

Developing a conceptual framework for delivering better cumulative impact assessment through ecosystem services review

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Abstract

Cumulative impact assessment is one of the most challenging and complex impact assessment practices. Ecosystems Services Review (ESR) has been suggested as a means of helping impact assessment practitioners to both identify the services impacted by proposed developments, and also the indirect and cumulative effects of ecosystem changes external to a specific project. We therefore conceptualise how ESR can be used to deliver cumulative impact assessment by combining the existing approach for integrated assessment used to identify cumulative impacts in Brazilian hydropower planning with a proposed method for ESR from the literature. We test the feasibility of this conceptual approach through a partial assessment of a Brazilian hydropower plan. We find that our conceptual approach can act to bundle the consideration of ecosystem stressors in a way that makes analysis of cumulative impacts practicable and more meaningful to impacted communities. However, further testing in other contexts is still

needed to fully evaluate the potential for an integrated IA and ESR process to efficiently assess cumulative impacts.

1. Introduction

Cumulative impact assessment (CIA) or Cumulative effects assessment (CEA) (CIA used hereafter) represents one of the most challenging processes of impact assessment (IA) (Neri et al., 2016), subject to weak understanding and practice (Sinclair et al., 2017). Judd et al. (2015, p. 254) defined CIA as *“a systematic procedure for identifying and evaluating the significance of effects from multiple sources/activities and for providing an estimate on the overall expected impact to inform management measures”*. However, Greaves and Parrot (2024, p.1) express concern that *“the practice of CEA has struggled to overcome siloed and reductionist underpinnings common in the impact assessment arena”*.

Since CIA was proposed as an instrument to address the limitations of project impact assessments (Council on Environmental Quality, 1978; Spaling et al., 2000) many guidelines have been developed to promote (e.g., Duinker and Greig, 2006; Canter and Ross, 2010; Gunn and Noble, 2012; Canter et al., 2013; Noble, 2015) and to evaluate (e.g., Bragagnolo et al., 2012; Foley et al., 2017; Muir, 2022) this practice.

Duinker et al. (2013) highlight the challenges of CIA based on a review of literature on the topic. One key consideration they identify relates to the difference between an EIA (Environmental Impact Assessment) and a CIA, the former focusing on environmental stressors related to a planned project, with the latter needing to focus on the effects of multiple environmental stressors on particular components. The focus of multiple environmental stressors simultaneously impacting geographical locations creates an additional challenge of establishing scale and temporal boundaries (Therivel and Ross, 2007). This led Canadian researchers to focus on the role of Valued Environmental Components (VECs), generally described as components of the physical, biological or socio-economic environment, as the focus of CIA (Duinker et al., 2013; Sinclair et al., 2017). *“Valued ecosystem component (VEC) selection is a core component of cumulative effects assessment (CEA) and gives direction to impact analysis, mitigation and monitoring. Yet little is known about CEA VEC selection practices”* (Olagunju and Gunn, 2015, p.207). Specifically, it is argued that CIA represents an instrument that

comprises the systematic identification of changes to VECs or valued components (VC) caused by multiple and diverse human activities over time and space (Morrison-Saunders et al., 2014; Noble, 2015). The current practice for CIA in Canada is focused on a restricted number of VECs chosen by a combination of their ecological significance, value to the public, and regulatory requirements (Ball et al., 2013), and practice and associated guidance varies between states/territories (Muir, 2022).

Ecosystem services (ES) represent the benefits that people receive directly or indirectly from functioning ecosystems (Costanza et al., 1997) and ES have sometimes been integrated into IA processes (Gallardo et al., 2022; Gallardo et al., 2023). Baker et al. (2013) suggested the ES approach as another means of overcoming the time and space issues of cumulative effects in Impact Assessment (IA) because the bundled nature of ES allows their consideration to cross environmental stressors and to represent a more holistic framing of effects, helping to focus the assessment. In fact, the mapping of cumulative impacts over time and space using the concept of ES has been the subject of several studies applied to sensitive ecosystems areas (Cooper, 2010; Singh et al., 2017; Wang et al., 2020) or in areas where changing land use affects ES (Clerici et al., 2019; Petroni et al., 2022).

Given the complexity of undertaking CIA, we hypothesize that using an ES approach can increase its efficiency by bundling environmental stressors (Saidi and Spray, 2018) which facilitates the analysis of causal predictions that need to be made. As highlighted by Baker et al. (2013), ES integrates service packages that flow from the environment instead of taking a fragmented look at different topics, considering the affected environment in terms of its ability to offer ES not just as a place to absorb environmental impacts.

The benefits of including ES into IA are argued to encompass: including community perspectives (Rosa et al., 2018); integrating of knowledge areas and participation of affected communities (Rosa and Sánchez, 2016); giving stakeholders some ownership over their ecosystem resources (Partidário and Gomes, 2013; Rozas-Vásques et al., 2018); enabling the framing and valuing of provisioning services for affected beneficiaries (Karjalainen et al., 2013) among others. These benefits are closely related to the VECs that are usually the focus of the CIA.

The World Resources Institute developed the Ecosystem Services Review (ESR) for Environmental and Social Impact Assessment (ESIAs) to promote guidance on integrating ES into IA (Landsberg et al., 2011; 2013). The ESR for IA is a pioneering methodological guide developed by a well-established environmental non-governmental organization collaborating with IA practitioners to integrate ES into different approaches to environmental assessment to identify measures to mitigate project impacts on the benefits provided by ecosystems and measures to manage operational dependencies on ecosystems (Landsberg et al., 2011; 2013). The identification of indirect and cumulative impacts was an expected output of the application of this guidance (Landsberg et al., 2011). However, the authors were clear that this approach requires testing in order to evaluate its efficacy.

Thus, this research aims to conceptualise how ESR can be embedded into impact assessment to deliver cumulative impact assessment. We do this by combining an existing approach for integrated assessment used in Brazilian hydropower planning, develop an approach for embedding ESR into this, and then test its ability to identify cumulative impacts using a Brazilian hydropower planning case study.

In the next section, we set out the methods used to achieve this aim. Section 3 then presents the results achieved based on the application of the methods to the case study; these results are discussed in section 4 before conclusions are reached in section 5.

2. Methods

2.1. Case study focus

In river systems environmental effects are largely cumulative in nature, and even minor individual projects can result in significant effects when collectively considered with other projects that accumulate over time and space (Seitz et al., 2011). Watersheds are under increasing stress from cumulative effects and therefore an effective watershed CIA and associated management actions are needed (Sheelanere et al., 2013).

Hydropower has a pivotal place in the Brazilian electricity mix, providing more than 65% of the country's electricity generation, which is around four times higher than

the worldwide average (Vieira Valadão et al., 2023). Hydropower plants provide renewable energy but are responsible for significant environmental impacts on biodiversity loss, indigenous territories and disturbance of traditional populations, modifications in water flows, among others (Lima Andrade and Santos, 2015).

Since 2003, Integrated Environmental Assessment (IEA) has been applied in the Brazilian hydropower planning sector before applying environmental impact assessment (EIA) for each hydroelectric plant. According to Tucci and Mendes (2006), an IEA has to assess the environmental situation of the watershed considering the implemented and the potential planned hydroelectric projects in terms of: (i) their cumulative effects on natural resources and human populations; and (ii) the current and potential uses of water resources, considering the need to produce energy in balance with the conservation of biodiversity, the promotion of socio-diversity, and the trend of socio-economic development within the river basin. For Westin et al. (2014) the IEA can be understood as a CIA required to study socioenvironmental fragilities and assess the effects of a set of hydropower plants on river basins. As such, IEA practice on hydropower planning provides suitable evidence to facilitate a test of the Landsberg et al. (2011) and Landsberg et al. (2013) method. From 2007 to 2014, 15 IEAs were prepared for Brazilian watersheds, with nine being prepared for Amazonian river-basins (Athayde et al., 2019).

