

Assessment of the difference in ecosystem services between ecologically and conventionally managed ponds: An empirical study from the South Bohemia region, Czech Republic

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Abstract: The aim of this article is to demonstrate the difference in the production of ecosystem services depending on the management method using a selected sample of fishponds from the South Bohemian region of the Czech Republic and subsequently monetarily to assess this difference. Using 16 fishponds over a 10-year period, the research evaluates key services such as biodiversity conservation, water purification, and fish production, employing the opportunity cost of foregone profits methodology. The results reveal that ecologically managed fishponds provide enhanced ecosystem services at a financial trade-off, with an average annual profit difference of EUR 142 per hectare compared to conventional management. This trade-off translates to a present value of EUR 1 288 per hectare over a decade, reflecting the additional societal value of ecosystem services from ecological management. The findings underscore the economic and ecological challenges faced by stakeholders, particularly fish farmers, in balancing conservation goals with economic viability.

Keywords: biodiversity conservation; ecosystem services; fishpond management intensity; nature's contributions to people; opportunity costs

Freshwater pond farming is a specific segment of aquaculture that has always been closely linked to rural life and has inseparably connected the social, ecological, and economic dimensions of fish farming activities. Pond farms, integral to rural economies, serve as valuable wetlands, enhance ecosystem quality, play a crucial role in water management and landscape

shaping, support recreational activities, preserve cultural heritage and typical biodiversity, and contribute to fish production (Fu et al. 2018; Popp et al. 2019; Alves et al. 2020). These dimensions contribute to human well-being and belong to ecosystem services (ES), or currently, Nature's Contributions to People (NCP) (Díaz et al. 2018; Hill et al. 2021). Artificially created

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fishponds are important part of European wetland ecosystems. In developing the management of these water bodies, it is therefore important to consider their multifunctionality (Bekefi and Varadi 2007; Popp et al. 2019). Among the ES, or NCP, provided by fish ponds are the provision of a diverse range of habitats for biodiversity (Hill et al. 2021), pollination, nutrient supply to adjacent ecosystems (Landuyt et al. 2014; Pascual et al. 2017; Walton et al. 2020; Cuenca-Cambronero et al. 2023), carbon sequestration (Holgerson and Raymond 2016), flood risk mitigation, groundwater recharge, water pollution reduction, as well as opportunities for recreation, tourism, cultural services, and related commercial activities (Biggs et al. 2017; IPBES 2018; Vo et al. 2023).

To optimise the public and private benefits of fishpond management, it is necessary to achieve a compromise between the goals of biodiversity conservation and the interest of fish farmers in maintaining the possibility of commercial fish production (Hambäck et al. 2023). Fortunately, there are not only conflicts but also synergies and co-production between the interests of different stakeholder groups and the mechanisms for providing ecosystem services (Landuyt et al. 2014). These include, for example, the impact of submerged vegetation on nutrient retention, greenhouse gas emissions reduction, and biodiversity conservation. Similarly, wetland-related characteristics appear to have largely positive impacts on flood protection, water storage, nutrient retention, methane reduction, and biodiversity conservation goals (Landuyt et al. 2014). Likewise, the complexity of the shoreline has synergistic effects on both biodiversity protection and cultural ecosystem services (Hambäck et al. 2023). Societal expectations today include not only the demand for healthy and safe fish products but also for environmentally friendly production and efficient resource use (Hassall et al. 2016). Multifunctional pond farms, where visitors can learn about fish farming directly, can be very useful in raising ecological awareness about fishpond farming. One of the important elements of multifunctional pond farming is openness and 'social communication', where visitors to the farm can not only learn about sustainable fish production but also about the aquatic environment, fish species, and aquatic wildlife. They can also learn about the positive impact of ponds on the natural environment, water management, and landscape (Bekefi and Varadi 2007; Popp et al. 2019).

Pond management strategies play a crucial role in shaping the type and extent of ecosystem services

provided by these aquatic systems. According to Landuyt et al. (2014), various management approaches can be observed in Europe, each reflecting distinct objectives and practices. Broadly, these approaches can be classified into three main categories: ponds managed primarily for nature conservation, those utilised for low-intensity fish farming, and those dedicated to semi-intensive fish farming. Ponds managed for nature conservation purposes often focus on maintaining or enhancing biodiversity (Hill et al. 2017; Higgins et al. 2019) and ecosystem health, with minimal human intervention and limited fish stocking. In contrast, low-intensity fish farming typically involves low-density fish stocking, relying on the natural productivity of the pond without the use of industrial feeds, thereby maintaining a relatively high level of ecological balance. On the other hand, intensive fish farming (operated e.g. in Belgium) is characterised by high stocking densities, the use of industrial fish feeds, and active interventions to maximise fish yield, often at the expense of ecosystem complexity and biodiversity (Landuyt et al. 2014). Key differences among these management strategies include factors such as the complexity and naturalness of the pond shoreline, the intensity of human intervention, the volume and type of fish stocking, the use of supplementary feeds, and the level of accessibility for recreational activities (Krivtsov et al. 2021). These differences not only influence the ecological state of the ponds but also determine the range and quality of ecosystem services they provide, such as water purification, habitat provision, carbon sequestration, and opportunities for leisure or educational experiences.

