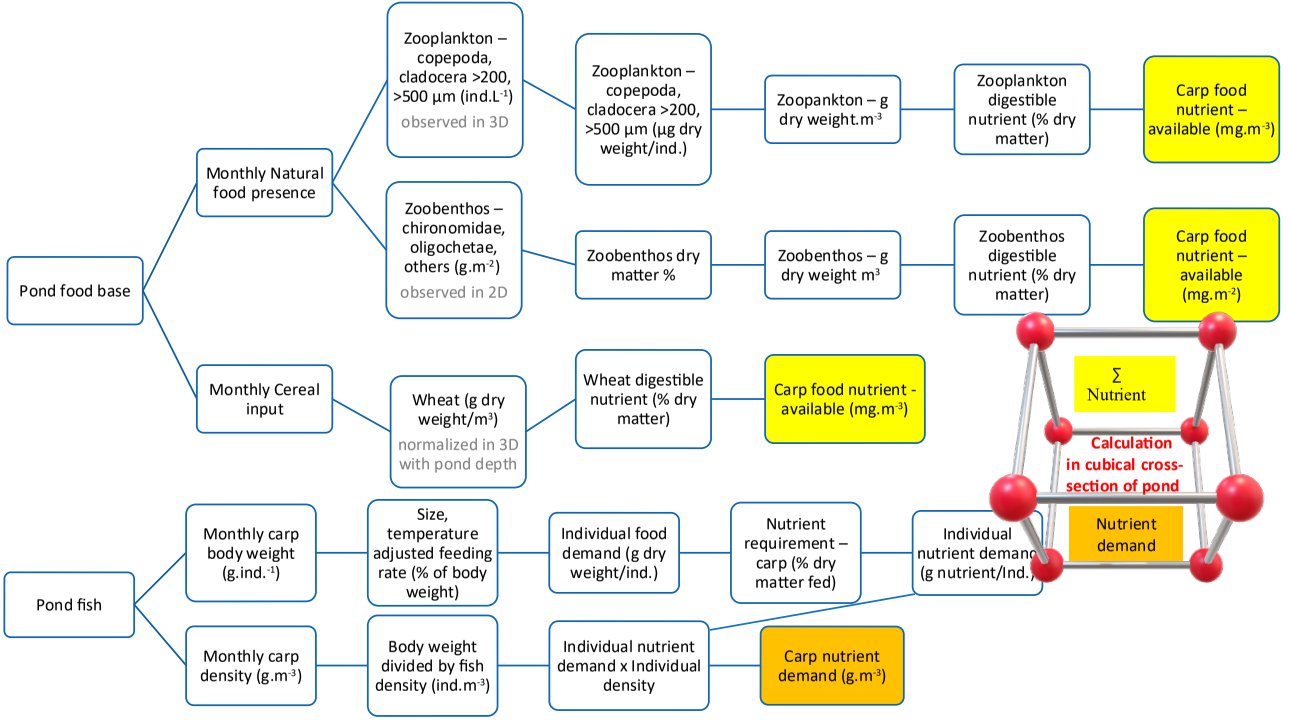


***Fig. 13.*** *Mind map of carp nutrition supply-demand gap modelling in ponds using advanced version of the methodology (Mraz et al., 2025).*

## 7. Recommendations for practitioners

- Conduct monthly nutritional supply assessments from April to October. By monitoring large zooplankton sedimentation volume (>500 µm mesh; basic version) or cladoceran abundance in pond (>200 µm mesh; *advanced version*). **See Tab. 4 and 6 for planning.**

- Cereal-based supplementary feeding begins already in May when water temperatures ≥12 °C, because grains have prolonged water stability even if uneaten, and carp may eat at high noon if temperature permit. Make transitions to balanced compound feeds by 1$^{st}$ of July and continue till end of culture until water temperature drops below 13 °C. **See Tab. 4 for planning.**

