ARTICLE IN PRESS

Marine Policy xxx (xxxx) xxx

Contents lists available at ScienceDirect

Marine Policy

journal homepage: http://www.elsevier.com/locate/marpol

Full length article

Understanding impacts of dams on the small-scale fisheries of the Madeira River through the lens of the Fisheries Performance Indicators

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ARTICLE INFO

Keywords:
Amazon
Fisheries
Development
Riverine communities
Fishery evaluation indicators

ABSTRACT

The small-scale fisheries in the Amazon region are diverse, target a large number of species and often define rural riverine livelihoods. Data limitations and uncertainties constrain proper management for species conservation, not to mention for sustainable development. Large hydroelectric dams can negatively impact the local fisheries systems in many ways, including the fish biodiversity and income of fishing dependent communities. This paper uses the Fishery Performance Indicators (FPIs) to evaluate the impact of two major hydroelectric dams on the Madeira River. The FPI assessments were conducted in 2010 and 2017. The results show declines in ecological health and some economic and social dimensions. Catch and fisher income have noticeably declined. Ineffective management has also failed to reduce fishing effort and overfishing. The fishery has shown improvement in fish price, but the higher fish prices are more volatile. Impacts to fisher livelihoods was distinctly greater than the impact on the livelihoods of market intermediaries such as fish traders.

1. Introduction

Construction of hydroelectric dams triggers transformations of the physical-chemical dynamics of aquatic ecosystems and alters the composition and abundance of the local fish fauna [9,18,19,37]. Dams can obstruct fish migratory patterns and contribute to extinction of fish and other aquatic species as well as destabilize riverine food webs. Beyond threats to biodiversity, dams impact fishing culture, livelihoods and societies through reduced income, occupational displacement, social reorganization, and threats to food security [25,34]. According to [22], the literature on dams in the last 50 years shows the lack of systematic approaches, which integrate the different components of the affected system, and this research gap harms the usefulness and credibility of the analysis of social impacts of dams. Despite the relevance and importance of these studies, most deal separately with the impacts of enterprises on fisheries resources [37], on fisheries [23,33], on social economic aspects [26,36], or on system's governance [15]. An integrated view of these aspects is important to understand how hydroelectric dams affect fishing performance as a whole.

Small-scale fisheries in the Amazonia region are an important source of traditional livelihood, identity, income and protein for local riverine communities [10,20,21]. Installation of two hydroelectric dams on the Madeira River, an important tributary of the Amazon River, hinders efforts to protect and strengthen the small-scale fisheries and fishing communities that the Madeira River supports. Some research effort in the Amazonian region have been directed towards quantifying the impact of the dams on local fisheries and fishing activities, including assessment of catch and effort of targeted fisheries, and evaluating threats to the ecosystem and fish diversity ([1,6,23,32,33]; [12]). However, fisheries data are scarce due to limited and irregular monitoring and data collection programs, discrete sampling, and lack of historical data [17,31]. Such data limitation makes it difficult to assess

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https://doi.org/10.1016/j.marpol.2020.104261
Received 4 May 2020; Accepted 3 September 2020
Available online 3 November 2020
0308-597X/© 2020 Published by Elsevier Ltd.

Please cite this article as: Carolina Rodriguesda Costa Doria, *Marine Policy*, https://doi.org/10.1016/j.marpol.2020.104261