The provision of ecosystem services by ponds is strongly influenced by the management practices applied, leading to significant differences in the types and scale of ecosystem services provided. While ponds have the potential to deliver a wide array of ecosystem services – including biodiversity support, water purification, carbon sequestration, and recreational opportunities, up to now evaluations of their management practices often focus predominantly on a narrow subset, such as fish production, leaving many other benefits underexplored (Pechar et al. 2000). The lack of methodological or legal frameworks, as well as difficulties in evaluating the actual non-production assets of ponds, are considered one of the main obstacles to the integration of pond farming compounds into integrated water resource management and the recognition of their proper role in the country's water management (Kaczkowski and Zalewski 2010; Turkowski and Lirski 2011). This oversight highlights a critical

research gap, particularly in regions like South Bohemia in the Czech Republic, where fishponds play a vital role in the landscape and local economy. Addressing this gap, this paper analyses how different management regimes – ranging from low-intensity to semi-intensive fish farming – affect the structure and value of ecosystem services provided by ponds, with a focus on the monetary valuation of the difference in ecosystem service values between ponds under protected and conventional management regimes. We aim to offer a comprehensive understanding of these differences. First, we identify the range and scale of ecosystem services associated with different management practices, focusing on their homogeneity and variability across different management regimes. Second, we assess the economic implications of these differences through the opportunity cost of foregone profits methodology, leveraging insights from a detailed review of relevant literature.

MATERIAL AND METHODS

Study area. The fishpond system analysed in this study is located in the South Bohemian region of the Czech Republic, an area renowned for its long-standing tradition of fish farming and the presence of numerous entities engaged in aquaculture. This region is also recognised for its high ecological value, partly attributed to the extensive management employed in certain fishponds, which support biodiversity and contribute to the region's environmental sustainability. For the purposes of this analysis, 16 fishponds were selected, representing a diverse range of sizes, management approaches, and ownership structure. Half of them are located in areas with some degree of environmental protection (e.g. sites of European importance, nature reserves, national nature reserves, nature monuments, national nature monuments), and the other half in areas where management is not regulated. Both groups have an equal representation of annual management cycle ponds and biennial management cycle. Within the group of protected fishponds, a higher proportion are smaller (up to approximately 10 hectares) and primarily focused on fry production compared to the conventionally managed group, which includes higher number of larger fishponds managed towards market fish production.

Figure 1 provides an overview of the group of analysed fishponds, illustrating their distribution in the landscape and size. This selection captures the variability within the region, allowing for a comprehensive

examination of the relationship between management practices and the provision of ecosystem services. The ponds chosen are owned and managed by different economic entities, reflecting the heterogeneity in management goals and strategies. This selection serves as the foundation for assessing the ecological and economic implications of pond management practices, with a focus on understanding how varying approaches influence ecosystem service provision and overall sustainability in this ecologically significant region.

Pond management strategies. Well-managed pond farms are considered sustainable when they efficiently utilise natural resources, minimise environmental impact, provide public goods, and generate profit for farmers (SustainAqua 2009; Bosma and Verdegem 2011). The key challenge in pond farming development lies in preserving the benefits of traditional practices while simultaneously increasing production and employment opportunities without compromising sustainability. A promising solution is multifunctional pond farming, which systematically integrates traditional and innovative functions into a comprehensive system, emphasising resource effi-

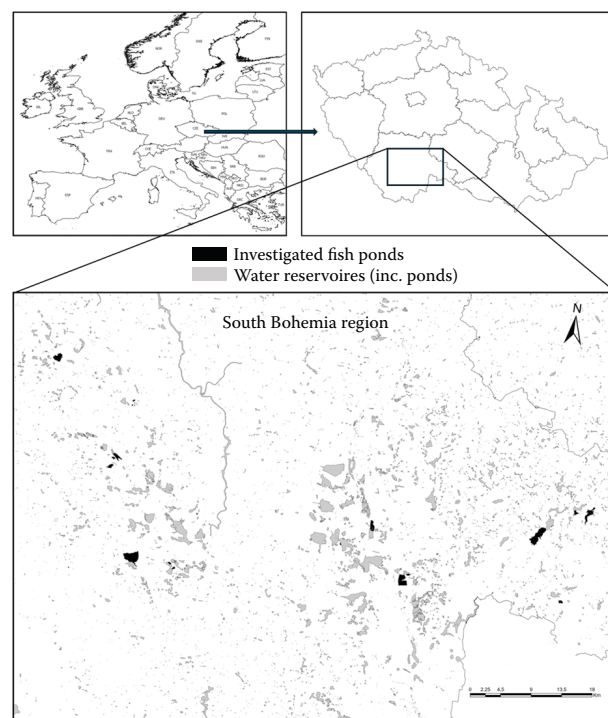


Figure 1. Overview map of the analysed fishponds in the South Bohemian Region

Source: <https://heis.vuv.cz/>

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ciency and circularity (Popp et al. 2019). The current pond management strategies in the South Bohemian region of analysed fishponds can be classified into two major types (Spurný et al. 2019):

Extensive fishponds are water bodies where fish farming relies exclusively on the natural food present in the ecosystem. These fishponds are typically located in protected areas or serve as recreational ponds. The primary goal is to maintain high water quality. Fertilisation is prohibited, with the potential exception of a spring starter dose of organic fertilisers, and feeding the fish is not allowed. Stocking densities are chosen to align with the pond's natural characteristics and the available food supply.

Semi-intensive fishponds are the most common practice in aquaculture in the Czech Republic. Fish production is primarily based on natural food sources, which are supported by fertilisation and often supplemented with carbohydrate feed (Spurný et al. 2019).

Most ponds in the South Bohemian Region are managed using a semi-intensive strategy, which balances natural food production with moderate fertilisation and supplementary feeding. A significant number of ponds in the region are also managed for nature conservation purposes, placing them in the category of extensive fishponds. These ponds are located in protected areas and are maintained with a focus on preserving ecological balance, strictly prohibiting artificial feeding or intensive interventions. The study includes fishponds belonging to both categories: conventionally managed fishponds, which use semi-intensive methods, and protected (or ecologically managed) fishponds, where management is regulated and limited to ecologically sustainable practices. This approach ensures that the analysis reflects the prevailing aquaculture practices in the region while aligning with conservation priorities.

