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Article

Payment for Ecosystem Services: An Efficient Approach to Reduce Eutrophication?

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Abstract: The CPES (Channel Payments for Ecosystem Services) project developed PES schemes remunerating farmers for their activities in improving water quality by reducing the emissions of nutrients (both nitrogen and phosphorus) or erosion from agricultural activities. Catchment-wide approaches were tested in six case studies, and ecology, hydrogeology, agroecology, law, and farming expertise was combined. Collaborations were established with farmers, their associations, chambers of agriculture, and local and regional stakeholders. One case study concerned Lac au Duc (Brittany), a reservoir suffering from recurrent cyanobacterial blooms. Curative actions to control cyanobacteria had limited success. The main sources of excess P entering the lake were of farming origin but varied between the sub-catchments according to hydrogeological characteristics and agricultural practices. Long-term prevention possibilities to ameliorate agricultural practices and their costs were developed with the farmers and included permanent cover or anti-erosive hedges. During the project, PESs were successfully applied for ground water protection by the water supply companies as drinking water protection has a strong business case to preserve this ecosystem service. For recreational or multi-purpose lakes and reservoirs, it remains difficult to find financing to meet the monetary requirements to address farmer's transition to ameliorate land management.

Keywords: cyanobacteria; agriculture; phosphor; water quality; hydrogen peroxide



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1. Introduction

Agriculture has traditionally focused on ensuring food quality and quantity as well as production of other raw material for consumption by a growing world population, respectively, due to the expenditure of more resources for a higher living standard. This agricultural intensification to maximize crop and livestock production during recent decades was achieved with the help of agrochemicals (fertilizers and crop protectants) and an intensive use of agro-techniques, thus creating the problem of pesticide residues, soil degradation, and soil erosion, as well as the eutrophication of adjacent water bodies [1]. Environmental degradation due to agricultural production has long been perceived as an unavoidable trade-off until its consequences of decreased soil quality and biodiversity, loss of water regulation, and climate impact became alarmingly concerning [2]. Runoff and erosion pose major problems, which urgently need actions, as up to 75 billion tons of soil are lost from arable land world-wide on average per year [3]. Congruently, the water quality of surface- and groundwaters and of marine ecosystems have greatly decreased as those are the receptors of nutrient-loaded runoff with a limited capacity for auto-purification [4,5].

Improving water quality thus remains a challenge in numerous countries despite it being directly connected to human health and recreation [6], and reducing excess nutrients (phosphorus, P and nitrogen, N) is one of the main factors. Leaching N is threatening freshwater reserves intended for drinking water production if it exceeds the limits for

nitrate and nitrite (50 resp 3 mgL^{-1}) set by the WHO, due to the possibility of causing methemoglobinemia in infants [7]. At the marine site, in particular in bays of coastal waters, excess N is the cause of mass developments of sea weed (e.g., from the genus *Ulva*), the so-called green tides [8,9]. In freshwater lakes and reservoirs, P-eutrophication is the main driving factor causing cyanobacterial blooms, with the additional impact of N [10–13]. Addressing point sources of P through the purification of industrial and household waste waters and the ban of P in detergents in the late 1970s in Europe and other places world-wide resulted in the visible amelioration of eutrophicated lakes [14–16]. Nowadays, eutrophication is again increasing slowly but steadily with P from agricultural non-point sources, and alongside this, cyanobacterial blooms are on the rise again [11,17]. World-wide, these mass developments of cyanobacteria outcompete eucaryotic phytoplankton, impairing the ecological quality of surface waters, and besides producing bioactive, toxic, or allergen compounds, they pose a risk to human and animal health [18–20]. Human health risks from the variety of cyanobacterial compounds include genotoxicity, tumor promotion, and hepato- and neurotoxicity in acute or chronic exposure [19]. Recently, an increased risk of intestinal injury via chronic exposure to environmental levels was evidenced in mice [21]. Therefore, upon a certain cyanobacterial density, recreational activities, but also crop-irrigation or fishing, are regulated or banned in many countries, and costs for drinking water purification are increased or abstraction is interrupted, as per [22] and the references therein.

Current approaches to control cyanobacterial blooms include curative actions such as the application of algicides (organic pesticides or copper sulfate, both with increasing restrictions, and hydrogen peroxide) or of P-binding and flocculating agents in combination with sediment capping, the oxygenation of deep lakes to avoid P-remobilization, an ultrasound if lake bathymetry is sufficiently deep, and the installation of wetlands in order to reduce P-entry into the lake [23–25]. In cases of very dense cyanobacterial blooms, the biomass is removed mechanically (salvage), is subsequently dewatered or dried and, treated (e.g., fermented or combusted), utilized as a biofuel, or discharged into landfills, as per [26] and the references therein. Unarguably, the best lake restoration would reduce the diffuse P-entrance from the catchment, and hence tackle it at the source, e.g., [14,27,28]. This is possible by reducing the application of fertilizer to the necessary amount for soil and plants [29] and by reducing its erosion via increased soil contact or creating barriers [27]. The relatively high financial burdens that come along with ameliorating agricultural management or eventual agricultural losses need compensation.

A new system of financial incentives, the eco-schemes, have been introduced to encourage farmers to fully commit to the ecological transition in the new Common Agricultural Policy [30]. The new eco-schemes establish a clear link between good agricultural practices and nature-based solutions for producing ecosystem services that have significant positive impacts on society. One of these eco-schemes are the Payment for Ecosystem Services (PESs) where farmers are paid to ameliorate their agricultural practices that would in turn improve ecosystem services such as water quality, biodiversity, climate mitigation, and soil sustainability. In contrast to the above-mentioned traditional methods controlling cyanobacterial development within a water body, PESs aim to control the eutrophication of a water body by analyzing its sources in the catchment (merely agricultural) and reducing losses from agricultural plots. However, designing a PES is not straightforward. It involves the creation of a new (market-based) institution in which the beneficiaries of ecosystem services are prepared to pay for the providers of those services. The multiplicity of beneficiaries, due to the number of ecosystem services provided by lakes, and the multiplicity of providers, mainly represented by farmers, offer potential for the design of PES schemes [31]. While private or public water institutions ratify the responsibility of drinking water resources, for recreational waters, however, like Lac au Duc, private investors who were not directly linked to drinking water production were the focus for private-by-private PES schemes. PES payments designed and financed solely through private funding evidenced benefits in terms of flexibility in the payment and allocation process, as they were based purely on

private contracts. Farmers could be paid according to the implementation of the number of interventions agreed in the catchment area, or the evaluation of the outcome according to evaluation schemes.

Throughout Europe, farmers who participate in actions reducing the environmental impact of agriculture are equally interested in the ecological improvements as in the financial offset mechanisms paid by different agri-ecological schemes [32]. This emphasizes the close connection between the economic and environmental role of farmers in producing in a sustainable way [33]. More than 80% of the participants in a questionnaire concerning the acceptance of practices in Michigan would apply pesticides only after the detection of the pest instead of as a preventive action, and would reduce tillage (e.g., chisel ploughing), thus lowering the amount and ameliorating the quality of the water draining from a plot [34].

Soil functions, including agricultural soil functions, by far exceeds crop and material production. Soil ecosystem services include its water-holding, water-regulating, and water purification capacities, carbon sequestration and storage, support for biodiversity including pollination and pest mitigation, regulator and recycling of P and N, and air quality, e.g., [1,35]. Within the given ecological structures and hydrogeological characteristics, agricultural management can strongly influence these ecosystem services.