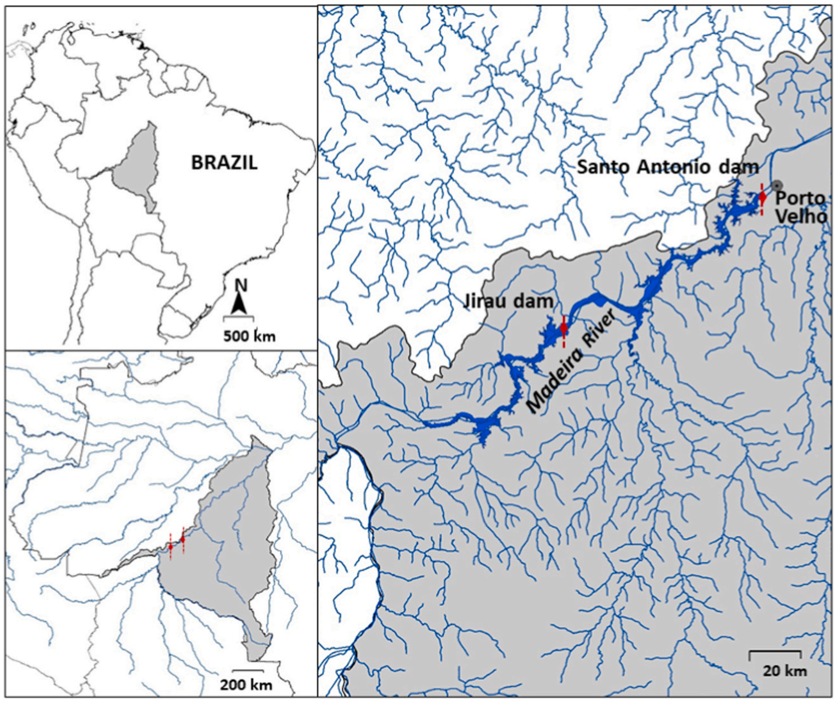

Fig. 1. Map of the study area highlighted showing the Madeira River Basin, the two hydroelectric dams, and the state capital, Porto Velho. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the impacts of dam installation and suggest effective management and mitigation measures especially in social and economic dimensions ([17]). While there is broad consensus that construction of the dams has disrupted livelihoods ([17]; [33]), quantifying the socioeconomic impacts of the dams is more challenging given that no socioeconomic data are collected, and this is characteristic of many small-scale fisheries in developing countries [7,11].

In this study, we apply the Fisheries Performance Indicators (FPIs) to assess the impact of two hydroelectric dams on a small-scale, data-poor fishery in a tributary of the Amazon River. The FPIs were designed to evaluate performance of socio-ecological fishery systems with the notion that a successful fishery is one that is biologically sustainable and generates resource rents to support an economically sustainable and socially acceptable industry and community [3]. The FPI framework is beneficial in broadening the thinking process on what constitute a well performing fishery and helps to break through the unidimensional focus on environmental conservation. The performance measures (68) can be aggregated into 14 output dimensions which can be further aggregated into the ecological, economic and social sustainability pillars[3]. The FPIs also measure 54 inputs or enabling factors ranging from specific indicators related to fisheries management to more general indicators of the society and governance that the fishery operates in. We use the FPIs to collect data on the small-scale fisheries of the Madeira River at two time points: prior to dam installation in 2010 and following the completion of the dams in 2017.

1.1. Small-scale fishery system in the Madeira River, Brazil

1.1.1. Characterization

The fishing activity in the middle Madeira River is characterized as a small-scale fishery with high socio-economic importance for the local riverine communities. It is estimated that 50,000 riverine families and 1500 commercial fishers are supported by the Madeira River [17]. Much of the catch is landed in Porto Velho (Rondônia State capital with 519,000 habitants) and to a lesser extent in Humaitá (Amazonas State city with 46,000 habitants). Our data and analysis are focused on the Porto Velho fish market which is the largest local market (Fig. 1) selling nearly 60 different species that are commercially harvested [14]. Before the operationalization of two large hydroelectric dams in the Madeira River (i.e., Santo Antonio and Jirau dams), the top five species, representing about 70% of the total catch in 2009–10, are migratory species, including Characiformes curimatã (*Prochilodus nigricans*), pacu-comum (*Mylossoma duriventre*), jatuarana (*Brycon amazonicus*), jaraqui (*Semaprochilodus insignis*) and Siluriformes: dourada (*Brachyplatystoma rousseauxii*) [14].