Differences in the scale and extent of ecosystem services for fishponds with different management regimes. From the perspective of ecosystem service provision as the primary outcome of management, the following scenarios can occur along a spectrum ranging from fish production to biodiversity conservation:

i) Fish production is the dominant ecosystem service in this scenario. However, the ecosystem still provides other services to a limited extent, including the maintenance of biodiversity.

ii) The management goal is a relatively even provision of all ecosystem services, without any single service being dominant. The total production of ecosystem services may vary – potentially higher or lower

than in scenarios 1 and 3 – depending on specific site conditions and economic factors (Figure 2).

iii) In this case, biodiversity protection is the dominant ecosystem service. Other services, such as fish production, are still provided but at a reduced level.

iv) One ecosystem service, such as fish production, is intensively supported through external inputs (e.g. fish feeding or fertilisation), leading to a decline in the provision of other ecosystem services, both in relative and absolute terms. This approach is inherently unsustainable.

The management regime of ponds offers considerable flexibility. Even ponds under varying levels of nature protection can accommodate fish production, while production ponds contribute to biodiversity conservation to some extent. This multifunctionality increases with larger pond areas, greater ecosystem diversity, and more developed anthropogenic infrastructure. The largest ponds analysed, exceeding 150 hectares, provide a balanced range of ecosystem services, including significant fish production, biodiversity conservation, and recreational opportunities. Similarly, large fishponds under nature protection still support notable fish production. In contrast, the smallest ponds, often shallow and well-suited as habitats for wetland biodiversity, are typically under strict nature protection with minimal fish production. This relationship suggests that the greater the disparity between the goals of the management regime – focusing either on fish production or nature protection – the higher the costs associated with maintaining and safeguarding biodiversity.

Model fishponds do not represent the extremes of monofunctional management on the spectrum of target management approaches. Even in such cases, ecosystems still provide additional ecosystem services to a limited extent, such as climate regulation and recreation (Figure 2). Similarly, fishponds under varying levels of nature protection are also used for fish production. This assumption aligns with national legislation, as all ponds are designated as significant landscape features under Act No. 114/1992 Coll. on Nature and Landscape Protection. Naturally, each fishpond prioritises a specific ecosystem service as its management goal. However, overall management typically incorporates, to varying degrees, four primary groups of ecosystem services: fish production, biodiversity conservation, recreation, and other regulatory services. While there are differences between pond types in terms of target use and management priorities, these approaches are not entirely contradictory. This has

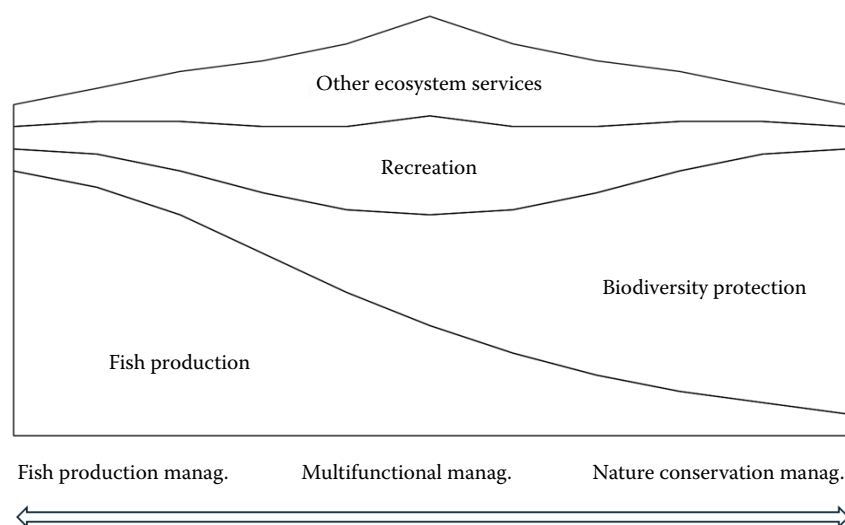


Figure 2. The relative ratio of the provision of ecosystem services of fishponds under different management regimes on the scale from intensive to extensive production fishpond

Source: Author's own elaboration

been confirmed through the analysis of management plans for fishponds located within protected areas. The principles of their management differ from those of ordinary fishponds mainly in restrictions on fish stocking density, feeding, and fertilisation. However, they partially fall within the same general management category as ponds located outside protected areas, partially are low-intensively managed.

It is important to note that targeted multifunctional management is highly unlikely in practice. This is primarily because it reduces farmers' profits while simultaneously increasing their costs, with no financial mechanism in place to offset both impacts. Addressing this challenge requires a combination of knowledge and coordinated actions, including:

- i) Identifying and aligning management practices with the ecosystem services most valued by society.
- ii) Designing and implementing strategies that create synergies among multiple ecosystem services to maximise overall benefits.
- iii) Developing a mix of market-based mechanisms and subsidies to compensate for the financial shortfalls associated with multifunctional management.
- iv) This integrated approach can help bridge the gap between ecological sustainability and economic viability.

Valuation of ecosystem services of ponds. Non-production values of ponds are generally not subject to direct market transactions; they create significant and most often freely available values but do not directly increase the income of pond owners. On the contrary, they are often the cause of certain burdens and limitations on fishing production, which in extreme cases can lead to the loss of market value of pond farming facilities. Social values, which are

difficult to capture, are associated with enriching and improving the quality of life of entire societies as well as individuals due to the existence of the resource. For example, a well-managed multifunctional pond complex that is attractive to fishermen, wildlife enthusiasts, and cultural tradition lovers, while generating income for fishers and pond owners, will simultaneously contribute to improving the quality of life and well-being of the general public.