- Detailed nutritional requirements for European ponds are summarized in Tab. 4. To fulfil the requirement, a recommended composition and daily input rate of a model pond feed is also provided in Tab. 6. It is applicable to ponds having stocking density in April in the range of 300–600 kg ha$^{-1}$

- The monthly feeding plan (% of total feed dose) can be as follows based on the *balanced pond feeding concept* (Tab. 4): April (3%), May (7%), June (11%), July (32%), August (25%), September (15%), and October (7%) of total dose. *Example:* for 472 kg.ha$^{-1}$ stocking density, a total supplementary feeding of 3,518 kg.ha$^{-1}$ can be planned for an RFC around 2–2.5 and yield ≥1.5 ton.ha$^{-1}$ ecologically.

***Tab. 4.*** *New and improved methodology – Zooplankton (>500 µm) as proxy marker of pond supplementary feeding requirement with slight modifications to Schlott et al. (2023). To be used by pond managers directly.*

| Level | SV* (ml) | Density (Ind.L$^{-1}$)# | Feeding Recommendation |
|---|---|---|---|
| 1 – Energy poor and low protein | <0.3 | <30 | Switch to **Protein feed.** Suggested specifications to complement/ mirror natural food availability and quality: *30–32% crude protein, lysine ≥1.9%, methionine ≥0.6%, starch+sugar >25%, lipid 7–10%, phosphorus <0.9%, acid detergent fiber <14%, Gross Energy (DE): >320 kcal.100 g$^{-1}$, non-protein Energy (NPE): >150 kcal.100 g$^{-1}$.*<br>***Options:*** any extruded or pressed cyprinid pellet fulfilling the above range. A summer pond feed formulation tailored for temperate European ponds has been developed under the project. The carp feed for pond is special (*not intended for use in RAS without a natural food web)* presently undergoing protection as an IPR. Formulation is available on request to authors, for personal use only.<br>***Feeding rate:*** Feed at 2–3% of body weight. At water temperatures >13 °C, dissolved oxygen (DO) >3 mg.L$^{-1}$ and body size between 300–1,500 g. Feed at upper limit (3%) when temperature is >19 °C and body size is <1,200 g. Stop feeding at low DO or heat wave episodes (surface water temperature ≥28 °C). |
| 2 – Energy-poor but high protein | 0.3–0.4 | 30–40 | **Energy feed** to be applied in ponds. >50% starch (with or without lipid fraction combined) is suggested to provide enough non-protein energy (including lipids) that would "spare" the natural food and its high-quality protein + lipids from metabolic losses.<br>***Options:*** whole grain (whole or mechanically pressed/ crushed to enhance digestibility), factory discards of early morning cereals – highly gelatinized with high oil (e.g., cornflakes, chocoballs having starch as high as 60% and 15–30% lipid).<br>***Feeding rate:*** Feed at 2–3% of body weight. At water temperatures >13 °C, dissolved oxygen >3 mg.L$^{-1}$ and body size between 300–1,500 g. Feed at upper limit (3%) when temperature is >19 °C and body size is <1,200 g. Feed at upper limit (3%) when temperature is >19 °C and body size is <1,200 g. Stop feeding at low DO or heat wave episodes (surface water temperature ≥28 °C). |

| | | | |
|---|---|---|---|
| 3 – High to excess natural food | ≥ 0.5 | >50 | **Still, feed energy feed.** Because natural food is quite poor in non-protein energy. Feed at lower dose 0.8–1% BW when feeding conditions (water temperature, dissolved oxygen) are met.<br>***Options:*** only grain is enough for sparing valuable protein (amino acids) and lipid (long-chain polyunsaturated fatty acids) from the dense natural food, and net retention in fish body. The digestible NPE in copepods, cladocerans, and chironomids is mostly insufficient: 117 kcal, 154 kcal, and 33–103 kcal NPE 100 $g^{-1}$ dry matter, respectively (while carp requirement is >150 for efficient bioenergetics).<br>***Feeding rate:*** Feed at 0.8–1% of body weight. At water temperatures >10 °C, dissolved oxygen >3 $mg.L^{-1}$, and only 2–3 times a week by whole grains. This feeding is advised for more efficient utilization of high-quality natural food web nutrients (to accelerate fish biomass gain and shorten the production cycle to market size). |