Landing data from 1990 to 2011 shows high variation between years, a pattern common to Amazonian fisheries, and the trend in fish production indicated fish stocks were stable [15,30]. The average annual catch was 566.5 tons (±193.6) [14] and the average value of the fishery was about US$2.5 million. In 2009, there were 1200 fishermen registered with the local Fishermen's Colony and catch per unit effort (CPUE) was reported as 25–42.71 kg per fisher per day. The construction of Santo Antonio and Jirau dams started in 2008. The Santo Antonio dam was completed in 2011 and the Jirau dam in 2012. [23] studied a 25-year time series (1990–2014) of landings in the Porto Velho fish market and showed that catches and fish supply to market declined quickly following the dam installation, which were followed by changes in the price per kg of exploited fish species. There was a clear decline in the catches of some species (e.g., the dourada and the curimatã), but increased catches of others (e.g., the sardine and the tucunaré). Price increases were observed for fish species that became scarcer.

The fishing fleet consists mostly of small wooden fishing vessels (more than 1000 non-motorized and motorized canoes). Non-motorized and motorized small wooden canoes (average length 5.8 m) have limited storage capacity (250 kg and 600 kg, respectively) and are used for fishing and transporting fish. Prior to the dams, five larger motorized fishing boats (average size 9 m) with larger storage capacity (average 2500 kg) served as logistical bases for fishing trips. These fishing boats used to carry ice and provided storage and transportation of fish to the city for smaller fishing vessels. In general, non-motorized and motorized canoes make shorter trips that range from 1 to 5 days, while larger fishing boats make longer trips, up to 15 days. In years following dam installation, these fishing boats were not operative, because of high travel costs. Nowadays, the fishers send their catches by large boats that

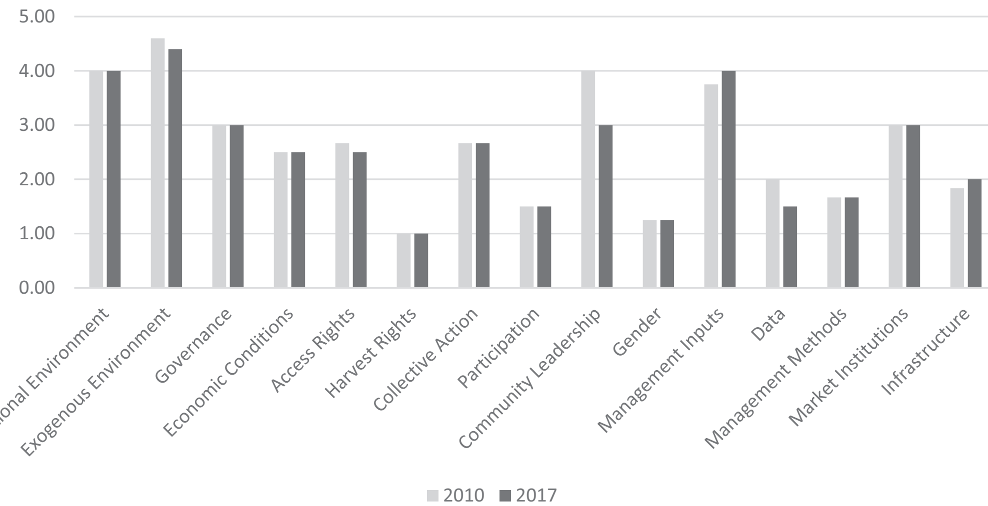

Fig. 2. Comparison of input dimension scores of pre-dam and post-dam periods of Madeira River fishery FPI.

transport people and local products as well. Most of the fish is caught using gill nets (over 50% of total catch), followed by drift net, and longline gear and all fish are for human consumption. The fishers sell whole, unprocessed fish directly to middlemen, who will sell directly to the final consumer at local markets or restaurants.