Common methods for assessing ecosystem services include models, matrix scoring, and questionnaires (Turner et al. 2016). These approaches are commonly (e.g. Landuyt et al. 2014) employed to evaluate the total economic value of ponds, which encompasses three main categories of value:

(i) direct use values, derived from the current or potential use of ponds for commercial purposes such as aquaculture or irrigation,

(ii) indirect use values, stemming from the ecological functions of ponds, such as water retention, climate regulation, sediment control, and biodiversity support,

(iii) non-use values, often referred to as cultural values, based on social, aesthetic, and symbolic significance. In the context of aquaculture, including fishponds, various economic valuation methods are utilised to estimate these values. The most common techniques include replacement cost analysis, which estimates the cost of replacing ecosystem services if they were lost; direct market valuation, which measures the financial value of goods produced by ponds; and production function analysis, which evaluates the contribution of ponds to broader production systems (Weitzman 2019).

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For the purpose of this study, we chose the methodology of the opportunity cost of foregone profits, based on a review of the literature on possible approaches. This methodology values ecosystem services based on the economic profits sacrificed due to more sustainable management or handling in the affected area. Specifically, we divided the studied ponds into two groups based on their management practices: conventionally managed ponds and ponds located in protected areas where management is regulated and restricted to ecological practices (in further text referred to as 'protected fishponds'/'conventional fishponds'). Ponds in protected areas produce a higher level of ecosystem services, the societal value of which is determined by the foregone profits (lower yields and higher costs due to regulated management) of the fisheries operating on these ponds. The opportunity cost method is a widely recognised approach for valuing ecosystem services by quantifying the economic benefits forfeited when an area is managed for conservation instead of alternative, potentially more profitable uses. This approach has been used in various studies to estimate the value of ecosystem services by considering the costs associated with restricting land use to preserve ecosystem functions. Apart from the others, Ickowitz et al. (2017) analysed the opportunity costs for smallholders by comparing potential profits from conventional agricultural practices with those under conservation commitments, highlighting economic trade-offs faced by smallholders in different tropical regions.

Similarly, Silva et al. (2019) assessed the economic costs of preserving the Brazilian Amazon rainforest by calculating foregone profits from agricultural activities that could otherwise occur in forested areas, providing a clear estimate of conservation costs. Ruijs (2017) broadly used the opportunity cost approach to value ecosystem services, analysing trade-offs between different land uses and the associated economic impacts of conservation efforts. By applying this methodology to the case study involving fishponds, we quantify the societal value of ecosystem services provided by ecologically managed ponds through the calculation of foregone profits due to ecological restrictions. This approach enables a clear comparison between the economic benefits of conventional and ecological management, underscoring the true value of ecosystem services in monetary terms. The opportunity cost method provides a robust framework for valuing ecosystem services, capturing the economic trade-offs associated with different land-use deci-

sions, and informing policy decisions that balance economic development with conservation goals (Ickowitz et al. 2017; Silva et al. 2019).

Monetary assessment of the difference in ecosystem services production between conventionally and ecologically managed ponds. To verify that the selected ponds represent the two management categories and differ significantly in variability, we apply a two-factor *F*-test for variance comparison. This test assesses whether economic outcomes per hectare vary significantly between ponds in environmentally protected areas and conventionally managed ponds. We compare the *F*-value to the critical value from the *F*-distribution at a significance level of $\alpha = 0.05$. If the *P*-value is below 0.05, we reject the null hypothesis, confirming a statistically significant difference in variance.

To determine the economic value of the difference in ecosystem service production between conventionally and ecologically managed ponds, the primary variable chosen is the difference in average profit per hectare between the two groups of ponds, which is calculated using the following formula:

$$\Delta \frac{\bar{P}}{ha} = \left(\frac{1}{t} \sum_{k=1}^t \left(\sum_{j=1}^i \frac{Pcon_{j,k}}{ha_{con_{j,k}}} \right) - \frac{1}{t} \sum_{k=1}^t \left(\sum_{j=1}^i \frac{Peco_{j,k}}{ha_{eco_{j,k}}} \right) \right) \quad (1)$$

where: $\Delta \frac{\bar{P}}{ha}$ – the difference in average profit per hectare between the two groups of ponds; $Pcon_{j,k}$ – the profit from the conventionally managed j^{th} pond in year k ; $ha_{con_{j,k}}$ – the area of the conventionally managed j^{th} pond in year k ; $Peco_{j,k}$ – the profit from the ecologically managed j^{th} pond in year k ; $ha_{eco_{j,k}}$ – the area of the ecologically managed j^{th} pond in year k .

The final value represents the monetary difference in profit per hectare between conventionally managed and ecologically managed ponds, indicating how much more (in currency per hectare) conventional ponds earn compared to protected ponds.

In the calculation of profit (both $Peco_{j,k}$ and $Pcon_{j,k}$), the Equations (2 and 3) consider only those revenues and costs whose amounts are dependent on the management method. These costs include expenses for fish stock, feed, and fertilisation, which can be termed as direct costs in economic terminology. Similarly, revenues include only the sales of fish, calculated as the physical production of the ponds in tons multiplied by the price per ton of fish according to the different species. The prices used for revenue calculations are standardised across all fisheries to avoid the influence of varying pricing policies on the valuation of ecosystem services.

$$Pcon_{j,k} = Rcon_{j,k} - DCcon_{j,k} \quad (2)$$

where: $Pcon_{j,k}$ – the profit from the conventionally managed j^{th} pond in year k ; $Rcon_{j,k}$ – the revenue from the conventionally managed j^{th} pond in year k ; $DCcon_{j,k}$ – the direct costs on the conventionally managed j^{th} pond in year k .

$$Peco_{j,k} = Reco_{j,k} - DCeco_{j,k} \quad (3)$$

where: $Peco_{j,k}$ – the profit from the ecologically managed j^{th} pond in year k ; $Reco_{j,k}$ – the revenue from the ecologically managed j^{th} pond in year k ; $DCeco_{j,k}$ – the direct costs on the ecologically managed j^{th} pond in year k .