2.2. Case study selection: Teles Pires IEA watershed report

The Amazon region represents 40% of Brazil's territory, comprising more than 60% of all Brazilian water availability, and is the world's largest river basin (Pacheco et al., 2018) split into ten river basins. Of these ten river basins, the Tapajós river basin (which encompasses the Teles Pires watershed and Juruena watershed) is considered the most vulnerable Amazonian River system (Latrubesse et al., 2017). Whilst both watersheds have been subject to an IEA, the Teles Pires watershed was selected as the focus of this study due to its great importance in two (Center-West and North) of the five regions of Brazil, and because the hydroelectric plants are at different stages of implementation which presents CIA challenges. The Teles Pires watershed covers an area of 141,279 km², with 35 municipalities in the states of Mato Grosso and Pará, in the Amazon and Cerrado biomes, and is inside the Territory of the Portal da Amazônia (also

known as the Arc of Deforestation of the Amazon forest), characterised by socio-environmental conflicts caused by the advance of the agricultural frontier and the presence of mining among other economic activities (Bernasconi and Micol, 2008).

According to the IEA of the Teles Pires watershed (EPE, 2009), the energy potential is 3,697 MW (EPE, 2005), distributed across six high hydropower plants (HPP Magessi, Foz do Apiacás, Sinop, Colíder, Teles Pires and São Manoel) and seven small hydropower plants (SHP North Arm, North Arm II, North Arm III, North Arm IV, Canoa Quebrada, Brigadeiro Veloso III) (Figure 1).

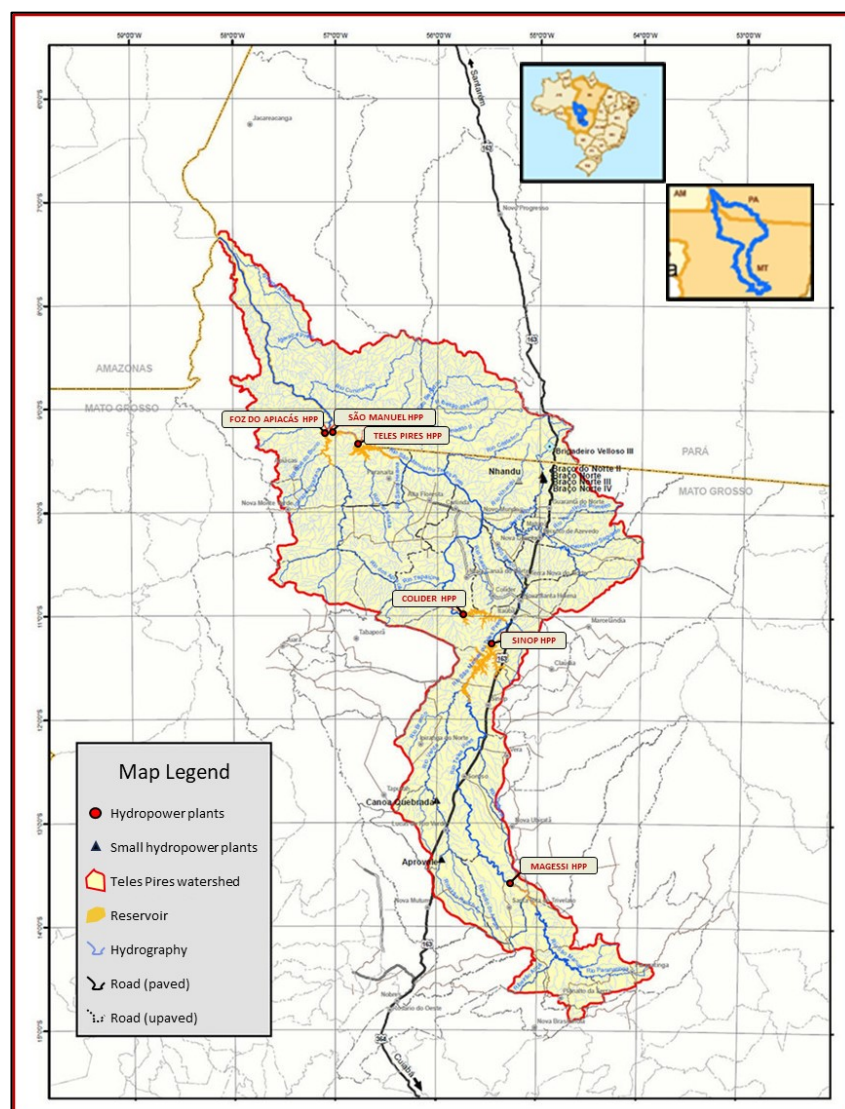


Figure 1 – Hydropower plants inside Teles Pires watershed (modified from EPE, 2009).

According to the IEA of the Teles Pires watershed (EPE, 2009), the IEA process comprises four main procedural steps, as presented in Figure 2, based on the following

assumptions: an interdisciplinary approach is adopted in the studies; a regional view of the watershed is promoted; environmental studies are conducted at the hydropower plant level; feedback is promoted between methodological stages; and a spatiotemporal analysis is conducted throughout the watershed.

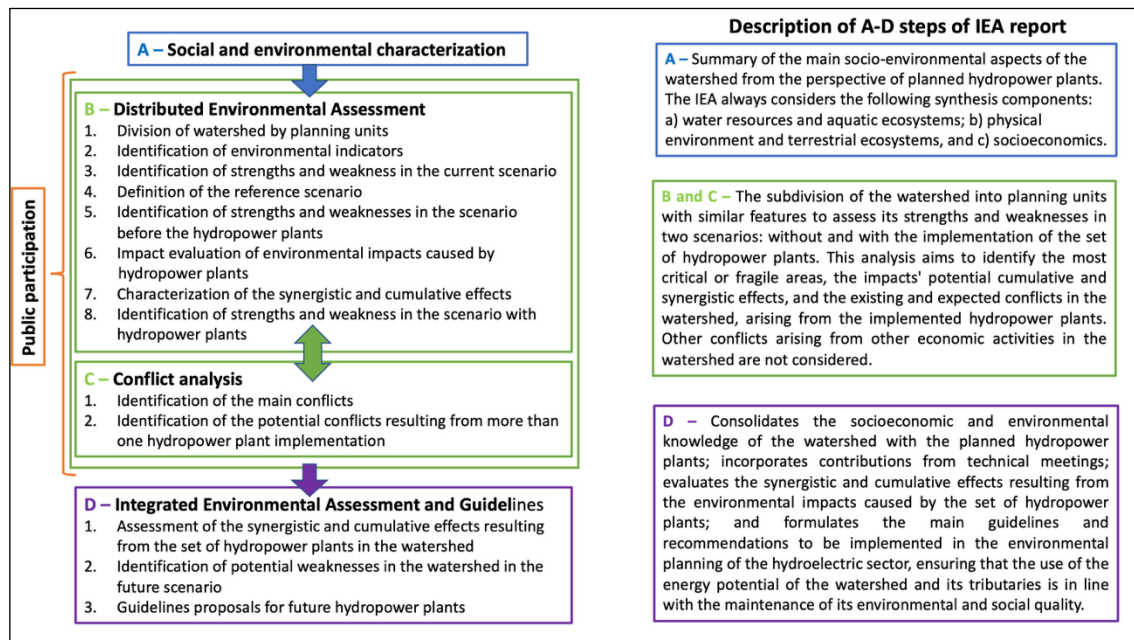


Figure 2 – IEA procedural steps (EPE, 2009).