1.1.2. Fisheries management

The Madeira River fishery is regulated open access. A fishing license is required to participate, but licenses are allocated without limit (i.e., entry to the fishery is not limited). Fishing licenses must be renewed annually and cost around US$ 10, plus a fee equivalent to 5% of ex-vessel value paid to the Fishermen Association, and a 20% fee paid into the government's National Institute for Social Security (INSS).

The artisanal fisheries in the Amazon region are governed by national and state laws. The state environmental agency (Secretaria Estadual do Meio Ambiente, SEDAM) is responsible for the oversight, planning and management of fisheries. SEDAM mainly works on the supervision of the fishing activities and the enforcement of fisheries regulations but does not conduct research or data collection. Decrees are published annually, establishing: 1) the open season for fishing, usually with restrictions on fishing during the months of November to March which is the reproductive period of most fish species in the Amazon (called "período do defeso"); 2) the minimum size limit for each species; 3) the size and type of fishing gear; 4) harvestable species; and 5) fishing areas as fishing in some major tributaries of the Madeira River is prohibited.

After the construction of the dams, the existing fishing regulations, (i.e., species, gear, and size restrictions) continued to be applied. However, fishing activity within 4 km of the dams has been prohibited as a safety measure (CRCD personal observation).

2. Methods

In this study, we evaluate the impact of two hydroelectric dams on the Madeira River fishery system using the Fishery Performance Indicators (FPIs). The fishery data were collected by the Ichthyology and Fisheries Laboratory, Federal University of Rondônia from 2001 to 2010 (pre-dam) and from 2011 to 2020 (post-dam). Data was analyzed with the FPIs to measure fishery performance in 2010 prior to dam construction and in 2017 after construction of two hydroelectric dams, Jirau and Santo Antonio, was completed (Fig. 1).

The FPIs is a multi-dimensional evaluation tool to assess performance of fishery systems in a cost-effective, quantitative and comparable manner even in data-limited systems [3]. The FPIs are scored using two types of metrics: 68 output indicators which provide an assessment of the ecological, economic and social performance of the fishery management system, and 54 input indicators which are the system attributes that enable the outcomes. Ecological performance reflects the status of the fish stocks and the overall health of the ecosystem. Economic performance reflects whether the fishery is generating resource rents and is a measure of indicators such as international trade, product enhancement, and ex-vessel and wholesale prices. The contribution of fishery to livelihoods and other community services is reflected in community performance. The input metrics vary from specific indicators related to fisheries management to general indicators of governance and society. As shown in [3], the output and input indicators can be aggregated into 14 and 15 dimensions, respectively. The FPIs have been used to compare fisheries at a global scale [5] and to assess performance of specific species complexes [27] and specific projects [11].

Two local researchers with 20 years of experience (CRCD and STBS) with the local fisheries and close relationships with the fishing communities scored the FPI indicators for 2010 and 2017. By using the same scorers for 2010 and 2017, inter-observer error was avoided. Scores were assigned based on expert assessment (CRCD and STBS), local landing data (total production; price per kilo per year) from Porto Velho Fishermen's Colony and/or interviews with key local fishers, middlemen, and members of the Fishermen's Colony director for vessel and revenue value. A detailed FPI manual is available to explain the definitions of the FPI metrics, the scoring and to provide specific examples [4]. Data on fish landings and prices for the Porto Velho fishing market were available through the Ichthyology and Fisheries Laboratory at the Federal University of Rondônia. Scores and explanations were verified by the FPI developers to maintain quality control.

3. Results and discussion

3.1. Inputs

The input metrics for the Madeira River fishery were similar in the pre- and post-dam observations (Fig. 2; Table 1). The scores of a macro indicator, exogenous environmental factors, and three fishery-specific measures, access rights, community leadership and data, declined in the post-dam observation. This is consistent with weaker and reduced exclusive fishing rights and an increase in conflict between the fishers and the dam developers as construction of the dam has eliminated historically important fishing grounds. Lower exclusivity resulting from intrusion of developers on the resource yielded weaker access rights of fishers. Moreover, the lack of engagement of fishers in the planning,

Table 1
Input scores for the fisheries of the Madeira River in 2010 and 2017.