The advantage is that individual fisheries maintain so-called production cards for each pond separately in their internal accounting, and these production cards contain the necessary information. Thus, it is not necessary to retroactively calculate direct costs from the overall accounting. Other costs of the fisheries, such as wages, depreciation etc., which are characterised as indirect costs, are not included in the calculation because the research focuses on the impact of the difference in management methods (conventional vs. protected) on the ecosystem services of the ponds, not on the efficiency of the processes within the fisheries. Our results should not be influenced by factors such as accounting performance, quality of management, energy prices, or the number and wages of employees. These are factors that characterise the economic process of the fishery, not the method of ponds management, which is the subject of this research. Since the objective is to determine the difference in profits between two groups of ponds that differ in management methods, indirect costs per hectare, which are not influenced by the management method, will cancel each other out when calculating the difference. Therefore, it is not necessary to ascertain their value for inclusion in the Equation (1). The data from the production cards of individual fisheries were originally reported in CZK. For the purposes of this study, they were converted to EUR using the exchange rate of 24.94 CZK/EUR, as published by the Czech National Bank on May 22, 2025.

The result of Equation (1) represents the cost incurred by a fishery when it opts for (or is compelled to adopt) protective management practices, thereby forgoing the opportunities associated with conventional management. This cost is incurred annually, meaning that the total value of this difference throughout the entire lifespan of the pond corresponds to the

cumulative sum of discounted differences in average profits per hectare. This, in turn, reflects the monetised expression of the difference in the present value of ecosystem services (PV ES) provided by conventional versus protected ponds. To calculate the economic value of this difference, a standard financial mathematics formula used for annuity payments can be applied (Chmelíková 2008; Brealey et al. 2023):

$$PV ES = \Delta \frac{\bar{P}}{ha} / i \times \left\{ 1 - \frac{1}{(1+i)^n} \right\} \quad (4)$$

where: $PV ES$ – the difference in the present value of the price of ecosystem services produced by a conventional and a protected fishpond; $\Delta \frac{\bar{P}}{ha}$ – the difference in average profit per hectare between the two groups of ponds; i – discount factor (10-year CNB repo rate); n – number of calculation periods.

RESULTS

To address our research questions – what the difference in ecosystem service production between conventionally and ecologically managed (protected) ponds is, and how can this difference be monetarily assessed – we divided our analysis into two key steps. In the first step, we evaluated the delivery of ecosystem services for individual ponds and identified the differences in service production between conventionally and ecologically managed ponds. This involved a detailed assessment of key services, such as fish production, biodiversity conservation, recreation, and regulatory functions, to capture the scope and scale of these differences. In the second step, we conducted a monetary valuation of these differences. By applying appropriate valuation methods, we quantified the economic implications of varying management practices, providing insights into the trade-offs and benefits associated with each approach. This two-step process allowed for a comprehensive understanding of the relationship between management regimes and the value of the ecosystem services they generate.

Assessment of ecosystem service delivery under different management regimes. The assessment of ecosystem services was conducted in three stages. First, resources for ecosystem services were mapped using the Consolidated Ecosystem Layer (KVES) (Vačkář et al. 2019) and expert estimates of the potential for economic utilisation of ecosystem services for different ecosystem types (Schneider et al. 2024; Zourková et al. 2024). Second, the potential for eco-

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nomic use of ecosystem services was evaluated for individual pond types. Finally, the overall potential for economic utilisation of ecosystem services was determined for each fishpond.

The mapping process utilised the Consolidated Ecosystem Layer (KVES), developed by CzechGlobe, in combination with publicly available orthophoto maps. Ecosystem service resources were described at the level of Land Use/Land Cover (LULC) types, such as arable land, natural and artificial water bodies, meadows, and pastures. Figure 3 presents an example of a map layer showing ecosystem types based on KVES, used as a basis for assessing ecosystem services. On the left side of the figure is an example of a conventionally managed pond focusing on fish production, while the right side shows a representative of the protected pond group, primarily aiming at biodiversity conservation. Figure 3 also highlights that the mapping did not only cover the pond areas but also adjacent and interconnected terrestrial ecosystem types. These ecosystems form a 'natural' continuous landscape mosaic with the ponds, making it logical to map and evaluate their ecosystem services as well. However, the inclusion of substantial terrestrial areas (especially forest ecosystems) significantly influences the overall ecosystem service potential attributed to the ponds.

The differences in the potential for providing ecosystem services between production fishponds and fishponds under nature protection are primarily driven by variations in the composition of ecosystem types and their current characteristics. For simplicity, this analysis focuses solely on differences arising from the composition of ecosystem types. The results of ecosystem type mapping are presented in Figure 3. The left side of Figure 3 represents an example of a production fishpond (with some support for biodiversity functions), while the right side represents an example of a fishpond under nature protection and a regulated management system. Although the conventionally managed fishpond is larger, both ponds fall into the same size category.

The mapped segments were assigned a point value of the importance of individual types of KVES ecosystems for the provision, use and management of ES in current conditions in the Czech Republic as follows (Schneider et al. 2024; Zourková et al. 2024): H – main ecosystem service, almost always managed (usually the main goal of management), used (protection declared by law, subject of trade, intensity of visitation), value 4; V – secondary ecosystem service, almost always used (consumed), but not always the goal of management, value 3; O – occasional, the ecosystem has the potential