2.3. Exploring the integration of ecosystem services review with Brazilian IEA

The ESR approach proposed by Landsberg et al. (2011 and 2013) consists of six sequential steps (Figure 3) which are used to integrate ES into other IA instruments (e.g., EIA – Rosa and Sánchez, 2016 and SEA – Partidário and Gomes, 2013).

To integrate the ESR with the IEA, documentary data from the existing IEA was combined with primary data collected to facilitate an assessment of cumulative effects, as explained below. Primary data collection (interviews and surveys) was conducted in the cities of Cuiabá, Sinop, Colíder, Alta Floresta and Paranaíta situated inside and outside Teles Pires watershed (see Figure 1) in 2018 and 2019. Data already presented in the Teles Pires IEA (EPE, 2009) were used as the initial data source to avoid the need for new data collection effort where possible. The aim was to not reanalyse the same set of data presented in this IEA, but to embed it within the ESR, supplemented with

additional data collection as necessary. Figure 3 presents the premises of this research on exploring which elements of six steps of the ESR are already covered in the IEA and which require additional study in order to deliver CIA. Figure 4 presents our conceptualisation of how to integrate IEA and ESR; practitioners can use this as their instruction on how to conduct CIA using ESR.

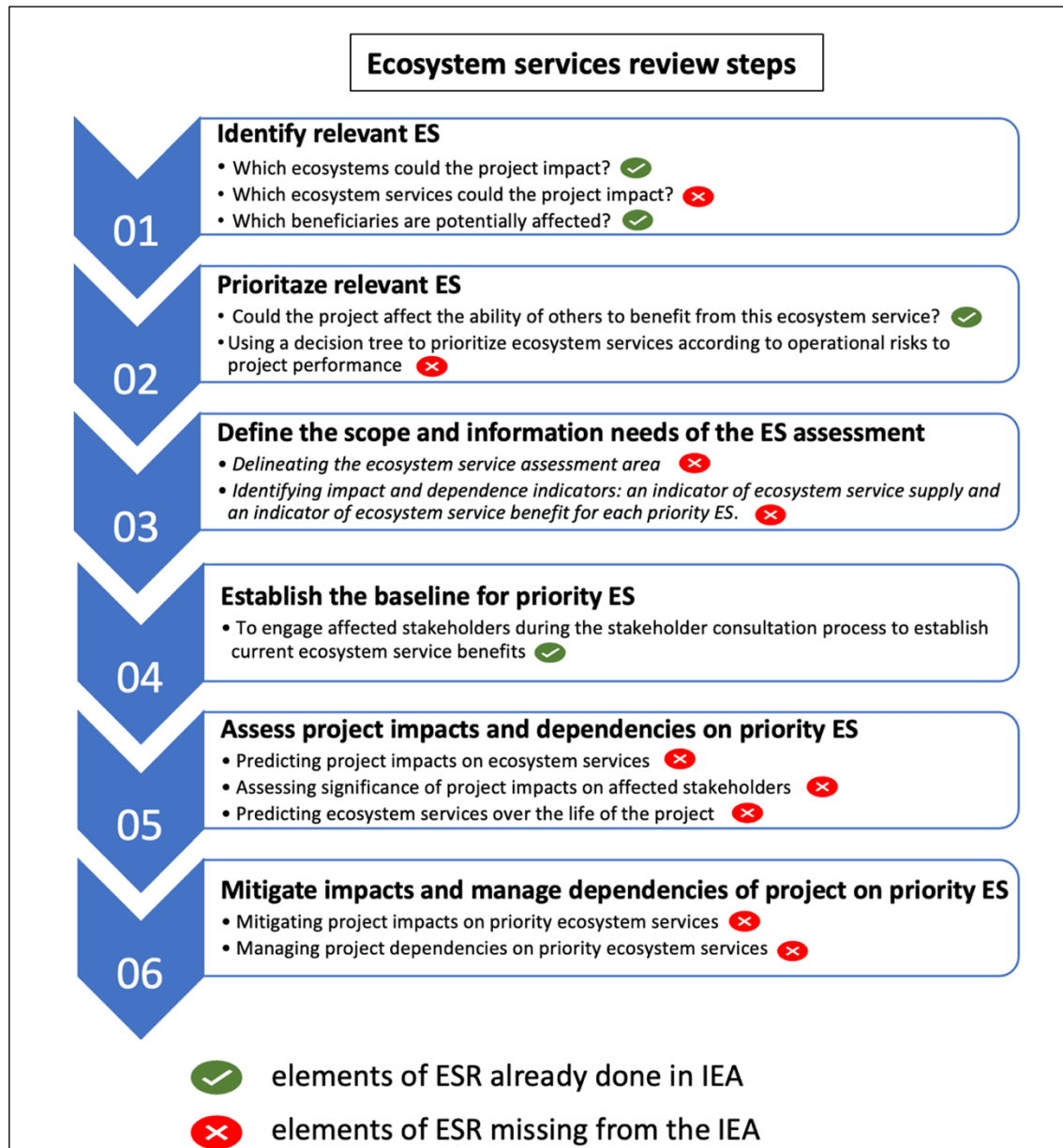


Figure 3 – The ESR and the IEA connections and elements already completed in the IEA and those missing from the IEA.

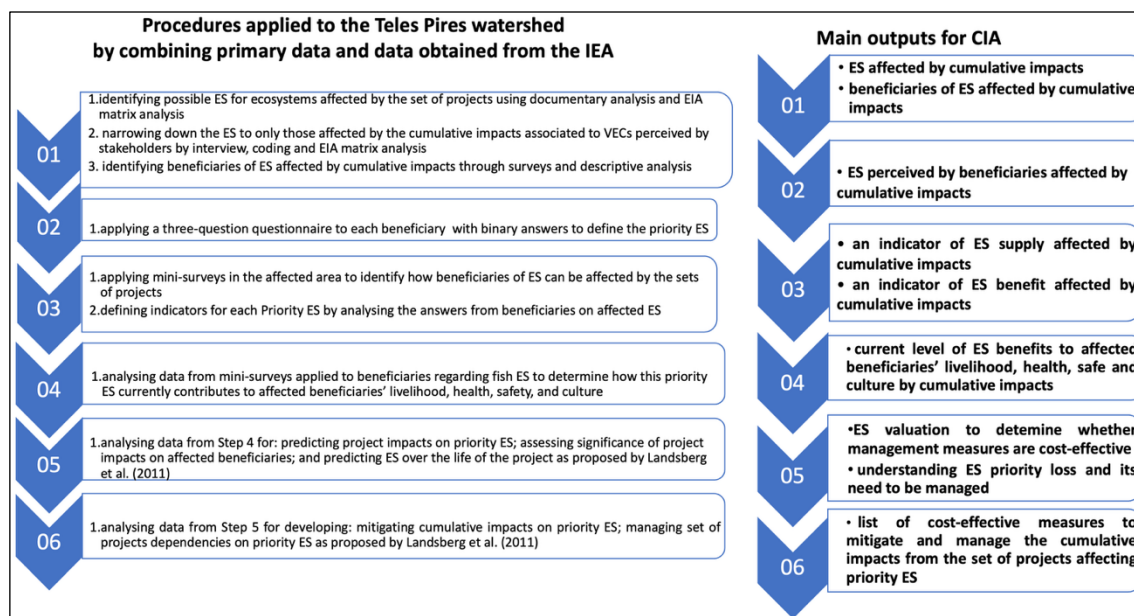


Figure 4 – The conceptualisation of how to integrate IEA and ESR.