Concerning water quality, erosion and nutrient loss from agricultural fields are both disadvantageous for the farmer, and are connected to eutrophication and to economical costs for drinking water purification, investments in lake or shoreline restoration, or losses for the tourism industry [36,37]. As agricultural practices can make a significant contribution to the control of erosion and runoff, the application of PESs to ensure water quality and quantity could provide a suitable tool [38]. A high level of farmer participation could have a significant impact on reducing the proliferation of cyanobacteria, if the control of runoffs in the PES plots covers the majority of the areas that emit the most effluent, while continuing to invest in curative measures.

Stakeholders' interests may differ, however, along with current urgent actions needed against the consequences of global change concerning the sequestration and storage of carbon, the preservation of biodiversity, or erosion and flood protection. A solution could be the development of actions which would serve more than one single ecosystem service, e.g., carbon sequestration, biodiversity, and water quality simultaneously through the implementation of hedgerows perpendicular to the downhill slope on a plot. This fact holds a high potential of synergies of joint actions, but conflicts are possible too due to the different resources needed of the catchment by its stakeholders. Unfortunately, difficulties in implementing PESs could also arise from natural processes due to their temporal variability, time needed for measurable results, non-linearity, and sometimes thresholds or tipping points [7]. For a catchment restoration, the interaction between environmental (lake and catchment) managers, community stakeholders and politicians, and the public is necessary to enable farmers to ameliorate their practices [33,39].

PES schemes highlight the importance of ecosystem services provided by aquatic ecosystems for the benefit of our societies and economic sectors and for the resilience of water catchment areas to climate change. These ecosystem services, considered as public goods, have been, and still are, under regulation by the environmental authorities, which so far has resulted in centralized contractual practices with standardized contracts (specifications) according to environmental assets and single, capped amounts to comply with European regulations.

Here, we tested whether PES schemes could be developed to increase the water quality of a reservoir, Lac au Duc, France, which is suffering from eutrophication and thus cyanobacterial blooms. We analyzed the ecological state of the lake, the P sources in the catchment, and the environmental costs (costs of non-action). We summarized the agricultural practices that would decrease erosion and nutrient loss from the fields with their evaluation plans and the required expenses; moreover, we modeled the costs of their implementation in connection with the P-reduction goal. The farmers' willingness to accept

these practices was analyzed as well as the investors' willingness to pay, and the conditions of private–private-based contracts were elaborated.

2. Environmental Analysis of the Study Site

One of the CPES pilots concerned the eutrophic reservoir Lac au Duc in Brittany, France, with its agriculturally dominated catchment from which the river Yvel drains most of its sub-basins into the reservoir (Figure 1A). Lac au Duc is a multi-purpose reservoir of 250 ha and 3.5 million m³ capacity with 3–5 m maximal depth and approximately 30–60 days' retention time. It is used for recreational activities and drinking water abstraction and is the main resource of drinking water supply for the district of Ploërmel with an average annual production of 2,500,000 m³ (information obtained from Syndicat Mixte du Grand Bassin de l'Oust, Ploërmel, France, 2018). Like many water bodies in Brittany and world-wide, Lac au Duc suffers from the recurrent development of dense cyanobacterial blooms in summer. In France, recreational lakes are monitored by regional health agencies, and exceeding a density threshold of 10⁶ cells/mL leads to a ban of swimming, boating, and fishing (https://baignades.sante.gouv.fr/baignades/editorial/fr/controle/critere_s.html, accessed on 1 June 2018). Cyanobacterial densities measured by the Agence Regionale des Santé Bretagne are depicted in Figure 1B, and shaded according to the different curative treatments over the years (communicated by the Syndicat Mixte du Grand Bassin de l'Oust, Ploërmel, France, 2018). The closing times of recreational activities concern the main touristic season in August, with economic consequences for the tourism industry. Moreover, due to the lack of sufficient ground water resources in Brittany, drinking water purification from this surface water becomes difficult and expensive, and a nearby river is relied on as a source. With the implementation of regulations concerning nitrogen output from the catchment, a reduction in N has already been achieved in Lac au Duc [40]. Despite the efforts in reducing P are measurable in the rivers of Brittany including the incoming river Yvel [41], it is not yet evident in the reservoir [40]. The river Yvel transports a yearly average load of 100 µg L⁻¹ P_{tot} of which 80% is particular-bound [42]. While this P load corresponds to a mediocre quality for the river (Guide EEE ESC 2019), it causes eutrophic to hypertrophic conditions in the reservoir [43–45]. The total P remained elevated with on average 0.1 ± 0.067 mg P L⁻¹ over the period studied [40]. Consequently, phytoplankton densities are high in Lac au Duc, with great inter-annual variations corresponding to the weather conditions but are homogenous throughout the reservoir [40]. Similar to the long-term observations (2007–2019), cyanobacteria dominated the planktonic community during the project phase (1.5 × 10⁶ cells mL⁻¹ in the late summer of 2018 and one order of magnitude less in the summer of 2019), whereas Chlorophytes dominated the eukaryotic phytoplankton community but reached only 72,000 cells mL⁻¹ in the summer of 2018. *Planktothrix agardhii* dominated until 2012, accompanied by *Microcystis* sp., and in recent years also by *Dolichospermum*, corresponding to the reduced N-load [40]. The determination of cyanobacteria was completed according to [46–48]. Due to this, the reservoir is classified as in poor ecological conditions. As the fish stock was in line with demand for both leisure (merely carp) or commercial fishing, an evaluation of the fish community would be disconnected from the eutrophication or cyanobacterial situation, and was not included in the study. Joint political and administrative (control) actions would be required to reduce fish stock, particularly benthic fish, and the use of bait for angling. Lac au Duc is, unfortunately, just one of many lakes world-wide suffering from cyanobacterial blooms [18]. For example, Lake Erie became infamously known for the shut-down of its drinking water supply for several days in 2014, concerning the whole city of Toledo, due to a cyanobacterial bloom event [27,49].