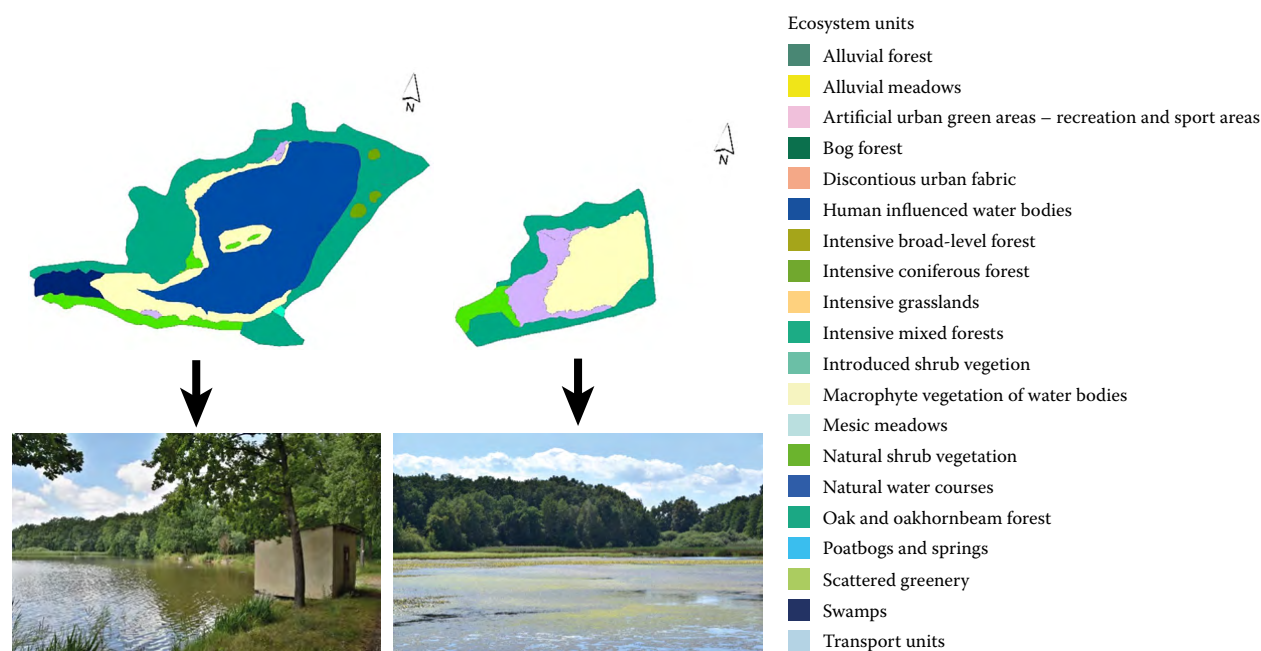


Figure 3. Ecosystem units of KVES – example of conventionally managed fishpond (left) and ecologically managed fishpond (right)

KVES – Consolidated Ecosystem Layer

Source: Author's own elaboration

for its use (produces a function), but is used in a targeted manner rather exceptionally, or often, but on a negligible scale, value 2; T – theoretical, the ecosystem has the potential for the use of ES, but is not so used (or was used in the past), value 1; unused or unmanaged ecosystem services – value 0, unlabelled.

Figure 4 presents the summary value of the importance of individual types of KVES ecosystems for the provision, use and management of ES.

The mapping highlights two key differences. First, the water body of the fishpond on the left (conventional) is classified as an artificial water body, while the water body of the fishpond on the right (ecologically managed) consists of macrophyte vegetation characteristic of stagnant waters. Second, there is a notable difference in the diversity and area of ecosystems associated with water and ponds, as well as the size of their mosaic landscapes. From the perspective of usable production, forest ecosystems have greater potential than water bodies. Similarly, open water bodies offer more or more intensive ecosystem services than areas dominated by macrophyte vegetation in stagnant waters, although the difference is not substantial. Notably, the production fishpond on the left includes both types of ecosystems – open water and macrophyte vegetation – whereas the protected fishpond on the right consists solely of macrophyte vegetation. These distinctions underline the significant role of ecosystem type composition and diversity in determining the potential of fishponds to provide ecosystem services, whether the focus is on production or conservation goals.

Monetary assessment of difference in ecosystem services between ecologically and conventionally

managed fishponds. To assess the disparity in ecosystem service values between two distinct management types of fishponds, data from the production cards of the fishponds within the research sample were utilised. Given that these fishponds are managed by various fish farms and the production cards represent confidential economic data, anonymisation of the pond sample was necessary. Fishponds were assigned abbreviations based on alphabetical letters rather than their actual names. To differentiate management approaches, conventionally managed fishponds are indexed as 'con' and ecologically managed (protected) fishponds as 'eco'. Table 1 presents the observed values of profit per hectare for each fishpond in the study sample.

Table 2 delineates the descriptive statistics of the research sample regarding the economic activities of each fishpond, with economic results monitored over a decade from 2013 to 2022. The primary variable measured is the profit value, calculated according to Equations (2 and 3), and normalised per hectare of each fishpond's area.

A two-sample *F*-test was conducted to compare the variances between the datasets $Peco_{j,k}/ha_{j,k}$ and $Pcon_{j,k}/ha_{j,k}$. The computed *F*-statistic was 0.2569, with degrees of freedom 65 and 65. The resulting *P*-value was 5.487×10^{-8} which is below the significance level (0.05), leading to the rejection of the null hypothesis. This indicates that the variances of the two groups are significantly different. This demonstrates that the variance in the two datasets is not equal, suggesting greater variability in one group compared to the other. Based on these findings, there is a statistically significant difference in variance between $Peco_{j,k}/ha_{j,k}$ and $Pcon_{j,k}/ha_{j,k}$.