From Figure 4, for each step of ESR applied to the Teles Pires watershed, the methods used are presented below:

- **Step 1: Identify relevant ES**

- 1) identifying possible ES for ecosystems affected by the set of projects using documentary analysis and EIA matrix analysis

The ES have to be evaluated for the different ecosystems within the planning area of influence. To characterize the ecosystems that will be affected by the cumulative impacts from the set of hydropower plants within the Teles Pires watershed, information on vegetation cover and land use contained in the IEA report was interpreted following some recommendations from Landsberg et al. (2013). Table 1 shows how the different ecosystems were deductively coded and classified in the main affected ecosystems.

Table 1: Main affected ecosystem coded and classified in the Teles Pires watershed

Forest ecosystem	Forest Formations	Dense Rainforest/Tropical Rainforest: Submontane
		Dense Alluvial Rainforest
		Open Rainforest (Dense Forest Facialities)
		Seasonal Forest (Deciduous or Semideciduous)
	Savanic Formations	Contact Savanna/Ombrophylous Forest
		Wooded Savanna (Cerrado)
		Forested Savanna (Cerradão)
		Open Tree Savanna (Campo Cerrado)
		Savana Park (Campo Sujo)
		Grassy-woody savanna (Campo Limpo)

Riparian forest	Alluvial Seasonal Forest (Gallery Forest and Riparian Forest)	Savanna/Seasonal Forest Contact
		Riparian Formations
		Ombrophylous Forest/Seasonal Forest
	Campinarana	Wooded Campinarana
		Grassy-woody Campinarana
	Pioneer Formations (Pathways, Wet Areas)	
	Secondary Vegetation	
Aquatic ecosystem	Bodies of water (Rivers, lakes, groundwater)	
Anthropic use	Anthropic Use	Agriculture
		Livestock (Planted and Natural Pastures)
		Forestry

This identification of ES and ES subcategories was based on the list of the ES considered by Landsberg et al. (2013) and Rosa and Sánchez (2016), which considers provisioning, regulating and cultural services, but does not explicitly include the supporting services category, which is implicitly considered in the other categories. An environmental impact assessment (EIA) matrix method (Leopold, 1971; Weldu and Assefa, 2016) was used to associate the main ES categories and subcategories with the main affected ecosystems within the area of the set of hydropower influence.

- 2) narrowing down the ES to only those affected by the cumulative impacts associated with VECs perceived by stakeholders through interview, coding and EIA matrix analysis

The definition of VECs was carried out through interviews with some stakeholders as recommended by Luyet et al. (2012). 15 Interviewees identified in the IEA report as being stakeholders or people potentially affected by the cumulative impacts from the set of hydropower plants (including Environmentalists, Research Institutions, Fishermen, Inn Owners, Entrepreneurs, Farmers, People relocated because of Dams, MAB, City Halls, Health Bodies, Concessionaires, and local and indigenous people) were interviewed in three municipalities: two inside the watershed (Colider and Alta Floresta) and one outside the watershed (Cuiabá – the capital of the state of Mato Grosso) (see Figure 1). While the interviewees represent public institutions (city hall, universities, research centers), and private institutions, and civil society (unions, fishing colonies, NGOs), both the representative of the hydroelectric sector and the representative of indigenous groups chose not to participate. Interviewees were asked to answer two questions: 1 – What are the main problems faced by the Teles Pires watershed in social, environmental, and economic terms? Question 2 – Of the issues you

raised, which would be the most important? Make a list with the most important issues ordered by their importance?

To analyse these data to identify the main VECs the answers were subjected to content analysis (Kleinheksel et al., 2020). A list of VECs compiled from Olagunju and Gunn (2015) and Ball et al. (2013) was used as an analytical framework for guiding deductive content analysis of VECs. Based on semantic similarity, the responses were grouped into categories and then ranked according to the frequency of mentions in response to the second question. This process enabled the identification of the VECs perceived as the most relevant by the stakeholders. The most cited are taken to represent the main VECs.

The main VECs prioritized by the interviewees were associated with the cumulative impacts described in the IEA report (see step B in Figure 2), thus directing the focus on the cumulative impacts related to the VECs actually perceived by the stakeholders. To represent this association between VECs and cumulative impacts, indicators of cumulative impacts were established. These indicators were used to synthesize the association between VECs and cumulative impacts with ES. An EIA matrix method was used again to associate the relevant cumulative impact indicator with the ES potentially offered by affected ecosystems. This procedure narrows down the ES to only those that will be affected by the cumulative impacts, ensuring focus and rigor in the CIA scope.

3) identifying beneficiaries of ES affected by cumulative impacts through surveys and descriptive analysis

To identify the main beneficiaries of the ES affected by cumulative impacts, the IEA report data and primary data from interviewees were used. Data presented in the IEA regarding possible conflicts and key actors (see step C in Figure 2) allowed the identification of a broad list of potential beneficiaries. However, only those beneficiaries that are related to the main VECs should be identified. A semi-structured questionnaire adapted from Rosa and Sánchez (2016) was designed based on the VECs and ES affected by the cumulative impacts to identify the main beneficiaries. Due to the size of the Teles Pires watershed and the predominance of rural and/or forested areas, it was not possible to visit all the 35 municipalities within the watershed. The selection of

municipalities was based on the accessibility of the main roads (BR-163, MT-206, and MT-208) to the important socioeconomic centers (see Figure 1). The only exception was Paranaíta City, which was included since the interviewees had highlighted several changes suffered by this city since the implementation of the hydropower plants. Of all potential actors, for some municipal departments, staff of concessionaires, and indigenous communities, questionnaires could not be applied as individuals were either unavailable or did not return contact. The questionnaire was applied to 46 beneficiaries (fishermen, inn owners, entrepreneurs, farmers, and an energy concessionaire representative) through a mini-survey (defined as between 25 and 50 respondents – Bihu, 2021) with 68 questions, in March 2019, in the municipalities of Sinop, Colíder, Alta Floresta, and Paranaíta, over a geographical area extending over 371.7 km of the river. “Convenience” sampling was used (interviewing interested parties in places where they are likely to be or where they will meet the campaign), rather than attempting a representative sample of beneficiaries, because the objective was to demonstrate the applicability of the ES approach in CIA. To interpret the questionnaires, a descriptive analysis of the responses was used. Thus, the identification of ES beneficiaries was carried out based on the association between the information obtained from the questionnaires, field observations, and the conflicts (see step C-1 and C-2 in Figure 2) that affect actors in the Teles Pires watershed as shown in Table 2.