Indicator	Dimension	Metric	2010	2017
Macro Factors	General Environmental Performance	Environmental Performance Index (EPI)	4	4
	Exogenous Environmental Factors	Disease and Pathogens	5	4
		Natural Disasters and Catastrophes	4	4
		Pollution Shocks and Accidents	4	4
		Level of Chronic Pollution (Stock effects)	5	5
		Level of Chronic Pollution (Consumption effects)	5	5
	Governance	Governance Quality	3	3
		Governance Responsiveness	3	3
	Economic Conditions	Index of Economic Freedom	2	2
		Gross Domestic Product (GDP) Per Capita	3	3
Property Rights & Responsibility	Fishing Access Rights	Proportion of Harvest Managed Under Limited Access	5	5
		Transferability Index	1	1
		Security Index	3	2
		Durability Index	3	3
		Flexibility Index	3	3
		Exclusivity Index	1	1
	Harvest Rights	Proportion of Harvest Managed with Rights-based Management	1	1
		Transferability Index	NA	NA
		Security Index	NA	NA
		Durability Index	NA	NA
		Flexibility Index	NA	NA
		Exclusivity Index	NA	NA
Co-Management	Collective Action	Proportion of Harvesters in Industry Organizations	4	4
		Harvester Organization Influence on Management & Access	2	2
		Harvester Organization Influence on Business & Marketing	2	2
	Participation	Days in Stakeholder Meetings	2	2
		Industry Financial Support for Management	1	1
	Community	Leadership	3	3
		Social Cohesion	5	3
	Gender	Business Management Influence	1	1
		Resource Management Influence	1	1
		Labor Participation in Harvest Sector	2	2
		Labor Participation in Post-Harvest Sector	1	1
Management	Management Inputs	Management Expenditure Compared to Value of Harvest	5	5
		Enforcement Capability	3	3
		Management Jurisdiction	2	3
		Level of Subsidies	5	5
	Data	Data Availability	3	2
		Data Analysis	1	1
	Management Methods	MPAs and Sanctuaries	2	2
		Spatial Management	2	2
		Fishing Mortality Limits	1	1
Post-Harvest	Markets & Market Institutions	Landings Pricing System	5	5
		Availability of Ex-vessel Price & Quantity Information	4	4
		Number of Buyers	2	2
		Degree of Vertical Integration	1	1
		Level of Tariffs	5	5
		Level of Non-tariff Barriers	1	1
	Infrastructure	International Shipping Service	1	1
		Road Quality Index	1	2
		Technology Adoption	1	1
		Extension Service	2	2
		Reliability of Utilities/Electricity	3	3
		Access to Ice & Refrigeration	3	3

licensing, and monitoring processes has intensified disputes [17]. The lack of available data and resources limits data analysis needed to support management decisions, and this brings major issues for assessing and managing the impact of the dams. Especially after the construction of the dams, the fishing data generated is controlled by the contracting companies and the licensing agency, which restrict access to fishing colonies, fishermen and researchers [17]. The decline in the exogenous environmental dimension reflects an increase of parasitism of fish in the Madeira River in 2017, although this may, in part, be endogenous to the dams and the altered hydrology of the river. The decline in the leadership score reflects the increase in conflict between fishers and their leadership regarding the negotiation related to the fisher's rights, the dam builders, and the government.

Two input indicators, management inputs and infrastructure, showed improvement between 2010 and 2017. Specifically, coordination of fishing regulations and enforcement between state and federal agencies has been improved, however, the agencies have been ineffective at mitigating and measuring impacts of the dam and adjusting public policy to local needs. The quality of roads increased from a score of 1 in 2010–2 in 2017. The region is remote with poorly maintained roads, which limits regional and international trade. Fishers and intermediaries will typically not travel to other markets even if they can get a better price because the costs of travel are too high.

