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POtential Ecosystem Services and Impacts Evaluation (PoESIE) method

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Abstract

Pond fish farming is a declining activity in France. The diversity of its roles raises the question of whether the framework of ecosystem services (ES) could give a better visibility of the assets of this activity. The aim of this study is to propose a method called "Potential Ecosystem Services and Impacts Evaluation" (PoESIE)" to evaluate ES to clarify the ES provided by ponds in France. PoESIE is based on the combination of LCA and EA to assess jointly ES and environmental impacts, highlighting trade off associated to management practices in fish ponds. The PoESIE framework is based on the four steps of LCA: (i) *Goal and scope* consists of defining boundaries of the ecosystem of interest, the technosphere and the ecosphere that support it. Functional unit is defined as "to occupy and value a surface by supplying ES" (ha); (ii) *Ecosystem inventory* consists of quantifying the capture and emission of matter by the ecosystem and the technosphere, as well as the emergy value of each of these flows; (iii) *Assessment step* covers two stages. First, each material or energy flow is linked to an ES. Then, characterization factors are defined based on LCA impact categories to assess each ES. The emergy value of each flow is aggregated according to ES. Finally, each ES is assessed through two metrics: potential biophysical value and potential environmental work done to produce an ES. Environmental impacts assessment is performed by an attributional LCA; (iv) *Interpretation* follows the classic LCA step. The two metrics of each ES are compared and synergies and trade-offs among ES are analyzed. PoESIE was applied on 135 ponds grouped into five management classes. The main results show that each management class has his own impact and service pattern. The method shows trade-offs. For instance, intensive and semi-intensive managed ponds provide the best level of ES, and have moderate environmental impacts, but EA show poor sustainability performances. The proposed PoESIE method has shown its applicability to a slight anthropised system at the interface between the natural and the productive environment. Pond aquaculture can provide a good level of ES, mainly when ponds are managed in order to produce fish.

Keywords: *ecosystem services; life cycle assessment; emergy accounting; fishpond; sustainability.*

Introduction

Ecosystem services (ES) became an active field of research after publication of the Millennium Ecosystem Assessment (MEA, 2005). Following a proliferation of conceptual frameworks and typologies for ES (Braat, 2018; Haines-Young & Potschin, 2012), several methods were developed to quantify ES (Bennett & Isaacs, 2014; Othoniel et al., 2016). Two sets of scientific fields were used to develop assessment methods: (i) economics and sociology, to assess economic values and the perception of ES (Farber et al., 2002); and (ii) ecology, agronomy and environmental sciences, whose biophysical approaches were used to assess ES characteristics directly or indirectly (Zhang et al., 2010). The ES provided by natural ecosystems are now extrapolated to agro-ecosystems to broaden assessment of agricultural activities. Among livestock systems, fishponds have some specific characteristics. Since they are ecosystems managed by fish farmers, they produce finfish as food, but also provide a range of ES (Willot et al., 2019). Nonetheless, they also have negative impacts on the environment, which can be assessed by LCA. Therefore, developing a consistent framework that can assess and balance ES and impacts is a relevant goal for agricultural systems, especially fishponds. Our study consisted of developing a method to assess ES and environmental impacts, based on existing environmental assessment frameworks, and applying it fishponds in France to highlight trade-offs associated with their management practices.

Material and methods

1/ Framework

We developed the "Potential Ecosystem Services and Impacts Evaluation" (PoESIE) method based on the combination of Life Cycle Assessment (LCA) and Emergy Accounting (EA) (Odum, 2002) to assess both ES and environmental impacts. LCA estimates potential environmental impacts due to resource consumption and pollutant emissions, while EA estimates cumulative exergy via the use of natural resources and social and manufactured inputs.

In the first step, the ES considered were those directly connected to the material flows: provisioning and regulating ES (Haines-Young & Potschin, 2012). LCA was adapted to assess them according to the approach developed by Kuittinen et al. (2016). The EA part of the method consists of calculating emergy using LCIA characterization methods modified from their original use. Since EA and LCA have similar steps (Rugani & Benetto 2012), the PoESIE framework is based on LCA steps (Fig. 1).

(i) The goal and scope consists of defining the boundaries of the ecosystem of interest and the technosphere and ecosphere that support it. Within the system boundaries, the material flows of the ecosystem are modeled and "linked" to the ecosphere and technosphere.

In attributional LCA, functions refer to the performance characteristics of the system assessed (ISO, 2006). In LCA studies of managed ecosystems, the main functions are to provide food if the system is agriculture or aquaculture. An alternative function of ecosystems in LCA is to occupy an area (Henriksson et al., 2012a). In an ES context, emphasis is placed on the land used by ecosystems and comparison of types of management for a given ecosystem (Bennett and Isaacs, 2014). The functional unit must reflect the multifunctionality of ecosystems and the area occupied. Thus, the function of all types of ecosystems in the PoESIE method is to occupy and add value to an area of ecosystem by supplying ES. The related functional unit is a unit of area (e.g. ha, km2). The ES supplied by the ecosystem are then identified, as are potential environmental impacts associated with their supply.