Table 2: Example of how beneficiaries of ES categories were identified

ES/Subcategories		Benefits	descriptive analysis	Identification of ES Beneficiaries
Food	Crops	Food/Agricultural products	Communities that live in the city but work directly on the farms near the Sinop HPP reservoir. Rural residents who live near the reservoir and residents of settlements. Large and small farmers and ranchers who have land near the Sinop HPP reservoir.	Farmers; Cattle ranchers; Urban and rural communities
	Livestock	Food		
	Capture fisheries	Food/Fish	Fishermen, whether or not they are part of the Fishermen's Colony of SINOP and Regions - COLONY Z-16. Owners of hotels and inns whose main activity is sport fishing, mainly in the Alta Floresta Paranaíta region. Indigenous communities; Urban and rural communities that uses fish as a source of food	Fishermen; Owners of Sport Fishing Inns; Indigenous communities; Urban and rural communities

- **Step 2: Prioritize relevant ES**

The focus of this selection is on local beneficiaries (locally affected communities, i.e., ES beneficiaries) and ES essential to maintaining their quality of life (Landsberg et al., 2013; Rosa and Sánchez, 2016). The ES prioritization considered the potential for cumulative impacts to alter the beneficiary's ability to access the ES and its importance for them. The process of selecting priority ES was based on Landsberg et al. (2013) whereby the beneficiaries' dependence on the potentially impacted ES is analysed. This step aims to quantify the provision of the most important ES for the region. To this end, the prioritization considered the potential for cumulative impacts to alter the beneficiary's ability to access ES and the importance of ES for the beneficiary.

- 1) applying a three-question questionnaire to each beneficiary with binary answers to define the priority ES

Thus, each beneficiary, from the 46 beneficiaries interviewed in Step 1, was asked, in binary form, three questions: 1. Can hydroelectric plants impact the ability of others to benefit from this ES? 2. Is this ES important for the health, safety, or culture of its beneficiaries? 3. Do beneficiaries have an alternative to access this ES and is there a possibility of replacing this ES? To identify which ES can be considered priority the answers were analysed as proposed by Landsberg et al. (2013): one ES was considered a priority when the answers to the first two questions were “yes” or “I don’t know” and if the answer to the third question was “no” or “I don’t know”.

- **Step 3: Define the scope and information needs of the ES assessment**

All priority ES have to be evaluated, preferably in a quantitative way (Burkhard et al., 2012).

1. applying mini-surveys in the affected area to identify how beneficiaries of ES can be affected by the sets of projects

A questionnaire is applied comprising ten questions: the first three concern the socioeconomic profile of the beneficiaries; questions four to eight address the beneficiaries' perception of how ES is being affected; and the last two are related to the

quality of the ES and the meaning of the ES for beneficiaries in this region. Questions one to nine were analyzed using simplified statistics and question 10 using qualitative analysis.

2. defining both indicators for each priority ES by analysing the answers from beneficiaries on affected ES

We follow Landsberg et al. (2011) to define the indicator of ES supply and the indicator of ES benefits. For the indicator of ES supply we tried to define one that represents the maximum level of ES that the affected ecosystem can offer without damaging its future ability to offer. And for the indicator of ES benefits, those that represent how changes in the provision of ES may modify the supply of ES for human well-being and for the performance of the project.

- **Step 4: Establish the baseline for priority ES**

This step aims to understand the relationship between the ES and its benefits, i.e., how the priority ES currently contribute to the livelihoods, health, safety or culture of affected stakeholders.

1. analysing data from mini surveys applied to beneficiaries regarding ES relevant to them to determine how the priority ES currently contributes to affected beneficiaries' livelihoods, health, safety and culture

Data from the previous step (Step 3) based on the beneficiaries interviewed were analysed to predict the set of projects' impacts on priority ES, thus identifying the significance of cumulative impacts in actual and future conditions, also considering other potential undertakings in the area of influence. Thus, based on the questions asked in the mini survey, the current level of benefit was established, considering the percentage of the population that depends entirely on specific activities (e.g., fishing) and the perception of how their activity is modified by the implementation of the projects, that is, by the cumulative impacts.

- **Step 5: Assess project impacts and dependencies on priority ES**

According to ESR (Landsberg et al., 2011) this step aims to assess cumulative impacts and the dependencies of the set of projects on priority ES and thus identify which of them require mitigation and management measures.

1. analysing data from Step 4 for: predicting project impacts on priority ES; assessing significance of project impacts on affected beneficiaries; and predicting ES over the life of the project as proposed by Landsberg et al. (2011)

In this step, a schematic flowchart is presented, built with the purpose of illustrating how the current and future cumulative impacts can affect the priority ES to identify the need to propose mitigation and management measures and provide elements for carrying out the next step (step 6).

- **Step 6: Mitigate impacts and manage dependencies of project on priority ES**

According to ESR (Landsberg et al., 2011) this step aims to discuss the application of mitigation measures and the management dependencies on priority ES to integrate the environmental and social management plans for facing cumulative impacts.

1. analysing data from Step 5 for developing: mitigating cumulative impacts on priority ES; managing set of projects dependencies on priority ES as proposed by Landsberg et al. (2011).

In this step, based on the results of Step 4 and Step 5, mitigation and management measures are proposed for each of the priority ES facing cumulative impacts.

3. Results

This section presents the results of the six steps of the conceptual CIA process outlined in Figure 4 to show how to embed the ES approach into IA in the context of the Teles Pires watershed.

3.1. Step 1: Identify relevant ES

- 1) identifying possible ES for ecosystems affected by the set of projects using documentary analysis and EIA matrix analysis

Table 3 illustrates the potential ES offered by the main affected ecosystems in the Teles Pires watershed.

Table 3 – Potential offered ES by the main ecosystems

Ecosystem Services /subcategories		Main affected ecosystems *			
		Forest ecosystem	Riparian forest	Aquatic ecosystem	Anthropic use
Provisioning services	Food	Crops			
		Livestock			
		Capture fisheries			
		Aquaculture			
		Wild foods			
	Biological raw materials	Timber and Other wood products			
		Fiber and resins			
		Animal skins			
		Sand			
		Ornamental resources			
	Biomass fuel				
	Freshwater				
	Genetic resources				
	Biochemicals, natural medicines, and pharmaceuticals				
Regulating services	Regulation of air quality				
	Regulation of climate	Global			
		Regional and local			
	Regulation of water timing and flows				
	Erosion control				
	Water purification and water treatment				
	Regulation of diseases				
	Regulation of soil quality				
	Regulation of pests				
	Pollination				
	Regulation of natural hazards				
Cultural	Recreation and ecotourism				
	Ethical and spiritual values				
	Educational and inspirational values				
Offered ES					

* - Forest Ecosystems are formed by Forest Formations (Dense Rainforest/Tropical rainforest, Dense Alluvial Rainforest, Open Rainforest and Seasonal Forest) and Savanic Formations (Contact Savanna, Wooded Savanna, Open Tree Savanna, Savana Park, Grassy-woody savanna); Riparian Forest are formed by Alluvial Seasonal Forest (Savanna/Seasonal Forest Contact, Riparian Formations, Ombrophylous Forest/Seasonal Forest), Campinarana (Wooded Campinarana, Grassy-woody Campinarana), Pioneer Formations and Secondary vegetation. Aquatic ecosystem is bodies of water (Rivers, lakes, groundwater). Anthropic use is formed by agriculture, livestock and forestry.

The 27 identified ES represent a wide range of interactions between the four different affected environments and the proposed actions within the planning area of influence. Results from the interviews with stakeholders allowed the identification of six categories of important categories related to VECs: food (6.7%), security (6.7%),

sociocultural issues (6.7%), biodiversity (20%), land use (26.7%), water resources (33.2%); the three most cited were those considered as the main VECs.

- 2) narrowing down the ES to only those affected by the cumulative impacts associated with VECs perceived by stakeholders through interview, coding and EIA matrix analysis

The cumulative impacts were associated with the three VECs prioritized by the interviewees (Water resources, land use, biodiversity), as presented in Table 4. Cumulative impact indicators were inductively derived from this association.