**SV= Sedimentation Volume (From 20 L pond water sieved through 500 µm mesh).*
*#SV is converted to zooplankton density equivalent by a factor of 100 (Schlott et al., 2023)*

***Tab. 5.*** *New and improved methodology – Cladocera (>200 µm) as proxy marker of nutritional quality classification of ponds at any given point of time. To be used by pond scientists or water protection agencies.*

| Level | *Cladocera* >200 µm (Ind.L$^{-1}$) | Feeding Recommendation |
|---|---|---|
| 1 – Nutritionally deficient pond | <250 | Cereal cannot support yield, and it is time to discontinue them. Pellets are needed and should be allowed. Fertilizers may not help. |
| 2 – Zone of uncertainty | 250–500 | Nutritionally the pond hangs in a critical balance which would likely proceed to nutritionally deficient state. Cereal still can support growth by protein sparing from natural food, but to slow down the depreciation, co-feeding or alternative feeding of grains and pellet is suggested. |
| 3 – Nutritionally sufficient pond | >500 | Cereal can support yield. Pellets are not needed; fertilizers are not needed. |

***Tab. 6.*** *Nutritional requirement of European carp ponds for improved fish nutrition and supplementary feed utilization. Abbreviations: DE (digestible energy), NPE (non-protein energy), Bio. Phosphorus (bioavailable or digestible phosphorus), min. (minimum).*

| Nutrient | Unit | June (grain)* | July (pellet) | August (pellet) | September (pellet) |
|---|---|---|---|---|---|
| Protein | mg.m$^{-3}$ | – | 2,904 (min.) | 17,392±960 | 14,448±5,247 |
| Lysine | | – | 155 (min.) | 1,172±70 | 960±376 |
| Methionine | | – | 132 (min.) | 419±15 | 369±93 |
| Lipid | | – | 1,549±607 | 3,325±71 | 3,059±456 |
| Bio. Phosphorus# | | – | – | 293±0.2 | 209±1 |
| DE | kcal.m$^{-3}$ | – | 87±45 | 207±5 | 190±34 |
| NPE | | 33±4 | 67±9 | 107±3 | 106±6 |
| Model feed input | kg.ha$^{-1}$ day$^{-1}$ (for 1 m depth) | – | 18.2 | 18.2 | 16.4 |

**From April/May to June, there is no real nutritional requirement for pond fish except energy for fish growth. So, apply cereals. From July onwards, there is a real requirement of both protein and energy. So, apply pellets.* ***See Tab. 4 for specifications.***

*#Carp can absorb phosphorus (P) from water and meet requirements; no need to add extra P in pond feed (crude P content of pond feed should be <0.9% to avoid pollution). This level is below the P concentration factor (1.1% of dry matter) of zooplankton.*

## 8. Economic aspects and impact on pond aquaculture

As highlighted by Schlott and colleagues (Schlott et al., 2023), the RFC for supplementary feeding in ponds can vary significantly – from 1.5 when using adaptive feeding strategies to even 4 under rigid, fixed feeding plans. By implementing the methodology presented here, it is expected that supplementary feed use can be reduced to an RFC of 1.5–2.5 (from 2.5–4.0 of grain feeding). By this, the efficiency of supplementary feeding to support production improves to 45–55%. Usually for water protection agencies, any RFC ≤2 (i.e., supplementary feeding efficiency ≥50%) is welcome.

The return on investment (ROI) is estimated to be 10–20% higher than the traditional feeding, by saving on the supplementary feed used and getting higher production at the same time. Then there are mostly ecological benefits (lower environmental footprint, water protection, nature restoration, regenerative farming) which could be further incentivized by the farmer, the ROI of which shall depend on the rate of subsidy by the governmental schemes.

## 9. List of publications that preceded the methodology

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***Dedication***

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