Nine of the fifteen input indicators were unchanged between 2010 and 2017. Three of these were macro factors reflecting the broader environmental, governance and economic conditions in Brazil. Some management-related factors have not changed and as such the fishery continues to operate with limited enforcement, limited habitat

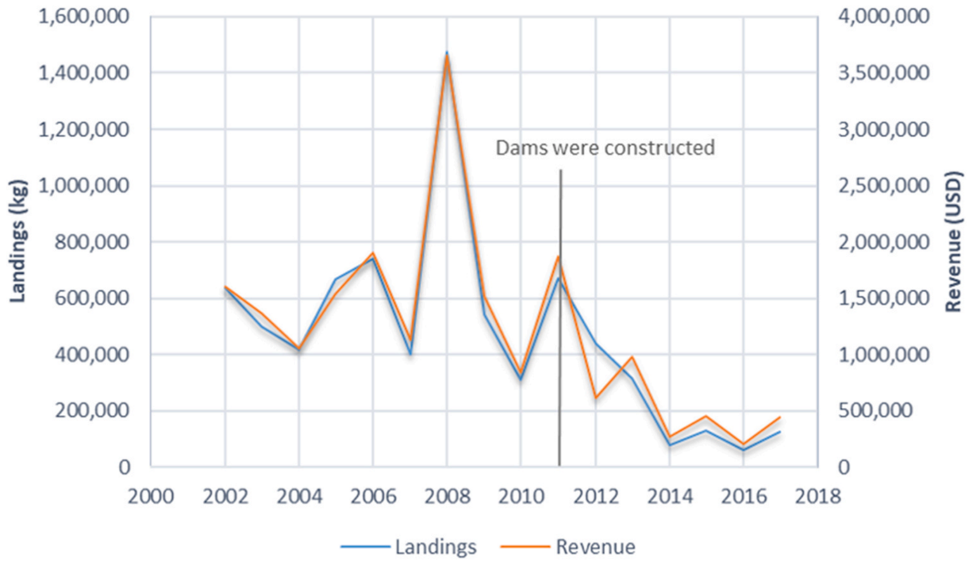

Fig. 3. Total annual landing (kg) and revenue (USD) of the small- scale fishery in Madeira River, Amazon.

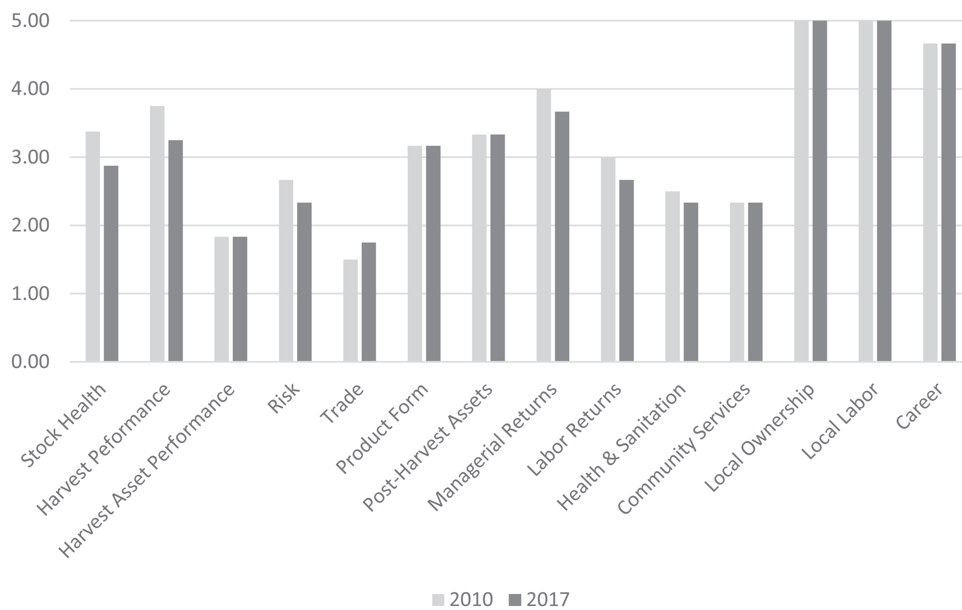

Fig. 4. Comparison of output dimension scores of pre-dam and post-dam period of Madeira River fishery FPI.

protections, gender inequities and without total catch allowances or harvest rights. Several social factors such as collective action and participation have also not improved.