Table 4 - Cumulative Impacts associated with the VECs confirmed by the beneficiaries as presented in Step 1.

IEA Teles Pires		VECs			Cumulative Impact indicators (codes)
IEA - Synthesis Component (Figure 2 – Part A - description)	Cumulative impacts (identified in the IEA Report – see step B-7 in Figure 2)	Water resources	Land use	Biodiversity	
Water resources and aquatic ecosystems	Change in the River Regime	X			flooded area (IDA01); residence time (IDA02); flow regularization index (IDA03)
	Eutrophication Potential of Reservoirs	X			phosphorus concentration (IDA04)
	Loss of Specific Ichthyofauna Habitats	X		X	flooded or affected rapids areas (ID05)
	Risk of Mercury Contamination	X			areas of illegal mining activity (ID06)
Physical Environment and Terrestrial Ecosystems	Loss of areas with mineral potential		X		flooded area (IDT01)
	Reduction and fragmentation of vegetation cover			X	flooded area (IDT01)
	Loss of habitat to wildlife			X	flooded area (IDT01)
Socioeconomics	Loss of productive areas		X		anthrophization rate (IDS01)
	Change in Land Structure		X		number of affected properties (IDS02)
	Pressure on Health Care				
	Municipal Revenue Growth				
X		cumulative impacts related to VECs			

Then these indicators which synthesize the association between VECs and cumulative impacts were related to the potential ES offered by the affected ecosystems

(Table 3). The ES affected by the cumulative impacts that affected VECs perceived by stakeholders are presented in Supplementary data, Table S1, which simply identifies which indicators are associated with which ecosystem services – and allows those ES which are not associated with cumulative impacts to be identified and removed from subsequent analysis.

- 3) identifying beneficiaries of ES affected by cumulative impacts through surveys and descriptive analysis

The next stage of the analysis focuses only on (19) ES with cumulative impacts associations and identifies the specific benefits and beneficiaries (see supplementary data, Table S2).

Table S2 - ES beneficiaries affected by cumulative impacts.

		ES/Subcategories	Benefits	ES Beneficiaries
Provisioning services	Food	Crops	Food/Agricultural products	Farmers; Cattle ranchers; Urban and rural community
		Livestock	Food	
		Capture fisheries	Food/Fish	Fishermen; Owners of Sport Fishing Inns; Indigenous communities; Urban and rural communities
		Wild foods	Fruits/Game foods	Indigenous and rural communities
	Biological Material	Timber and Other wood products	Wood	Indigenous and rural communities
		Fiber and resins	Vine, ropes	
		Ornamental resources	Plant seedlings	
	Biomass fuel		Firewood	Indigenous and rural communities
	Freshwater		Clean water/ Electricity/ Water for animals and for irrigation	Farmers; Cattle ranchers; Urban and rural community dealerships
	Genetic resources		Genetic information for biotechnology	Research Institutions; Entrepreneurs
Regulating services	Biochemicals, natural medicines, and pharmaceuticals		Medicinal plants, pharmaceuticals	Indigenous and rural communities
	Regulation of climate	Regulation of air quality	Good air quality	Population of Teles Pires watershed
		Global	Rain and temperature regulation	Population of Teles Pires watershed
		Regional and local		
	Regulation of water timing and flows		Prevention of floods and availability water	Fishermen; Indigenous communities; Rural communities; Farmers; Cattle ranchers; Dealerships
	Erosion control		Clean water and maintaining soil quality	Fishermen; Indigenous communities; Rural communities; Farmers; Cattle ranchers;

			Dealerships
	Water purification and water treatment	Clean water	Fishermen; Urban and rural communities; Farmers; Cattle ranchers; concessionaires
	Regulation of diseases	Maintenance of health	Population of Teles Pires watershed
Cultural	Recreation and ecotourism	Leisure/Income tourism	Inn Owners; Urban and rural communities
	Ethical and spiritual values	Fruition of ecosystems	Urban and rural communities; Indigenous communities
Brief description of the main groups of beneficiaries: a) urban and rural communities in the Teles Pires watershed: 675,545 inhabitants (2007): 68% urban and 32% rural; HDI: 0.737; limited revenues and high dependence on transfer of resources from the Union; predominantly low income; minimal water and sewage infrastructure; irregular settlements in rural areas; socioeconomic conflicts between farmers and ranchers and settlers. b) farmers and ranchers: large and medium-sized estates predominate; wood production, large-scale and extensive livestock farming, soybean, corn and rice crops; c) fishermen: for subsistence, tourist fishing and professional fishing with around 400 fishermen; d) indigenous communities: there are 6 indigenous lands with 5 ethnicities: Bakairi, Santana, Apiaká/Kayabi, Kayabi (includes Kayabi Gleba Sul) and Munduruku (with 7000 indigenous people).			

This identification of specific benefits and beneficiaries makes it possible to observe that the same group of beneficiaries may be harmed by the reduction of supply in one or more ES. This allows the design of mitigation actions to be directed at cumulative impacts not only for the most affected ES, but also to provide some safeguards for those who will benefit less from this ES.

3.2. Step 2: Prioritize relevant ES

Based on the methodological step set out in step 2, section 2.3 above, an ES was considered a priority when the answers to the first two questions (1. can hydroelectric plants impact the ability of others to benefit from this ES? 2. Is this ES important for the health, safety, or culture of its beneficiaries?) were “yes” or “I don’t know” and if the answer to the third question (3. do beneficiaries have an alternative to access this ES and is there a possibility of replacing this ES?) was “no” or “I don’t know”. Table S3 in supplementary data sets out the findings.

Of the 19 ES affected by cumulative impacts in the Teles Pires watershed (presented in Table 3), only 12 ES (crops, livestock, capture fishing, timber and other wood products, freshwater, regulation of climate, regulation of water timing and flows, erosion control, water purification and water treatment, regulation of diseases, recreation and ecotourism, ethical and spiritual values) were considered as priority ES

by their beneficiaries (Table S3). Provisioning and regulating services are the ES most affected by cumulative impacts in the Teles Pires watershed. Provisioning ES are crucial to different types of Amazonian communities due to the lack of infrastructure, basic sanitation, and employment opportunities as revealed by the affected beneficiaries. At this stage, the priority ES which will be affected by cumulative impacts stand out, allowing greater targeting of the impact analysis and its consequent mitigation actions. Unlike what is regularly practiced at CIA, where the approach is broader, mitigation resources can be used more effectively by using the ES approach.

3.3. Step 3: Define the scope and information needs of the ES assessment

Due to limited time and financial resources for developing this research only one priority ES from only one group of beneficiaries (interviewed in March 2019) was evaluated for testing this step for embedding the ESR approach in CIA as the research is illustrative.

1. applying mini-surveys in the affected area to identify how beneficiaries of ES can be affected by the sets of projects

To evaluate the priority ES “fishing”, from the perspective of five beneficiaries (fishermen; owners of sport fishing inns; indigenous, rural, and urban communities), only fishermen, were interviewed. In the assessment of the ES “fishing”, 32 fishermen who are members of COLONY Z-16, headquartered in SINOP, were interviewed. The interviews took place in March 2019 at a meeting of associated fishermen to provide training and resolve issues related to the association. That year, there were around 400 fishermen in the Teles Pires watershed, and 300 fishermen were members of COLONY Z-16. Due to the qualitative analysis of the data, there was no concern with the sample size.