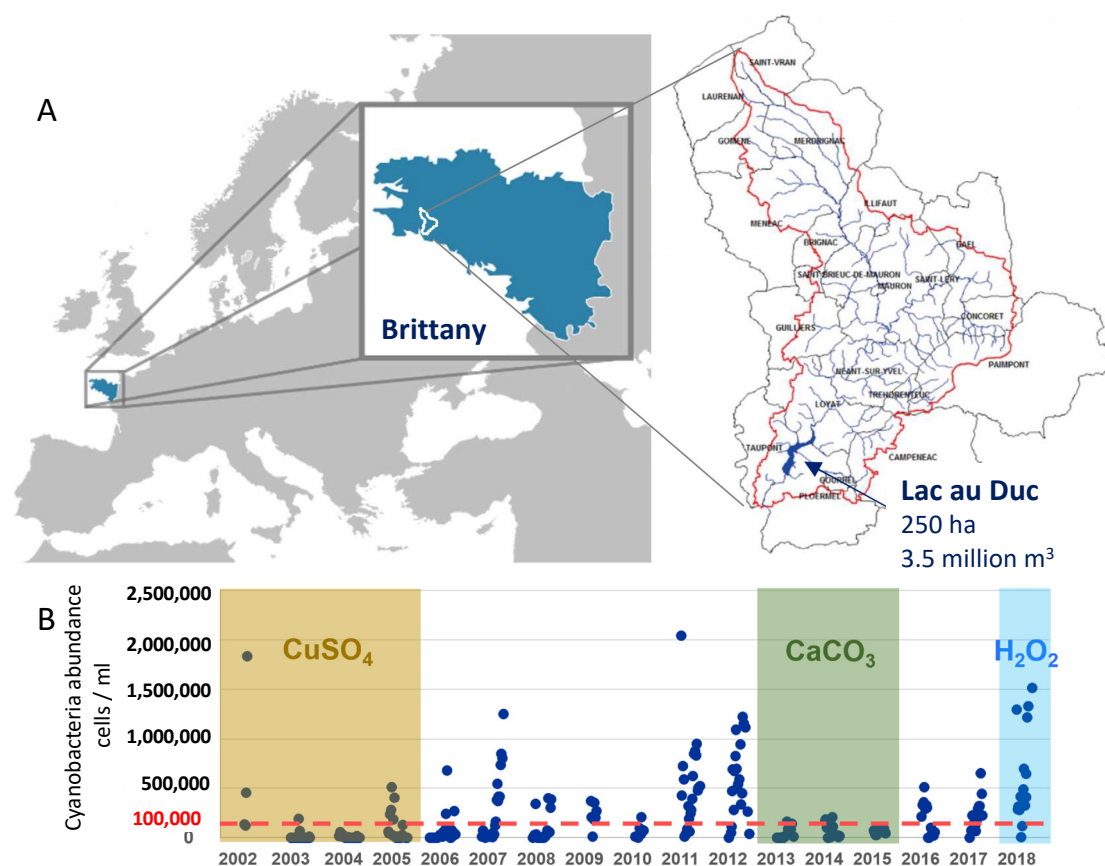


Figure 1. (A) Localization of Lac au Duc with its catchment in Brittany, France; (B) interannual dynamics of cyanobacteria abundance (cells/mL) in Lac au Duc and curative actions undertaken between 2002 and 2018 in the bathing zone of the reservoir. The red line indicates the alert-level and, depending on the content of microcystin-LR equivalents, the limit for bathing and other recreational activities.

3. Analysis of P Sources in the Catchment and Their Dependencies of Hydrogeological and Soil Characteristics as Well as Agricultural Practices

The catchment of Lac au Duc was merely agricultural as its main income source with cattle, pork, and crop production for 448 farms in 2018. Together, winter cereals and maize cover 54% of the area, grassland 21%, and forests 18%, with the remaining being built-up areas. The Luvisols and brown soils are generally shallow (less than 70 cm) and well drained, but are sometimes hydromorphic, leading to wetlands [43]. Without permanent cover, these fine soils are at a high risk of erosion.

The eight waste water treatment plants that empty into the river system of the Lac au Duc catchment were shown to contribute only 10% of the total P entering the lake [43]. In order to assess the possibility of targeting PESs at the areas with the highest emissions, the Lac au Duc catchment area was divided into 25 sub-catchments, at the outlets of which P_{tot} and PO_4 concentrations were monitored in 31 sampling campaigns between March 2018 and July 2019. Soil type, climate, and farming were similar in the sub-catchments, but landscape and spatial configuration as well as soil thickness were different. Concentrations and fluxes were significantly higher (by a factor of 1.5 on average) in the central and southern parts of the Lac au Duc catchment, compared to the northern part (Figure 2). This is consistent with thicker (and therefore perhaps more infiltrative) soils in the northern part compared with the central and southern parts of the basin where the soils were shallower and therefore probably more prone to P runoff [43]. Thus, targeting PESs aiming to reduce the diffusion of agricultural P emissions in the south-central part of the catchment area could have a maximum effect on reducing P flows at the lake inlet.

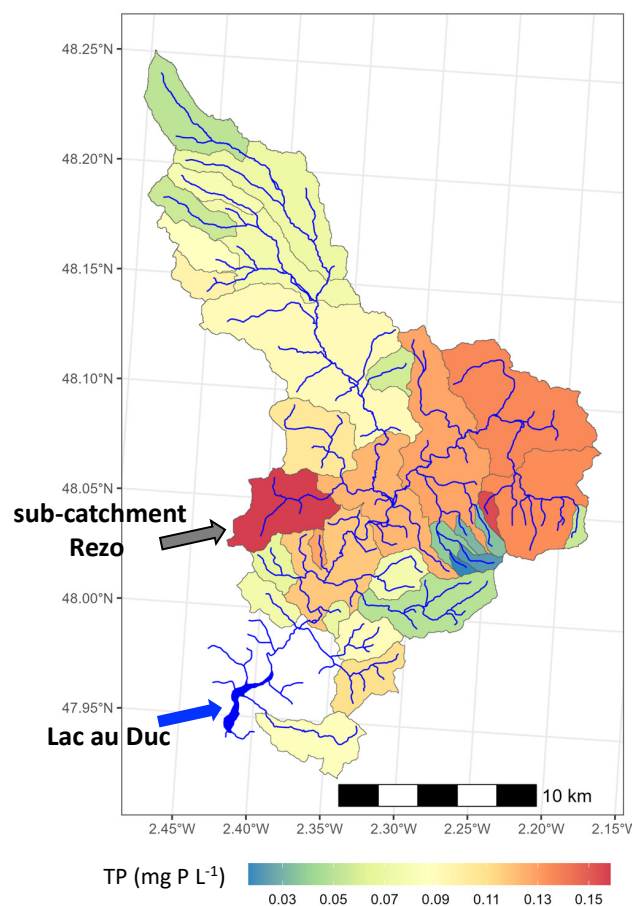


Figure 2. Distribution map of total phosphorus concentrations (weighted according to water flow) in the 25 sub-catchments making up the Lac au Duc catchment.

4. Curative Actions to Control Cyanobacterial Blooms

To control cyanobacterial blooms, generally, physical, chemical, and biological techniques are applied with the objective of directly reducing algal biomass, either by using algicides or by modifying the factors that favor cyanobacterial development, such as nutrient availability, water stratification, and food web structure [23–25]. The selection of the most appropriate method to restore a water body depends on multiple intrinsic and extrinsic factors influencing economical charges and efficacy; for reviews, see, e.g., [24,28,50–52]. Intrinsic factors include the eutrophication status, the characteristics of the dominating cyanobacteria [51], and hydrogeomorphology including bathymetry, as, for certain applications, a hypolimnion is compulsory (aeration or retraction of the hypolimnion, application of ultrasound) or beneficial (sediment capping, P-flocculation). Moreover, in reservoirs, the retention time plays a crucial role. Extrinsic factors include the sources and pathways of P and N introduction, the dimension, and the hydrogeological characteristics and usages of the catchment, e.g., [27]. Moreover, local climatic factors influence photosynthetic biomass production [17,53]; together with potential environmental damages or benefices, these are summarized in Table 1. The former application of copper sulfate (and other algicides) is no longer considered as environmentally safe in many regions of the world due to its low specificity and high risk of accumulation [23]. Applying hydrogen peroxide (or other oxidative products) provides an efficient and not too expensive acute treatment against cyanobacteria with limited side effects, but should be selected only if no other possibility to reduce the nutrient load exists [54–57].

Table 1. Comparison of selected cyanobacterial control methods with respect to their economical charges, their efficacy, and their potential environmental damages/benefices.