Figure 4. Total value of ecosystem services potential – example of conventionally managed fishpond (left) and ecologically managed fishpond (right)

ES – ecosystem services

Data source: Author's own elaboration

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Table 1. Profit per hectare of ponds during the observing period 2013–2022 (EUR)

$P(eco/con)_{j,k} / ha_{j,k}$	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
A_{eco}	n/a	n/a	n/a	553	488	579	346	207	320	390
B_{eco}	n/a	n/a	n/a	204	162	1 718	767	–436	1 616	258
C_{eco}	n/a	n/a	n/a	530	482	557	–98	–109	76	70
D_{eco}	n/a	n/a	n/a	–262	1 189	–362	569	–209	1 228	n/a
E_{eco}	–946	434	294	–315	219	–371	315	–112	35	n/a
F_{eco}	722	494	654	882	749	350	349	28	–85	186
G_{eco}	–662	1 760	794	478	588	346	–65	216	485	–15
H_{eco}	992	891	–1 023	577	–1 352	1 480	–366	–200	95	–27
A_{con}	205	340	126	1 204	405	844	1 401	988	929	1 121
B_{con}	–445	981	–365	–300	895	1 439	473	–443	665	327
C_{con}	n/a	n/a	n/a	931	1 024	454	729	–795	2 863	–1 227
D_{con}	n/a	n/a	n/a	987	–662	–226	938	–544	2 165	–783
E_{con}	n/a	n/a	n/a	–795	2 903	–639	1 290	–259	1 816	–877
F_{con}	n/a	3 884	–587	1 597	–393	–263	2 530	1 023	–396	n/a
G_{con}	–1 295	843	–2 454	2 419	–719	–833	–1 658	2 033	–1 236	n/a
H_{con}	n/a	76	–154	195	1 393	534	378	533	956	n/a

n/a – not assigned; A-H – fish pond codes; *eco* – ecologically managed; *con* – conventionally managed

Source: Author's own elaboration based on the data from production cards

Table 2. Descriptive statistics – variable $P(con/eco)_{j,k} / ha_{j,k}$ (EUR)

$P(con/eco)_{j,k} / ha_{j,k}$	Mean	Med.	Min.	Max.	SD	<i>n</i>
A_{eco}	413	390	207	577	135	7
B_{eco}	613	258	–437	1 716	802	7
C_{eco}	215	76	–109	557	297	7
D_{eco}	359	180	–362	1 227	738	6
E_{eco}	–50	35	–946	433	441	9
F_{eco}	433	421	–85	882	324	10
G_{eco}	393	413	–662	1 760	634	10
H_{eco}	107	34	–1 351	1 480	898	10
A_{con}	758	886	126	1 399	453	10
B_{con}	323	400	–445	1 439	682	10
C_{con}	569	730	–1 227	2 863	1 335	7
D_{con}	268	–227	–782	2 165	1 115	7
E_{con}	493	–259	–878	2 903	1 504	7
F_{con}	926	380	–585	3 885	1 648	8
G_{con}	–322	–834	–2 454	2 418	1 692	9
H_{con}	489	457	–154	1 391	497	8

A-H – fish pond codes; *eco* – ecologically managed; *con* – conventionally managed

Source: Author's own elaboration based on the data from production cards

After substituting the observed economic results for individual fishponds, represented as P_{con} and P_{eco} for the years 2013 to 2022, into Equation (1), the average difference in profit per hectare between conventionally and ecologically managed fishponds was calculated. The result for the analysed set of fishponds was determined to be EUR 142 per hectare and year. This value represents the opportunity cost to the fish farm, which, when choosing (or being compelled) to switch to protective management, forgoes the opportunities associated with conventional management. This cost recurs annually, so the total value of this difference is equal to the cumulative sum of discounted differences in average profits per hectare. This corresponds to the monetised expression of the difference in the present value of ecosystem services provided by conventional versus protected fishponds. The period over which this difference is realised corresponds to the duration of protective management. Following the approach of Costanza et al. (1997), this study assumes a 10-year time horizon to estimate the total value of differences in ecosystem services provided by s under different management practices. The discount factor used in this study is based on the ten-year repo rate set by the Czech National Bank. The calculation of the present value of future opportunity costs is performed according to Equation (4).

$$PV\ ES = 142 / 0.0182 \times \left\{ 1 - \frac{1}{(1 + 0.0182)^{10}} \right\} \quad (5)$$

$$PV\ ES = 1\ 288\ EUR\ per\ hec\ tar$$

After applying the formula, the present value of foregone profits per hectare for fisheries managed ecologically, compared to conventional management, amounts to EUR 1 288. This value also represents the worth of the ecosystem services that ecologically managed fishponds are capable of producing per hectare, in contrast to conventionally managed fishponds.

The results highlight the economic and ecological trade-offs between conventionally and ecologically managed fishponds. The study quantifies the differences in the provision of ecosystem services, with the monetary valuation indicating that the present value (PV) of ecosystem services represents the cost of producing non-production functions, such as biodiversity conservation and ecosystem regulation, in fishponds managed under ecological regimes compared to conventional management. This difference was analysed in two steps: first, by assessing ecosystem service delivery for each fishpond and identifying variations be-

tween management types, and second, by monetising the opportunity cost to fish farms of adopting ecological practices. The analysis revealed that the average annual difference in profit per hectare between the two management regimes was EUR 142, representing the annual opportunity cost incurred by transitioning to ecological management. Using a 10-year time horizon and a discount rate based on the Czech National Bank's 10-year repo rate, the present value of this cost was calculated to be EUR 1 288 per hectare. This figure corresponds to the monetised value of additional ecosystem services produced by ecologically managed ponds compared to conventionally managed ones.

DISCUSSION

This study demonstrates the significant differences in ecosystem service provision between conventionally and ecologically managed fishponds in the South Bohemian Region of the Czech Republic. Ecologically managed fishponds deliver enhanced ecosystem services, such as biodiversity conservation, water purification, and cultural benefits, but this comes at a financial trade-off reflected in reduced profits for fish farmers. The economic analysis revealed an average annual profit difference of EUR 142 per hectare, representing the opportunity cost of ecological management. Over a 10-year period, this results in a present value of EUR 1 288 per hectare, effectively quantifying the additional value of ecosystem services provided by ecologically managed fishponds compared to conventionally managed ones.