Within the 12 priority ES, the ES “food” (the most affected category), and its subcategory “fishing”, were selected due to their great importance for the communities located in the Teles Pires watershed. The importance of fishing was reinforced by Ziv et al. (2012) and Fearnside (2019) who highlighted several cases of sequenced dams

causing major impacts on fishing populations. Table 5 presents these results of 32 fishermen interviewed.

Table 5 – Questionnaire responses on the effects of cumulative impacts on food-fishing ES.

Question 1 – How long have you been fishing?
Up to 10 years: 20.6%; From 10 to 20 years: 32.4%; More than 20 years: 47.1%
Question 2 - Does all of your family income come from fishing?
Yes: 58.8%; No: 41.2%. Although most fishermen earn their income exclusively from fishing, many of them need to supplement it with other activities.
Question 3 – If you answered “no” to the previous question, what is your other family income?
Local business: 57.1%; Employee in private sector: 21.4%; Employee in public sector: 14.3%; self-employed in sales: 7.1%
Question 4 - Have hydroelectric plants reduced the number of fish you catch?
Yes: 94.1%; No: 5.9%. There was a drastic drop in the quantity of fish caught with the operation of hydroelectric plants in the watershed
Question 5 – If so, how many kg did you usually fish per month?
Question 6 - How many kg do you currently fish per month?
Before the hydroelectric plants: they caught 12,340 kg/month of fish and currently, they fish 8,190 kg/month of fish, which corresponds to a reduction of 33.6%
Question 7 - Have you noticed any changes in the fish caught since the implementation of hydroelectric plants? (Ex. size of fish, population, habits, taste, etc.).
Question 8 - If there are changes? Which are they?
Yes: 91.2%; No: 8.8%; Size: 46.3%; number: 1.8%; Variety/Diversity: 11.9%. The vast majority of fishermen have noticed different changes in the fish caught in the Teles Pires watershed
Question 9 - Has the water quality in the river worsened, improved or remained the same after the implementation of hydropower plants?
Improved: 0.0%; Worsened: 72.1%; Remained the same: 27.9%
Question 10 - What do the rivers inside the Teles Pires watershed mean to you in 3 words?
The fishermen used the following words: Everything; Wealth; Life; Money; Leisure; God; Fun; Nature; Life; Hope; Development; pleasure. The most cited words were Life, Wealth and Everything.

2. defining indicators for each Priority ES by analysing the answers from beneficiaries on affected ES

According to the beneficiaries' perception (Table 5), the fishing priority ES was greatly affected with 91.2% of respondents perceiving negative changes in fishing after the implementation of hydropower plants in the Teles Pires watershed related to size of catch (46.3%), as corroborated by the reduction in quantity of fishing after the implementation of hydropower plants in the Teles Pires watershed. These results align with those observed by Lees et al. (2016) who highlight that hydropower plants can alter connectivity, cause fragmentation, and interfere with the reproduction, size, and variety of fish populations, causing loss of species along with the ES they provide. The indicator of ES supply is, thus, the “quantity of fish that can be caught in the rivers affected by the

group of projects” and the indicator of ES benefit is the “number of fish in the rivers affected by the group of hydropower projects”.

3.4. Step 4: Establish the baseline for priority ES

From Table 5 it is possible to establish the current level of benefits on the priority ES that corresponds to: 58.8% of the population of fishermen depending on fishing; 94.1% of the fishermen population perceive a huge reduction in in the quantity of fish caught with the operation of hydroelectric plants in the watershed; they also perceived a reduction of 33.6% in terms of weight of fish caught.

3.5. Step 5: Assess project impacts and dependencies on priority ES

In this step the assessment of cumulative impacts and the set of project dependencies on priority ES and the determination of whether these ES require mitigation and management measures is conducted. Figure 5 presents a hypothetical representation of the steps to carry out the current and future assessment of the set of hydropower projects and their respective cumulative impacts.

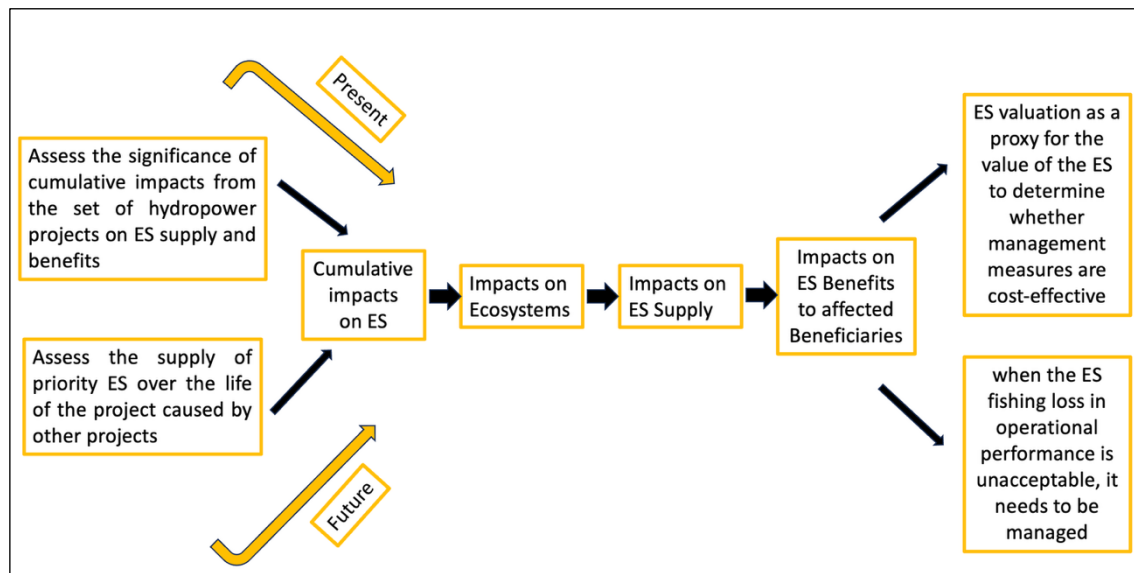


Figure 5 – Hypothetical representation of the steps to carry out the current and future assessment of the set of hydropower projects and their respective cumulative impacts on priority ES.

Figure 5 should be detailed for each priority ES so that it not only assesses the significance of current cumulative impacts, but also future ones, to be considered to define and qualify applicable mitigation and management measures in the next step of ESR.

3.6. Step 6: Mitigate impacts and manage dependencies of project on priority ES

This step identifies the measures to mitigate the cumulative impacts on priority ES and to manage dependencies on ES to be integrated into the environmental and social management plans. Figure 6 briefly discusses the mitigation of cumulative impacts on ES fishing and its benefits and the management set of projects dependencies on ES based on suggestions in the literature.