Control Method	Costs	Constraints	Risks for the Environment
Copper sulfate (and other algicides)	moderate	annual repetition necessary	environmental damaging due to low specificity and risk of accumulation → prohibited in many countries
Hydrogen peroxide (and other oxidative products)	moderate	annual repetition necessary	low environmental damage due to higher specificity, no accumulation
Ultrasound of epilimnion	medium	hypolimnion required	low environmental damage
Oxygenation or withdrawal of hypolimnion	medium	hypolimnion required	low/no environmental damage
Bio-manipulation	moderate to medium	efficient if applied at densities that can be controlled by zooplankton	no environmental damage
P-adsorption and flocculation	medium	efficient if P (and N) sources are reduced	limited environmental damage
Sediment capping (CaCO ₃ and other products)	medium	efficient if P (and N) sources are reduced	limited environmental damage
Salvage of cyanobacteria	Expensive, intense mechanical effort for the removal and treatment of the cyanobacterial scum	repetitive as long as eutrophication continues	environmental benefits: removal of potential toxic cyanobacteria
Sediment dredging/removal	Very expensive, intense mechanical effort for the removal and treatment of the sediment	efficient if P (and N) sources are reduced	high environmental damage
Payment for ecosystem services	Expensive, intense effort for farmers implementing methods to reduce losses from the fields	medium to long-term solution as it reduces P (and N)-load in the system	high environmental benefits: water purification, increase in biodiversity, carbon sequestration

The treatment of the internal pelagial P load through flocculation (moderate to medium cost) efficiently reduces the P availability for phytoplankton including cyanobacterial development. If P is not removed from the system, the risk of remobilization from the sediment [58] can be avoided through the oxygenation of the hypolimnion (low investment, [59,60]), sediment P capping (moderate to medium cost), or dredging (high technical investment and the issue of storing/reusing the sediments, for example, as agricultural fertilizer [50,52]). Moreover, dredging comes with a high disturbance of the sediment.

The possibilities of controlling cyanobacteria development through bio-manipulation include the augmentation of zooplankton grazing pressure on phytoplankton, reducing sediment perturbation, or increasing competition for nutrients, as per [61] and the references therein. Actions include the decrease in or removal of zooplanktivorous and benthic fish and the planting of macrophytes. Success depends on the initial cyanobacterial density, lake size, and hydromorphology, as well as climate conditions, and might be time-limited, hence requiring repetition leading to a high variability in costs [62].

Cyanobacterial salvage (the mechanical removal of dense cyanobacterial blooms) is applied in severe cases; for example, the yearly removal of millions of tons of cyanobacterial slurry from Lake Taihu in China [26]. Highly technical equipment and yearly repeated removals cause enormous costs; moreover, the (pre-) treatment of the slurry adds to it (de-watering, fermenting, oxidation, hydrothermal treatment, prevention of odor development).

New developments may decrease these costs; see [63]. The use of the salvaged phytoplankton biomass is possible as an addition to phytoplankton culture media to produce biodiesel or for the production of biochar [21,26].

In all cases, however, a reduction in incoming nutrients will boost the applied curative actions, and reducing P under a critical limit can be the decisive factor for reducing cyanobacterial blooms and their human health risk [11,14,16]. For their aim of reducing nutrient input from the catchment area, PES schemes should be included in the variety of methods to restore eutrophicated water bodies or to ensure the success of the applied method.

Even if the introduction of nutrients from the catchment can be achieved, P can be released from the sediment for several years [58], as demonstrated in the lag-phase of eight lake restoration examples by the authors of [15]. Therefore, successful projects typically combine several methods and include the knowledge of the hydro-geological characteristics of the catchment and the water body to control external and internal nutrient loads, and search for accompaniment from political and management framework and leadership, as well as capital support from stakeholders [28].

Lac au Duc underwent several curative actions with limited success: applications included copper sulfate (for the years 1996–2005; thereafter, it was banned), sediment capping with calcium carbonate (for the years 2013–2015 in the bathing zone), and air bubbling to destroy stratification and to oxygenize the sediment, which would reduce P-remobilization (in the year 2002). The use of hydrogen peroxide (H_2O_2) is a more acceptable alternative compared to other algicides [64–66] due to its rapid degradation to water and oxygen, hence leaving no chemical trace in the environment. In addition, at low doses, it appears to be selective against cyanobacteria, with a low impact on eukaryotic algae or aquatic flora and fauna [55,64]. Microorganisms naturally present in water, however, can be affected depending on the dose [55,67], and further studies are needed to evaluate effects on bacteria in sediments, and impacts on nutrient cycling.

In the present project, an application of hydrogen peroxide to destroy the cyanobacterial cells was tried in an enclosure in the bathing zone (in the year 2018). While cyanobacteria were successfully reduced in lake samples taken directly before the H_2O_2 application by 2.5 and 5 mg L⁻¹ of H_2O_2 (peroxide chemical test strips, Merck, Darmstadt, Germany) allowing eucaryotic phytoplankton to grow within nine days (Figure 3A, pigments were measured using the probe TriOS Optical Sensors micro-Flu-Chl, respectively, TriOS Optical Sensors micro Flu-blue), the situation proved to be more difficult in the reservoir. The applications of even higher concentrations in the delineated closed area of the lake did decrease cyanobacteria, but H_2O_2 concentrations were diminished rapidly (probably by the organic matter from the sediments). Cyanobacteria were determined according to [46–48], using a microscope Olympus BX 50 (Olympus, Tokyo, Japan) (objectives $\times 10$ et $\times 50$). They were not suppressed sufficiently or for long enough below the 1.5×10^6 cells mL⁻¹ limit (Figure 3B). The efficacy of a H_2O_2 treatment depends on the density and growth phase of the bloom and its nutrient status, but also on the presence of eucaryotic phytoplankton and other organisms capable of H_2O_2 reduction [56,68]. Moreover, abiotic factors such as a high content of organic matter (sediment in our case) can lead to a rapid decline in H_2O_2 . Moreover, the enclosure provided good growing conditions for the cyanobacteria, which apparently benefitted from the liberated nutrients, leading to a rapid regrowth. Other complications including a leakage of the underwater curtain after the renewal of the water and a frequentation by birds led to an abandonment of this action.

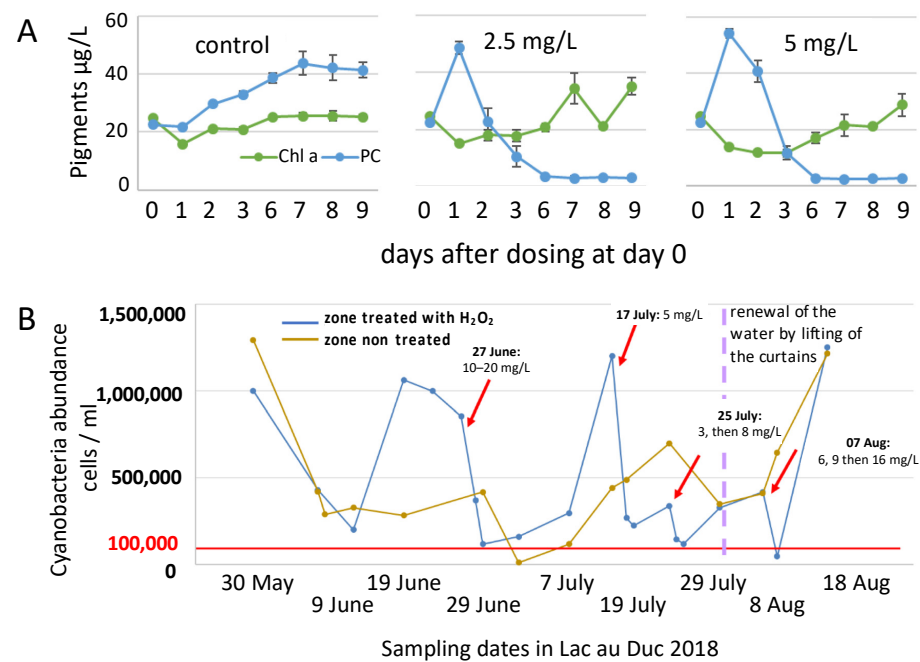


Figure 3. Hydrogen peroxide trial, (A) lake samples (2 L) treated in the laboratory, Chla, chlorophyll a, PC, phycocyanin, (B) survey of the cyanobacteria abundance in the bathing enclosure of the reservoir and outside that area; red line: limit of cyanobacterial abundance for bathing.