Our findings align with global studies that emphasise the broader ecosystem benefits of sustainable management practices. For instance, Landuyt et al. (2014) highlighted the synergies between biodiversity conservation and ecosystem service delivery in ponds managed for ecological balance, a conclusion supported by our observations of ecologically managed fishponds. Similarly, Hill et al. (2021) underlined the importance of ponds as aquatic biodiversity hotspots, particularly in modified landscapes, which resonates with the biodiversity functions evident in the South Bohemian ecologically managed fishponds. Nevertheless, the opportunity cost calculated in this study underscores a challenge not always explicitly addressed in prior research. While Costanza et al. (1997) emphasised the high intrinsic value of ecosystem services globally, they did not account for the specific economic burdens on stakeholders, such as fish farmers, transitioning to more sustainable practices. Our findings

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build on this by providing a clear monetary assessment of these trade-offs, contributing a practical dimension to theoretical evaluations.

Moreover, Hambäck et al. (2023) explored the multifunctionality of wetland systems, noting that management strategies must balance production and conservation goals to maximise benefits. Our results confirm this observation, illustrating how semi-intensive management can serve as a middle ground. In contrast to studies such as Silva et al. (2019) that focused on the broader societal value of conservation, our research underscores the economic pressures placed directly on individual stakeholders, offering a complementary perspective. Fishponds, as multifunctional ecosystems, hold unique economic and ecological importance. While conventionally managed fishponds excel in fish production, ecologically managed fishponds provide significant non-production functions, including biodiversity conservation and ecosystem regulation. On the other hand, an ecological way of farming, especially a reduced stocking of farmed fish species, can also bring many problems that are not so significant in semi-intensive ponds: the spread of invasive fish species. These findings align with Popp et al. (2019), who emphasised the potential for multifunctional pond farms to contribute to environmental and social well-being while supporting sustainable production. Our analysis suggests that the transition to such practices requires economic incentives to offset opportunity costs. The findings emphasise the critical role of fishponds in landscape management, not only as productive units but also as contributors to broader environmental and social well-being. By valuing ecosystem services monetarily, this study bridges the gap between theoretical and applied research, underscoring the importance of integrating ecological functions into economic decision-making. This approach provides a foundation for policies that support sustainable fishpond management while addressing the trade-offs between economic viability and environmental conservation. Our work reinforces the conclusions of Ickowitz et al. (2017) and Ruijs (2017), who argued for the necessity of balancing conservation goals with economic realities through targeted policies and incentives.

Limitations of the study that should be addressed here include firstly, the use of opportunity cost methodology identifying only the difference in the value of ecosystem services between ecologically and conventionally managed fishponds. Unlike previous studies that focused on monetising the total value of ecosystem services, this approach captures

only a partial aspect. Nevertheless, the value of this difference can serve as a basis for compensating fish farmers for maintaining non-productive fishpond functions, such as biodiversity conservation or ecosystem regulation. Secondly, although the sample of 16 fishponds and the 10-year dataset provided a solid foundation for analysis, a larger sample would be necessary for broader applicability of the findings. Such expansion would enhance the representativeness of conclusions and allow for more precise models of compensation mechanisms.

Future research could focus on broader monetisation of the total value of ecosystem services rather than only differences between management regimes. This would provide a more comprehensive understanding of the environmental and societal benefits of fishponds. Another important direction could involve expanding the sample size to include fishponds from different regions or climatic zones, which would improve the generalisability and comparability of results. Research should also explore interactions and trade-offs between individual ecosystem services, such as biodiversity conservation, carbon sequestration, and recreational services, within multifunctional management strategies. Additionally, future studies should investigate financial mechanisms, such as subsidies or market-based instruments, to compensate fish farmers for the costs of ecological management. This would facilitate the practical implementation of sustainable approaches. A significant area for future research could also involve examining the long-term dynamics of ecosystem service values and their evolution over time under different management regimes, climate change impacts, or market shifts. This would provide a deeper understanding of the sustainability of ecological practices and their effects on ecosystem resilience.

CONCLUSION

This study provides a comprehensive analysis of the differences in ecosystem service provision between ecologically and conventionally managed fishponds in the South Bohemian region of the Czech Republic. By evaluating 16 fishponds over a decade, the research highlights the trade-offs between biodiversity conservation and fish production, quantifying the economic implications of ecological management through the opportunity cost of foregone profits methodology. The results demonstrate that ecologically managed fishponds generate enhanced ecosystem services, including biodiversity conservation and water reten-

tion and flood regulation, but these benefits come at a cost of reduced financial returns for fish farmers. The findings reveal the critical role of ecologically managed fishponds in providing societal benefits beyond immediate economic gains, emphasising their importance in biodiversity conservation and sustainable landscape management. However, the study also identifies limitations, such as the restricted sample size and focus on the differential value rather than the total value of ecosystem services. These constraints suggest a need for further research to capture a more holistic understanding of ecosystem service dynamics and expand the applicability of findings.

The findings of this research underscore the necessity of financial mechanisms to support fish farmers transitioning to ecological management practices. Implementing subsidies, market-based incentives, or other compensation schemes could help mitigate the opportunity costs associated with environmentally friendly fishpond management, making sustainable practices more economically viable. Additionally, the study emphasises the need to integrate multifunctionality into fishpond management strategies, ensuring a balanced approach that maintains fish production while enhancing ecosystem services to align with both societal and environmental objectives. To strengthen the robustness of these findings and their applicability in subsidy policies and compensation schemes, it would be beneficial to replicate the methodology on a larger sample of ponds. Expanding the dataset could enhance the reliability of the results, allowing for more precise models of financial support and ensuring that compensation mechanisms effectively reflect the economic trade-offs of ecosystem-friendly fishpond management.

In conclusion, this study bridges the gap between ecological and economic priorities, offering valuable insights for policymakers, stakeholders, and researchers. By valuing ecosystem services monetarily, it provides a foundation for informed decision-making that reconciles economic viability with environmental sustainability in the management of pond ecosystems. Future research should focus on scaling up analyses, exploring broader geographical regions, and developing actionable strategies to enhance the resilience and multifunctionality of fishpond landscapes.

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