3.2. Outputs

Fig. 4 shows the scores of the 14 output dimensions for the Madeira River fishery in 2010 before the dams were built (2011) and in 2017 after the dams were built (Table 2). The scores for six dimensions of the 14 output dimensions showed noticeable declines, 7 dimensions were unchanged, and 1 dimension showed improvement.

The largest decline in the output dimension scores was in the dimension of stock health. The Madeira River fishery was relatively healthy prior to installation of the dams (score of 3.38). Among the 60 fish species commercialized in the region, only two species (curimatã and tambaqui) accounting for less than 20% of the total landings were threatened by overfishing [16]. The score of the stock health dimension declined to 2.88 in 2017 as two additional species were considered overfished and many fish stocks were believed to be in decline. The status of critical habitat also declined from a score of 4 in 2010–2 in 2017. Prior to the dam, the habitat of the Madeira River area was moderately healthy with about 9% of deforestation recorded in 2007 [35]. The evidence linking forest cover to higher freshwater fish diversity makes this important for the Amazon fisheries [24]. The environmental changes caused by the construction of two large dams in the Middle Madeira River area resulted in habitat loss and alterations such as flooding of the reservoirs which negatively impact critical fish habitats essential for feeding, spawning, growth, and refuge [37]. Furthermore, the deforestation of the Madeira River basin increased over 33% in the last decade [8].

Landings and revenue in the Porto Velho Fish market declined more than 50% within five years of the dam installation (Fig. 3). Lima et al., [23] show significant changes in the average catch of long-distance and middle-distance migratory species. This is not too surprising given the

Table 2
Output scores for the fisheries of the Madeira River in 2010 and 2017.

Indicator	Dimension	Metric	2010	2017
Stock Performance	Ecologically Sustainable Fisheries	Percentage of Stocks Overfished	4	4
		Degree of Overfishing- Stock Status	4	3
		Stock Declining, Stable or Rebuilding - Stock Dynamics	4	2
		Regulatory Mortality	4	4
		Selectivity	3	3
		Illegal, Unregulated or Unreported Landings	3	3
		Status of Critical Habitat	4	3
		Proportion of Harvest with a 3rd Party Certification	1	1
Harvest Sector Performance	Harvest Performance	Landings Level	4	2
		Excess Capacity	4	3
		Season Length	3	3
		Harvest Safety	4	3
	Harvest Asset Performance	Ratio of Asset Value to Gross Earnings	1	1
		Total Revenue Compared to Historic High	1	1
		Asset Value Compared to Historic High	1	1
		Borrowing Rate Compared to Risk-free Rate	4	4
		Source of Capital	2	2
		Functionality of Harvest Capital	2	2
	Risks	Annual Total Revenue Volatility	2	2
		Annual Landings Volatility	2	2
		Intra-annual Landings Volatility	2	2
		Annual Price Volatility	5	3
		Intra-annual Price Volatility	2	2
		Spatial Price Volatility	3	3
		Contestability & Legal Challenges	4	4
	Owners and Captains	Earnings Compared to Regional Average Earnings	4	3
		Owner/ Captain Wages Compared to Non-fishery Wages	4	4
		Education Access	2	2
		Access to Health Care	2	2
		Social Standing of Boat Owners and Permit Holders	3	3
		Proportion of Nonresident Employment	5	5
	Crew	Earnings Compared to Regional Average Earnings	3	2
		Crew Wages Compared to Non-fishery Wages	2	2
		Education Access	2	2
		Access to Health Care	2	2
		Social Standing of Crew	3	3
		Proportion of Nonresident Employment	5	5
		Crew Experience	5	5
		Age Structure of Harvesters	4	4
Post-Harvest Performance	Market Performance	Ex-vessel Price Compared to Historic High	4	5
		Final Market Use	3	3
		International Trade	1	1
		Final Market Wealth	2	2
		Wholesale Price Compared to Similar Products	2	3
		Capacity of Firms to Export to the US & EU	1	1
		Ex-vessel to Wholesale Marketing Margins	2	2
	Post-harvest, Processing & Support Industry Performance	Processing Yield	4	4
		Shrink	4	4
		Capacity Utilization Rate	4	4
		Product Improvement	2	2
		Sanitation	2	2
		Regional Support Businesses	2	2
	Post-Harvest Asset Performance	Borrowing Rate Compared to Risk-free Rate	4	4
		Source of Capital	2	2
		Age of Facilities	4	4
	Processing Owners & Managers	Earnings Compared to Regional Average Earnings	5	4
		Manager Wages Compared to Non-fishery Wages	5	5
		Education Access	2	2
		Access to Health Care	3	3
		Social Standing of Processing Managers	3	3
		Nonresident Ownership of Processing Capacity	5	5
	Processing Workers	Earnings Compared to Regional Average Earnings	4	3
		Worker Wages Compared to Non-fishery Wages	4	4
		Education Access	2	2
		Access to Health Care	2	2
		Social Standing of Processing Workers	2	2
		Proportion of Nonresident Employment	5	5
		Worker Experience	5	5