(ii) The ecosystem inventory consists of quantifying the capture and emission of matter by the ecosystem and the technosphere, as well as the emergy value of each of these flows. The quantification must remain consistent with the modeling assumptions made during the first step. Biophysical processes, biophysical elements and managed elements are identified, listed and quantified. During the ecosystem element and flow inventory, like for attributional LCA, all relevant flows of raw materials, energy and matter are listed for each unit process of the technosphere (Chomkhamsri et al., 2011). The environmental work inventory leads to the construction of an emergy table (Rugani and Benetto, 2012), which includes all inputs of the ecosystem (ecosphere and technosphere) and their Unit Emergy Values (UEV).

(iii) The assessment step covers two stages. First, each material or energy flow is linked to an ES. Then, characterization factors are defined based on LCA impact categories to assess each ES. The emergy values of each flow are aggregated by ES. Finally, each ES is assessed using two metrics: potential biophysical value and potential environmental work done to produce an ES. Environmental impacts are assessed by attributional LCA.

(iv) Interpretation follows the classic LCA step. The two metrics of each ES are interpreted and then compared. Synergies and trade-offs among ES, for both metrics, are analyzed.

2/ Application

This method was applied to 135 freshwater fishponds in the Dombes of France. To build a typology of the practices, we performed Hierarchical Multiple Factor Analysis followed by Hierarchical Clustering on Principal Components (HCPC) using R software. The parameters selected for the HCPC were the mean concentrations of total i) carbon, ii) calcium, iii) chlorophyll a, iv) nitrogen and v) phosphorus; vi) water pH; vii) macrophyte cover; viii) species richness of macrophytes, ix) phytoplankton, x) and invertebrates (specifically dragonflies); xi) fishing yield and xii) pond area and depth. To these data were added quantitative values associated with management practices, such as

liming, fertilizing and feeding. The ponds were grouped into five management classes: i) "Intensive" ponds with high levels of inputs, mean fish yield of 445 kg/ha, and a mean area of 10 ha; high concentrations of carbon, nitrogen, and phosphorus in water and the lowest level of biodiversity; ii) "Semi-intensive" ponds with high levels of inputs , mean fish yield of 397 kg/ha and a mean area of 11ha, high concentrations of carbon, nitrogen, and phosphorus in water and the lowest level of biodiversity; iii) "Semi-extensive" ponds with low levels of inputs, mean fish yield of 321 kg/ha, mean area of 10 ha, high biodiversity and mixed management that depended on fish farmers' choices; iv) "Extensive" ponds with no human activities (e.g. fertilizing) during the empty period and few during the filled period, mean fish yield of 240 kg/ha, high biodiversity and a mean area of 22 ha; and v) "Recreational" ponds with mean fish yield of 222 kg/ha, low nutrient concentrations in water, high biodiversity and a mean area of 45 ha.
We selected two provisioning ES (i) animals from in situ aquaculture (AFISA), which corresponds to fish production, and (ii) materials for agricultural uses (MFAU), which corresponds to the use of pond sediment (applied to crops in the Dombes region to decrease fertilizer applications) and three regulating ES (i) hydrological cycle and water flow maintenance (HCFM), which corresponds to water flows exchanges and stocking; (ii) global climate regulation (GCR), covering carbon sequestration and methane emissions; and (iii) water quality regulation (WQR), because freshwater fishponds are considered to influence river eutrophication strongly, which influences human well-being. Finally, five impact categories global warming (GWP), eutrophication (EUT), water consumption (WC), energy use (TCED) and land competition(LC) - and two emergy indicators - UEV and the percentage of energy renewability (%R) were estimated. To simplify interpretation, indicator values were transformed into four qualitative classes: good, moderately good, moderately poor, poor.