Despite promising lab and mesocosm studies using hydrogen peroxide as a curative action, few studies show the successful implementation in water bodies against cyanobacteria such as was demonstrated for the first time by [54] in a freshwater pond of 12 ha, and recently in three lakes in the Netherlands against *Dolichospermum* sp., *Aphanizomenon* sp., *Planktothrix rubescens*, and *P. agardhii* [66]. H₂O₂ was even applied to combat an *Alexandrium ostenfeldii* bloom in a brackish water [69]. Pokrzywinski and colleagues applied hydrogen peroxide in 1.300 L in-lake enclosures to reduce cyanobacteria from 1.32×10^5 phytoplankton cells mL⁻¹ to 7.11×10^4 , whereas controls increased in density. The similar rapid regrowth of picocyanobacteria and cyanobacteria in particular was, however, observed as they benefit from stable water columns [57]. In bigger in-lake enclosures (3000 L), cyanobacteria were successfully reduced over the 120 h experimental time (Secchi depth increase from 47 to 100 cm), whereas diatoms and green algae started regrowing, but nutrients (N and P) remained high [70].

With the limited depth of Lac au Duc, a decoupling of P in the hypolimnion is impossible. A bathymetrical analysis (conducted by Saunier-Techna and INSA, 2003) revealed a 1–2.5 m sediment layer over the bedrock with approximately 500 t P stock. A relatively short residence time between 30 and 60 days could allow for the slow but steady purification of the P stock in the sediment through a reduction in P input from the catchment. In the Lac au Duc reservoir, therefore, the focus was set to long-term restoration actions.

5. Establishing Measures with the Farmers to Avoid Erosion and Nutrient Loss

Reducing P inputs to the lake can either be achieved by reducing its application on the plots or by aiming to reduce runoff and erosion. The farmers of the Lac au Duc catchment had been involved for a long time in actions to reduce the diffusion of nutrient pollution. These actions involved the reduction in fertilization, systematic planting of cover crops in winter, or thorough planting of grass strips of at least a 5 m width along watercourses. A subscription to Agro-environmental and Climatic Measures (MAEC) compensates for the investments and eventual harvest losses. Moreover, the establishment or re-establishment of hedgerows was initiated within the framework of the “Breizh Bocage” program, resulting in 70 m of hedgerows per ha of which unfortunately only 30% were anti-erosive. These

measures contributed to the reduction in the diffuse flow of P and N from agricultural origins entering Lac au Duc, as elsewhere in Brittany, by an average factor of two in 25 years. This quantifiable success, however, is not yet reflected in Lac au Duc: the incoming river Yvel still promotes cyanobacterial blooms with a yearly average of $100 \mu\text{g P L}^{-1}$.

For proof of the PES concept, the sub-basin Rezo (10% of the whole area) was selected due to its highest P-output rate in the whole catchment, its close location to the lake, its substantial number of plots at risk, a rather low density of hedgerows, and more farmers showing interest in environmental programs, thus offering high potential to implement actions. It resembled the whole catchment area concerning farm and plot size and the use of agricultural land (cereals, maize, meadows, etc.).

Practices and actions reducing runoff and erosion were proposed to a dozen farmers, representing ~80% of the agricultural area of the sub-basin and are summarized on the project webpage (<https://www.cpes-interreg.eu/en/pes-toolbox/pse>, accessed on 5 April 2022). The utmost care was taken to not alter the main agricultural strategy, targeting the proposed actions to actions that aimed to reduce the loss of nutrients from the plot. Moreover, a realistic price estimation was asked from the farmers, of which an average was calculated. Both being able to choose the action and estimate the price motivated the farmers' participation. A detailed map was created to identify the plots at the highest risk and was presented to each farmer to identify their plots of urgent action. Actions chosen included the implementation of hedgerows or at least grassy strips perpendicular to the slope, the systematic use of cover crops after harvest (but not during crop season), restoring the water courses, or reducing tillage, and some farmers were interested in agroforestry.

6. Assessing the Costs

Prior to the detailed price elaboration with the farmers of the sub-catchment Rezo, a questionnaire estimated the prices for two actions, permanent plant cover and anti-erosion hedges, in the whole catchment area, revealing prices between EUR 300 and 600/ha of used agricultural land, depending on the action implementation rate (higher prices for the higher density of anti-erosion hedges, for example). The Annual P Loss Estimator Tool (Apple, Annual Phosphorus Loss Estimator) of the US Department of Agriculture (<https://data.nal.usda.gov/dataset/agle-annual-phosphorus-loss-estimator-tool>; accessed on 12 June 2018 [71]) was used to simulate the P loss reduction factor on the whole catchment scale, depending on the proportion of plots on which the action would be implemented and the current P loss risk of each plot. This model uses the data of soil characteristics (depth, clay and organic matter content, extractable P), rainfall, runoff and erosion rate, organic and mineral P inputs, and finally P exports by crops. The model's output data are P losses through runoff and erosion, distinguishing between dissolved and particulate forms of P [72]. The impact of ending mineral fertilization and planting a permanent cover crop can be simulated. Contrarily, for the impact of erosion control using hedges, no model simulating their impact of the erosive flow of P has been found in the literature; hence, a 50% reduction in P by 100 m of hedgerow per ha was hypothesized for the model. Other limits included modeling flexible land use for 5-year contracts, or by the variability of the plots included in the simulation, or with the special case of P-fertilization and bare soil in maize cultures.

With these restrictions, and targeting the plots where the implementation of actions would be foremost efficient, costs for the whole catchment area and the selected sub-catchment Rezo were calculated with the given goal of P-reduction (Table 2). Reducing the flux of P entering Lac au Duc by a factor of two or three, i.e., the factor necessary for Lac au Duc to regain a good ecological status, can be achieved either by targeting the most cost-efficient plots via establishing permanent plant cover and maximizing the linear length of hedgerows on these plots (100 m/ha), or by being less restrictive on the linear length of hedgerows and enrolling more plots, including plots that are less cost-efficient concerning permanent cover. Reducing the inflow by a factor of five is only achievable with a maximal implantation of hedges on all of the plots.

Table 2. Modeling of costs to reduce P entering the lake by a factor of two, three, or five for the whole catchment and the sub-catchment Rezo (Sub-c Rezo), with the implementation of hedgerows or permanent cover of fields. (*: hedgerows also downhill of meadows at risk).