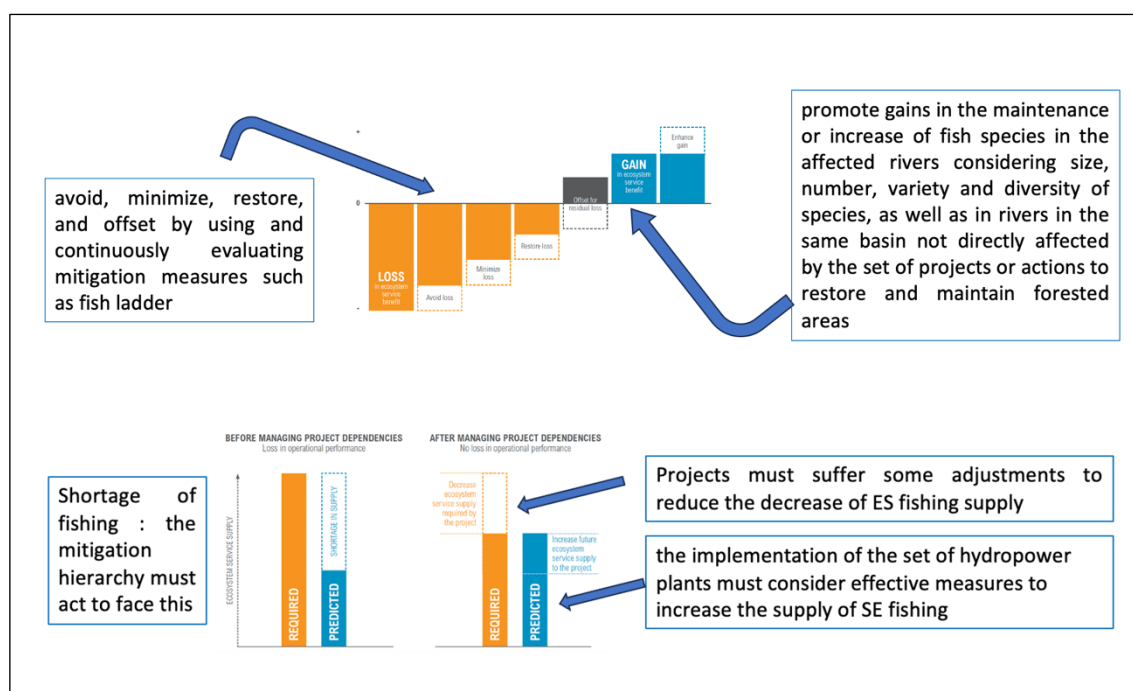


Figure 6 – Examples of how to mitigate and manage the priority ES affected by cumulative impacts. Adapted from Landsberg et al. (2011).

Figure 6 shows examples of how mitigation hierarchy measures can be applied to decrease the significance of cumulative impacts on ES fishing and how the set of hydropower projects dependencies can be managed during their lifetimes in order to increase the supply of the priority ES.

4. Discussion

This ESR details both the ES that will be most affected by the cumulative impacts and provides evidence to identify beneficiaries that will be most harmed by the cumulative impacts and thus how to mitigate them. These results show that integrating ESR into an IA process can facilitate a focus on the local effects of cumulative impacts. This allows a better understanding of the effects of cumulative impacts not only for the most affected ES, but also on the groups that rely most on these ES.

The proposed method established a much more focused consideration of impacts on stakeholders that are difficult to map and consider in conventional CIA or IA processes. The example of the analysis of the priority fishing ES by the ESR details important elements for an adequate impact assessment and mitigation of impacts on ES (Partidário and Gomes, 2013) with the adequate participation and listening of affected communities (Rosa and Sánchez, 2016). The involvement of the directly affected population is still a gap in the assessment of cumulative impacts in hydropower planning (DeLong and Fox, 2015), limited mainly to the communication of results (Pomeroy and Douvere, 2008), and this approach indicates how to fill this gap efficiently.

It is clear that integration of ESR with IA to analyse and mitigate cumulative impacts is possible, and we would argue that the ESR approach taken can help to improve the efficiency of CIA because:

- The scoping stage is an effective starting point for integrating the ESR approach with the IEA as it focuses resources on the key components.
- The focus on ES allows the CIA to give attention to the impacted communities by analysing the cumulative effects on the services they rely on. This increases efficiency by preventing a focus on environmental components that do not lead to significant cumulative issues for end users.
- A focus on ES allows the identification of potential sources of conflict – the loss of services that communities and other stakeholders rely on which may not obviously be threatened by individual projects, but whose loss will create hardship and may lead to action being taken against projects.

- The main contributions of the ESR approach in IA occur in the application of the concept of ES itself, which is a way of communicating and understanding the socio-environmental relationship (Fish et al. 2016) through from an anthropocentric view of ecological or biophysical issues (Scholte et al., 2016). In this sense, the benefits of nature are translated into the importance of biodiversity and nature itself to affected parties (Rosa et al., 2018).
- Priority ES identification allows an understanding of the effects that accumulate on the same ES and how they affect the beneficiaries as emphasized by Baker et al. (2013).
- This perspective also includes discussing synergies and trade-offs regarding cumulative impacts as presented by Wang et al. (2020) that can be found by embedding the ES approach in IA.
- The understanding of the pressures on the receptors identified by the ES approach can facilitate emergence of the risk assessment perspective in CIA as proposed by Judd et al. (2015), also reducing failures to protect important values for local communities as identified by Muir (2022).

5. Conclusions

We explored embedding the ESR into IA as a way of improving CIA, by conceptualising an approach and partially testing it using a Brazilian case. This research also provides evidence that supports the application of the ES concept as an innovation to the practice of IA to overcome recurring deficiencies such as the integration of knowledge and vision of affected communities as highlighted by Rosa and Sánchez (2016).

The test of the ESR by embedding it into the Integrated Environmental Assessment (IEA) for planning the Brazilian hydropower sector highlighted opportunities for improving the focus of CIA beyond the tested context.

All important steps to build the CIA are achieved using the ESR. From the potential benefits derived from the ES approach, the advantages of its adoption lie in an integrated view of the environment and associated communities in the face of the effects of cumulative impacts.

Westin et al. (2014), Lima Andrade and Santos (2015), Gallardo et al. (2017) and Athayde et al. (2019) who specifically studied Brazilian IEA are unanimous in recognizing the benefits of systematic use of IEA on the hydropower sector to deliver a form of cumulative impact assessment. However, they all highlight important limitations in this IEA practice: lack of broader public participation (Lima Andrade and Santos, 2015); the need for “complying with policies that protect human and environmental rights, and strengthening intersectoral dialogue and multi-stakeholder forums and committees)” (Athayde et al., 2019, p. 265); the need for “a broader and more independent vision about the social and environmental impacts” (Westin et al., 2014, p. 750); and some limitations in the scope of cumulative impacts at the projects level and in their consequent mitigation measures (Gallardo et al., 2017). Thus, the results of this research have the potential to address these limitations, demonstrating the feasibility of integrating the ESR into the current IEA structure and its added value in detailing the identification of cumulative impacts and consequent mitigation.

The integration of the ESR into CIA, using the IEA as an example, allowed us to demonstrate that cumulative impacts can be better featured in terms of effects on locally and regionally affected communities. Based on this detail, it is possible to define specific and targeted measures so that the mitigation hierarchy is implemented in a way that maximizes its scope in reducing the significance of cumulative impacts.

Such an approach is highly anthropocentric. Following Bond et al. (2021), it focuses on the environment as it is valued by human beings rather than granting intrinsic value to all aspects of the environment. This approach is subject to criticism, however, on the other hand it may well be better placed to deliver environmental outcomes for populations living more closely with the environment, whose livelihoods already depend on its endurance.

The ESR allows the vision of interested parties, especially the most vulnerable and ES-dependent communities, to be better considered in planning. Thus, affected ecosystems and their ES can be considered in an integrated way in planning to better highlight how cumulative impacts will temporally and spatially affect environmental resources in the area affected by multiple projects.

The ESR makes it possible to add more tangibility to the characteristics of cumulative impacts at the scoping stage, which can further facilitate their management over time and provide feedback to processes that must consider this type of impact for decision-making.

The approach taken in this paper was facilitated by the existence of IEA reports which have already undertaken a form of CIA. The next step in the development of an efficient and useful CIA approach is to test this approach in other contexts, so that more generic guidance can be developed that also includes the initial identification of cumulative effects.

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