Results
Each management class had a unique pattern of impacts and ES (Figure 2). All ES except WQR were correlated with intensification of practices, and AFISA and GCR positively so. Intensive and semi-intensive ponds supplied four ES at the highest level, while semi-extensive ponds supplied three ES at the highest level. Intensive and semi-intensive ponds differed in their supply of MFAU and WQR; the former supplied the highest WQR but lower MFAU, while the latter supplied the highest MFAU but the lowest WQR.
Environmental work showed a similar pattern for AFISA and HCFM and for MFAU and GCR. Recreational ponds had the best environmental work profiles. The pond classes had similar ESI patterns regardless of the SE. Although %R differed significantly among ES, it ranked the same for all pond classes. Thus, intensification of practices influences the indicators but does not change the sustainability greatly. Intensive practices seem to be the best way to manage ponds to supply ES, although special effort should be made to manage the ecosystem functions underlying MFAU supply. Environmental impacts also seemed to be sensitive to intensification of practices, except for WC and LC, which were related to physical components of fishponds. EUT was low in intensive classes. GWP was much lower than GCR, and the more intensive the pond class was, the less GHGs were emitted to the atmosphere. TCED differed only for recreational ponds, for which it was higher.
The method shows trade-offs between ES and environmental impacts. For instance, intensive and semi-intensive managed ponds provide the highest level of ES and have moderate environmental impacts, but the EA shows that they have poor sustainability performances.

Discussion
The three metrics show different aspects of anthropised ecosystems and their sustainability. Given their relatively low productivity and few management practices, freshwater ponds in France are considered as semi-natural ecosystems that provide several ES. From an aquacultural viewpoint, it is important to note that the classification of management practices in the Dombes region is not adapted

to other contexts. The "intensive" practices that produce fish yields of 445 kg/ha/year are far less intense than those that yield tens of thousands kg/ha/year in southern Asia.
Most of these ES (AFISA, MFAU and WQR) depended on intensifying management. In contrast, GCR did not, and was considered as a disservice due to the emission of GHGs. HCFM varied little among levels of intensification because the water cycle is connected more to physical flows (rain, evaporation). Environmental impacts and environmental work of the freshwater ponds were strongly correlated with the intensification of practices. EA provides information that relates environmental impacts to the ES.

Conclusions

The PoESIE method is a step toward valuation of ES, their associated impacts and their sustainability level. However, the PoESIE method does not consider cultural ES, mainly because it is based on an environmental assessment method and related biophysical measurements. Incorporating cultural ES and social aspects into environmental assessment remains a great challenge.

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References

Bennett, A.B., Isaacs, R., 2014. Landscape composition influences pollinators and pollination services in perennial biofuel plantings. Agric., Ecosyst. Environ. 193, 1.
Braat, L.C., 2018. Five reasons why the Science publication "Assessing nature's contributions to people" would not have been accepted in Ecosystem Services. Ecosystem Services. 30, A1-A2.
Chomkhamsri, K., Wolf, M.-A., Pant, R., 2011. ILCD handbook: review schemes for life cycle assessment, Towards life cycle sustainability management. Springer, pp. 107-117.
Farber, S.C., Costanza, R., Wilson, M.A., 2002. Economic and ecological concepts for valuing ecosystem services. Eco. Economics. 41, 375-392.
Haines-Young, R., Potschin, M., 2012. Common international classification of ecosystem services (CICES, Version 4.1). European Environment Agency. 33, 107.
Henriksson, P.J., Guinée, J.B., Kleijn, R., de Snoo, G.R., 2012. Life cycle assessment of aquaculture systems—a review of methodologies. The Int. J. of LCA. 17, 304-313.
Kuittinen, M., Moinel, C., Adalgeirsdottir, K., 2016. Carbon sequestration through urban ecosystem services A case study from Finland. Science of the Total Environment. 563, 623-632.
MEA, 2005. Ecosystems and Human Well-Being: Wetlands and Water Synthesis.
Odum, H. T. (1996). Environmental accounting: emergy and environmental decision making (p. 370). New York: Wiley.
Othoniel, B., Rugani, B., Heijungs, R., Benetto, E., Withagen, C., 2016. Assessment of life cycle impacts on ecosystem services: promise, problems, and prospects. Envir. Sci. & Tech. 50, 1077-1092.
Rugani, B., Benetto, E., 2012. Improvements to emergy evaluations by using LCA. Envir. Sci. & Tech. 46, 4701-4712.
Willot, P. A., Aubin, J., Salles, J. M., Wilfart, A., 2019. Ecosystem service framework and typology for an ecosystem approach to aquaculture. Aquaculture. 734260.
Zhang, Y. I., Singh, S., Bakshi, B. R., 2010. Accounting for ecosystem services in life cycle assessment, Part I: a critical review. Environmental Science & Technology. 44, 2232-2242.