P reduction Factor	Fields Permanently Covered %	m/ha of Hedges	Costs per Year E
2 (non targeted)	74	20	10,400,000
2 (targeted)	50	100	6,170,000
Sub-c Rezo	54	100	900,000
3 (non targeted)	100	37	11,900,000
3 (targeted)	79	100	10,330,000
Sub-c Rezo	93	100	1,400,000
5 (non targeted)	97	100	14,150,000
Sub-c Rezo	100	100 *	1,800,000

The costs of inaction must not be overlooked, even though they seem difficult to estimate, due to high variation in the probability of lesser income or changed investments for touristic-related enterprises, or uncertainties in increased costs for drinking water purification. For Lac au Duc, the cost of inaction was assessed by estimating the monetary value of the lake services through questionnaires completed by >250 lake users. The costs of inaction are estimated between EUR 14 and 34 million per year, depending on the level of the degradation of the services provided to the lake (the more degraded the services, the higher the costs of inaction).

7. Evaluation of the Implemented Actions

The evaluation of the implemented actions is necessary to justify investors' financial efforts. It can be conducted either by evaluating the outcome (e.g., P loss reduction factor) or through the proof of the implementation of the actions (e.g., density of anti-erosive hedge implemented by farmers). Outcome evaluation has been implemented for the CPES case studies concerning N (drinking water abstraction) by directly measuring the remaining N in the soil after the crop harvest. Creating groups of farmers acting as a consortium to reach the target proved very successful as well as bonus/malus points for the calculation of their remuneration.

The complete estimation of P loss from a plot includes various measurements (dissolved, colloidal-bound, etc.) and timepoints, and requires analytical equipment and costs; hence, evaluating the implementation of actions seemed more appropriate. The proposed amelioration methods were chosen because of their proven positive impact in reducing the loss of both N and P from fields. Hence, the proof of implementation and a follow-up of indicators for their functioning can be chosen as an indirect evaluation with respect to N and P loss. This would, moreover, provide the opportunity to include an evaluation of other ecosystem services than water quality such as carbon sequestration or biodiversity, which could enlarge the spectrum of investors that could participate to the Lac au Duc PES scheme. For each of the measures, besides the accounting in the farm records, a 5-year scheme of specifications (<https://www.cpes-interreg.eu/en/pes-toolbox/pse>; accessed on 5 April 2022) was developed detailing implementation conditions and timeframe, and the involvement of tiers and the farmers in the evaluation process. Suggested evaluation criteria for the Lac au Duc area depend on the realized amelioration and are summarized in Table 3. In simple cases, evaluation criteria may include geo-localized photos of implanted permanent plant covers and anti-erosive hedges or grass strips, which can be supplemented with information about biodiversity (e.g., plants, pollinators, soil, or aquatic fauna) and carbon sequestration. At the start and at end of the contracts, the evaluation would be accompanied by an expert; the aim was to enable the farmer to evaluate the progress during the contract.

Table 3. Summary of suggested methods in the Lac au Duc pilot study to ameliorate agricultural practices in order to reduce nutrient loss from farmland, and their specific addressed goal and evaluation by experts and farmers. (OAB: Observatoire Agricole de la Biodiversité).

Ameliorated practice and → goal for water quality	Evaluation by Experts		Auto-Evaluation by the Farmer
	Initial state and final evaluation after 5 years	Year 3	Years 2 and 4
Implant, restore, and maintain planted flat hedges or hedges on embankments downstream of plots/wetland belt/slope break (Those that are not included in the BZH Bocage framework) → Reduce runoff and erosion	Size: length, height, width, quantity of carbon stored in tons of CO ₂ equivalent/km/year Hedges: average number of trees/km of linear length, average number of species/100 m, presence of solitary bee nests Slopes: area/density of slopes reducing erosion (ha)	Presence and abundance of flora, soil fauna, and pollinators	solitary bees and invertebrates (simplified OAB protocol) Every year in June and December: Geo-referenced photo of the effects of erosion on high-risk plots after a rainy event In spring: geo-referenced photo of the slope planted
Manage field edges → Increase water infiltration → Limitation of runoff and transfer of P	Size: average width and length Inventory of indicator species for good biodiversity status (flora and fauna) at key periods	Presence and abundance of flora, soil fauna, and pollinators	Flora, soil fauna, and pollinators (simplified OAB protocol)
Sow a cover crop before harvesting/Plant short intercrops → Reduce runoff from plots	Presence and abundance of soil fauna	Presence and abundance of soil fauna	Soil fauna (simplified OAB protocol)
Plant perennial crops → Reduce runoff from plots → Increase water infiltration	If orchards or woodland: average number of trees/ha, average number of species/ha, presence of solitary bees' nest boxes, presence and abundance of soil fauna Quantity of carbon stored in tons of CO ₂ equivalent	Presence and abundance of soil fauna	Soil fauna (simplified OAB protocol)
Extend crop rotations → Reduce the transfer of pesticides	Presence and abundance of soil fauna Number of pesticide applications	Presence and abundance of soil fauna	Soil fauna (simplified OAB protocol)

Table 3. Cont.

	Evaluation by Experts	Auto-Evaluation by the Farmer
<p>Maintain the banks of watercourses</p> <p>→ Reservation of water quality by slowing down and oxygenating runoff, encouraging self-purification via riparian vegetation</p>	<p>Length of bank involved and nature of sections (natural, recalibrated, re-meandered). Ripisylve: average number of trees/100 m, number of species/100 m, presence of herbaceous/shrub/tree strata. Grass strip: average width, indicator species (fauna, flora). Aquatic fauna: IBGN index Quantity of carbon stored in tons CO₂ equivalent/km/year</p>	<p>Presence and abundance of aquatic fauna</p> <p>None</p>

8. Financial and Juristic Settings

8.1. Willingness of Farmers to Engage in PESs

The suggested actions may come to the decrease in crop yield (quantity or quality, such as protein content); hence, without a compensating remuneration, the farmer will not engage in PESs. The farmers' motivation to engage in PESs was, however, not only correlated to the price of remuneration, but also strongly correlated to the duration of the contracts, the possibility to adapt the content of the contracts to the specific characteristics of the farms, and the expectedly higher reactivity of private–private contracts. The Lac au Duc region, however, has a long history of publicly funded programs to improve water quality. These programs have had positive results, as already mentioned above, but they have also created a lot of weariness among farmers mainly due to late payment, contract administration considered too fussy, or contracts that are too uniform, not keeping enough consideration for the diversity of situations between farms. Farmers' trust is one key factor for the success of the acceptance of PES schemes, for which a collaboration with catchment managers and a farmers' association, and regular informal meetings, proved vital. The farmers' association was helpful with its expertise in the design and legal status of PES contracts between farmers and private companies, its ability to act as an intermediary between companies and farmers, and as a manager and provider of private funding to farmers. Nonetheless, its expertise in the farming profession was a lever motivating farmers' participation. Moreover, we collaborated with the regional agricultural chamber, who contributed with their experience and connections with farmer groups and agricultural union organizations.

8.2. Willingness to Pay

Private–private contracts of PESs offer the possibility for both farmers and investors to agree about the actions implemented and their duration. Some of the proposed actions would not only serve to reduce the nutrient input to the lake, but also to improve other ecosystem services such as an increase in biodiversity or carbon sequestration and storage, for example, by planting hedgerows. This in turn could augment the attractiveness for buyers who may be more interested in investing in carbon sequestration or biodiversity than in water quality.

It should be noted that communication is a key element in mobilizing all the stakeholders required to build a PES scheme and that all possible means (press releases, stands at festive events organized in the area of action, the organization of information meetings for the general public, film, etc.) were used to this end. The importance of a local connection for the valorization of investment by financiers may not be underestimated. Again, informative meetings for discussions with all stakeholders/farmers or individuals were helpful.

In total, the CPES project led to the signing of 138 PES contracts for a contractual length of 3–7 years in the six pilot studies. These PESs covered 48,232 ha of agricultural land for an investment of EUR 48.5 million. Those contracts concerned the reduction in nitrate leaching towards groundwater resources, for which the issues and levers of actions are clear (reduce the input of N-fertilizers, controlled via measurements of residual N). For the lake au Duc case study, both the issue (reduce cyanobacteria blooms) and levers of action (reduce P input to the lake) are much more complex; hence, a PES scheme has not yet been achieved.

Concerning the N-related issue, the impact in terms of the farmer's participation of the number of intervention measures to reduce the loss towards aquatic ecosystems or aquifers, on the one side, and of awareness and capacity building for stakeholders and public water authorities, on the other side, shows the attractiveness of this scheme as being more cost-effective for achieving good water quality status and being suitable for territories and catchment areas.

8.3. Juristic Frame

The CPES project demonstrated the interest in and viability of PESs for the preservation of the quality of water resources, thus reinforcing the objectives of water policy at both national and European levels. PES payments can be supported and managed by private or public water institutions which endorse the responsibility of drinking water provision and the management of water resources.

In the French CPES pilot studies concerning N in drinking water, the PES payment was set by considering individual performance on achieving greater quality of water resources (target objectives of the payment). As further motivation for the farmers, a bonus was added reflecting the percentage of the catchment area covered by PES contracts. A 5-to-6-year duration was considered sufficiently attractive from the farmers' economic point of view. The Lac au Duc PES schemes offered many environmental benefits related to recreational water, but very few related to drinking water, and were aimed to be financed solely by contributions from private stakeholders. However, private-private contracts may have an insufficient leverage effect at the catchment scale unless a broker/association/intermediary/private company invests in a business model that ensures long-term PES financial sustainability. In the case of Lac au Duc, a farmers' association took that responsibility.

The PES contracts need to comply with EU rules, in particular, the 'minimis' rules. As the minimis rule has a cap in the total amount of money allocated to each farmer, public water management could be faced with risking a breach of PES contracts during the timeframe of the PES program. This situation limits funding possibilities for public water managers who are keen to respond to their financial commitments on the length of the PES program. A call for private investments is a way to supply funding since public funding for PES is not legally possible outside the EU rules. This option opens the floor for public-private partnerships (PPPs) devoted to water resource preservation. However, the French legal basis for these new financial arrangements needs more consideration to set up a clear legal framework.

So far, from the public water manager's perspective, progress is required to increase transparency in the way funding is directed to improve key environmental services which are under the responsibility of public authorities. Issues related to control and the assessment of effects of PES schemes are key in dealing with a shared partnership at the catchment level for the provision of ecosystem services.

9. Discussion

Positive aspects of PES schemes for water quality protection/restoration.

The experience gained from the CPES project shows that PESs allow us to move away from polluter pays logic and to set up new ways of rewarding and financing farmers willing to change their practice to protect/restore water quality through the emergence of a market for environmental services. This market brings together buyers (beneficiaries) and suppliers (farmers) of an environmental service, here, the preservation of water quality. PES schemes are creating markets for ecosystem services that do not have a legal existence but are assimilated to market-based mechanisms. The PES contracts developed in the framework of the CPES project can be viewed as experiments allowing us to evaluate their performance in relation to other agricultural subsidies while respecting the national and European frameworks.

The institutional framework in France and the UK has shaped the nature of PES contracts and funding. In France, PES funding comes from the public sector; the French private sector has so far had very limited involvement. To escape the minimis rules, exemptions were requested from the European Commission, which granted them. In the UK, the approach of the CPES pilots favors the use of public-private partnerships in environmental financing, with private water companies being the first buyers of PES schemes for water conservation, as they serve the protection of their resources. The presence of non-profit organizations that act as intermediaries between farmers and water companies

can facilitate financial transfers and the construction of interventions that condition the allocation of PES amounts, and the monitoring of the contracted conditions. These are the 'Rivers' Trusts' who are in charge of reducing the costs of organizing the market for environmental services on behalf of the water companies in return for potential funding. The contractual arrangements are multiple. Rivers Trusts take charge of the costs of agricultural and financial governance.

The role of intermediaries is key in the financing for PESs because they can call on different sources of financing, either on-off (e.g., sponsorship) or multiple funding over time, depending on the nature of the ecosystem services in a given territory (e.g., carbon offsetting). They represent the new financial applications in the field of the ecosystem services marketplace. In the absence of intermediation, private water companies that could invest in PESs have no incentive for action, and neither do their French counterparts, due to a time lag between the potential benefits on water quality and the immediate and recurrent costs of PESs.

The agricultural landscape of a catchment such as the Lac au Duc catchment is characterized within its hydrogeological frame by soil related characteristics (composition, thickness, slope) and usage-related diversity; thus, different P outputs from the plots can be expected. Identifying plots at the highest risk and elaborating targeted actions to reduce P output in collaboration with the farmers has the advantage of their consent, and the security of the technical possibility to integrate those measures in their production strategy with only little change required. The CPES project evidenced that the obstacle in ameliorating agricultural practices is not the farmers, but the elevated cost of actions, and the difficulty of finding private investors to cover these costs in a country in which the production of drinking water is under the control of public authorities. Our results agree with several other studies that showed that farmers are willing to implement mitigating actions or even adopt new farming management strategies, provided a certain degree of financial security [34,73]. Farmers' experience, the availability of equipment for the new techniques, and the willingness to contribute to environmental health motivate their participation in addition to the monetary aspect [74]. Moreover, the farm size plays a role as it relativizes investment costs [34]. Farmers frequently favor private-private PES schemes due to their flexibility in targeted actions and low administration complexity.

PESs are successful in extending the realization of nature-based solutions, especially at the scale of watersheds or catchment areas. Evidence suggests that it is economically more efficient to organize payments at the landscape level than the current farm level approach, as per [1] and the references therein. To comply with this strategy, a sub-catchment was selected at the Lac au Duc pilot (Figure 2), and in other CPES pilots, farmers formed groups to reach the goals acting as a consortium. If the landscape-scale management of agriculture could be achieved, lakes as part of a landscape could largely benefit from concerted actions to reduce eutrophication and therewith cyanobacterial bloom densities and durations.

Identifying actions that would not only increase water quality, but also serve different ecosystem services increased the flexibility for marketing PESs. In particular, French private investors (e.g., Crédit Agricole, Suez) seemed more interested in the other services provided by the selected actions than the water quality improvement service targeted by the CPES project, such as the preservation of/increase in biodiversity through the restoration of certain habitats, and the mitigation of global warming by augmenting (soil) carbon storage. Some farmers, too, were attracted by actions providing those co-benefits; thus, the range of factors that would motivate both contract partners were broadened.