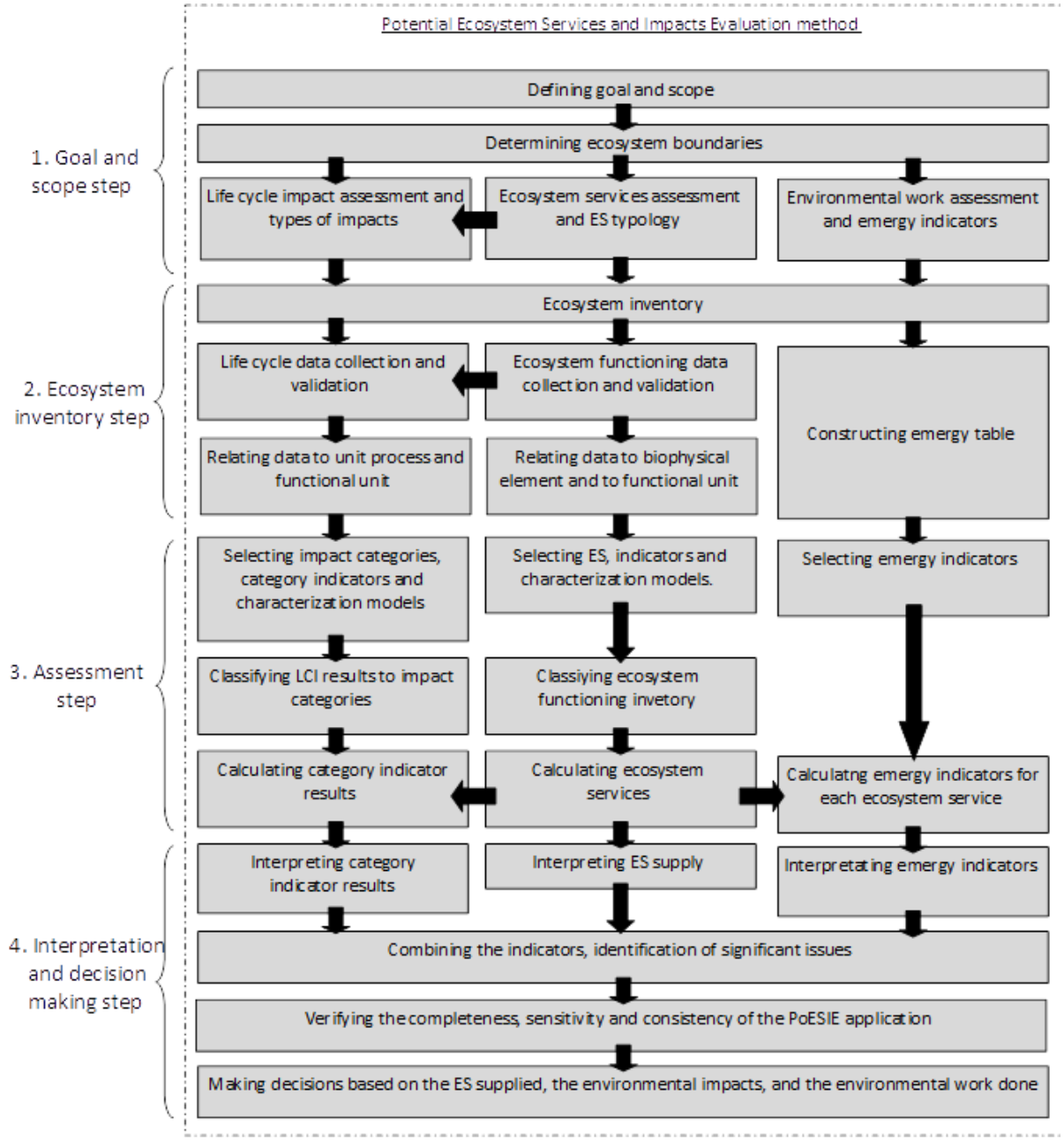


Figure 1. General procedure for applying the PoESIE method

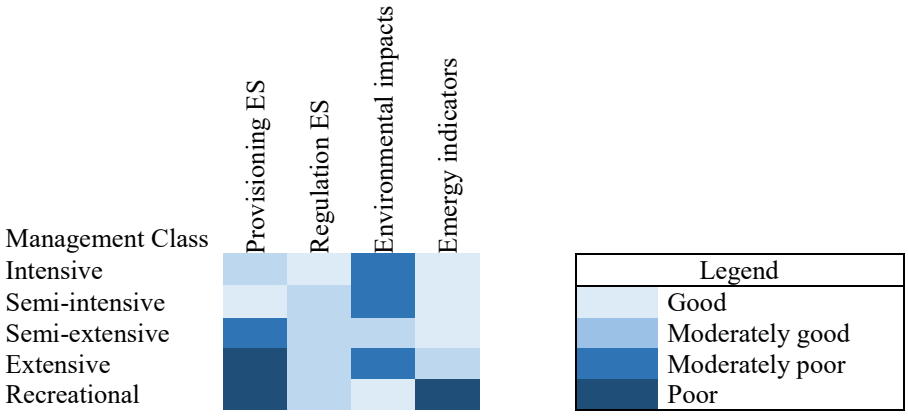


Figure 2. Summary of assessment of ES, environmental impacts and environmental work as a function of fishpond class