The development of robust evaluation schemes is necessary. While it is possible to directly measure P-fluxes as the control of the implemented actions, this comes with high time and analytical expenses. This study, therefore, developed indirect but robust and cost-effective measures for actions proven to achieve P-retention, such as the documentation of buffer stripes, the implementation and management of hedgerows, or the associated biodiversity of pollinators or soil fauna as indicators. The involvement of the farmers in

the evaluation program again increased motivation, as well as the direct feedback of the success of the implemented action.

Limits of Private–Private PES Implementation

As nutrient loss from farmland is diffuse, a key management challenge remains to coordinate actions between farmers, besides the administration for the juridic and subsidies' payments. This can be delivered by a farmers' organization or a broker.

As for so many environmental actions, the success is linked to the willingness to pay, be it by governmental paid actions or by private investors. PESs offer the possibility to create very flexible (tailor-made) arrangements on a farm scale or with a group of farmers on a landscape scale connecting farmers to investors in private–private contracts. This approach is effective for the situation of water-works, where one big investor finances the farmers' actions or compensates for their losses. The water-works' motivation is to protect the quality of their own resources, groundwater, or surface water from exceeding regulations (concerning nitrate levels) or from surpassing costs for purification. Private–private PES contracts are more difficult to implement for ecosystem services. Initially, the PESs in this study were built for a single ecosystem service, that is, the quality of water resources; the co-benefits on biodiversity and carbon opened the door to a multiplicity of ecosystem services whose demand could interest the private sector. However, the lack of specific rules governing PES transactions in the context of multiple ecosystem services may lead to a competition for funding where, for example, carbon storage is chosen over water quality or biodiversity-increasing services.

The CPES experience evidenced both legal and incentive barriers to private actors contributing financially to PESs in France. Moreover, French private investors are not used to investing in services which are considered by citizens and communities to be common goods whose management must consequently be covered by public funds. PES contracts in France are therefore mainly public contracts, managed by local authorities, whose upper amounts follow either the European minimis regulation or contracts resulting from a PES scheme notified directly by the European Commission. In the first case, the PES payment would be added to the total aid received by the farmer under the *de minimis* rule. The total amount is subject to the same cap, which implies for some farmers years of non-payment for PESs during the PES contract period. In the second case, the notification process is long and costly for a local authority and requires strong political support from the national authorities to be successful.

This legal context in France does not encourage public–private partnerships in the financing of PES schemes, especially in the framework of the *de minimis* rule. Indeed, any additional private funding becomes *de facto* public when the PES is managed by a public actor. This situation leads to the same limits as before and could lead to a decrease in the attractiveness of PES schemes.

Surface waters used for recreation or many purposes, as at Lac au Duc, do not belong to a single structure with sufficient possibilities enabling it to bear the costs; hence, multiple payers are needed to finance PESs. Even though they aimed to reduce the costs by identifying agricultural plots where actions were most urgent and enabled the installing of measures where they could be most efficient, the overall investments necessary for the whole catchment seemed too high to be financeable. Very few investors were identified and PES contracts are currently in the state of preparation.

Some, but few, differences in the acceptance by farmers of ameliorating agricultural practices were encountered, owing to the risk perception of economical insecurities that may come with it, but also owing to cultural resistance to implement new strategies. In a similar study, no-till farming in particular was seen as a risk for the following crop; reducing the fertilizer could reduce the quality (protein content) of the crop, and while cover crops were largely accepted as reducing erosion from the field, they came with an increased use of pesticides [34]. Likewise, in this study area, winter frosts are not sufficiently hard to destroy intercrops.

The activity of policy makers is necessary to motivate investment in a catchment-sized area, but political areas usually do not correspond to catchment borders. Nevertheless, as a certification of local products is possible and already applied to some products, the promotion of these products could help to increase farmers' income, and thus their willingness to implement strategies to reduce erosion.

The time necessary for lake restoration may be also seen as an obstacle. Even if P input would be reduced drastically, the P storage of the sediment would sustain eutrophic conditions for unknown years. International examples from lake restoration via P-reduction show an average of ~10 years after the inflow of P was reduced, accompanied by a decreasing cyanobacterial biomass [15]. The yearly average turnover time of the studied Lac au Duc reservoir is between 30 and 60 days, which could be advantageous for P-export, but its stagnation during several months in the summer coincides with the P-remobilization from the sediment [40].

10. Conclusions and Outlook

Unarguably, the main ecosystem service of agricultural landscapes is to provide food, nutrition, and raw materials. Nevertheless, these landscapes hold the capacity to provide other ecosystem services which would first of all sustain agricultural production, in terms of water holding capacity and plant nutrient cycling, in addition to assuring water quality and biodiversity [35]. Hence, the agricultural sector can be both a provisioner and a beneficiary of ecosystem services [1].

It is the management strategy of agricultural landscapes that influences its capability to provide ecosystem services (the regulation of water and carbon, biodiversity, and habitats for pollinators, in addition to food provision). This is, however, in turn, modulated by the consumers' demand of agricultural custodies, which then regulates the price and income for the farmers. Many farmers find themselves cornered between the supply of food in good quality, quantity, and variety to citizens, the increasing awareness of the importance of a healthy environment, and their need for sustainable revenue. Thus, society has to take the responsibility to ensure farmers' standard of living in return for the amelioration of agricultural practices aiming at ecosystem health.

The control/decrease in cyanobacterial blooms in eutrophicated water bodies faces the challenge of P diminution. PESs offer a possibility to incentivize farmers to implement measures against nutrient loss from the fields, but their financing is problematic in a multi-purpose and multi-owned recreational water body.

While the presented project developed PESs under the condition to not change farming strategies, another option to proceed with the restoration of the catchment could be to combine the PES actions with a movement towards regenerative or conservation agriculture. Both of these agricultural strategies base on restoring soil health in order to increase its ecosystem services in terms of water holding capacity, reduced runoff (30–70%) and erosion (by more than 90%) besides its climate change mitigation capabilities, while providing crops with the required nutrients [35,75,76]. Soil health is defined via its function as a central living ecosystem that preserves the favorable processes and interactions between plants, animals, and microorganisms. Less tillage and agrochemical input together with increased soil coverage raises the soil humus content and with that its capacity for P and N storage, merely in its living parts, which in turn accelerates their recycling towards the crops of interest [34]. A vivid microbiota community is important for plants, which form a network with bacteria and fungi for mutual support, reducing the plants' dependency on nutrients (N, P) and mineral (Fe, etc.) availability [77].

This reduced investment of the farmer for the harvest can be reflected in economic gain despite the possible drop in yield [78]. Investments in appropriate machinery, the risk of reduced crop production, and difficulties with weed/residue/soil fertility management, however, remain challenging [78].

To increase the willingness to pay for ecosystem services, there is a need to foster the awareness in the society of its unconscious benefits from these services, as for the

water quality in the CPES project. Other important ecosystem services such as flood control, the reduction in runoff and erosion, increase in biodiversity and pollination, or carbon sequestration could be achieved through the same measures. If the awareness of the inseparable reliance of agriculture on ecosystem services were to rise, so would the acceptance of the beneficiaries to invest. Soil health plays a crucial role, as soil provides more than 90% of human nutrition.

There is a need for natural and social sciences to further develop applicable frameworks, decision-making tools, and practical outputs to promote an integrative catchment management, allowing for the cooperation of multiple stakeholders in order to ameliorate the water-quality-related ecosystem services [6].

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