interruption of migratory routes caused by the dams which is well-documented in other studies [9,29]. The reduced supply of fish in the Porto Velho market raised average fish prices by 25% after the dam was installed, although the price of some fish increased more than 50% such as in the case of *Brachyplatystoma* spp. [23], affecting all fishers. It is important to note the overall decrease in price for high-value species (e.g., dourada, (*B. rousseauxii*), tucunaré (*Cichla* sp.) and pacu (*Mylossoma* spp)), and an increase in price for low-cost species (e.g., sardinha

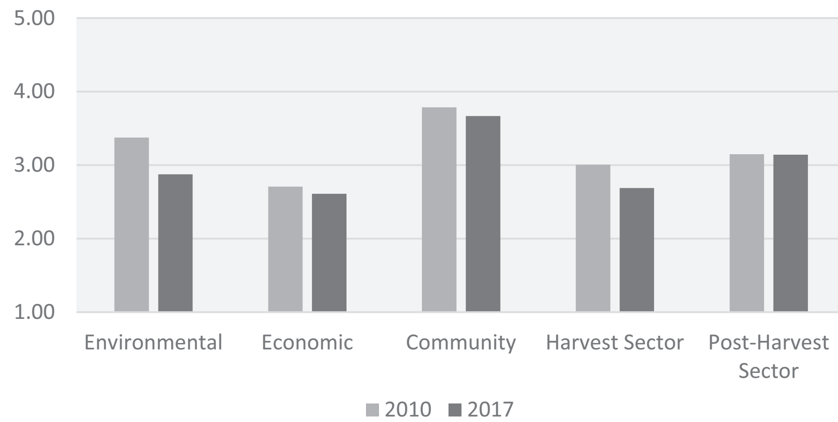

Fig. 5. Comparison of the Madeira River fishery by main performance dimensions and sectors in 2010 and 2017.

(*Triportheus* spp.) [23].

The Madeira River fishery scored low in the economic dimension of risk reflecting high inter-annual and intra-annual volatility in both biological and market conditions. The large intra-annual variation in landings is primarily due to the migratory patterns of the riverine species which leads to high volatility of fish price (ranging from US$3 to $9 per pound, depending on fish availability in the market). Price volatility increased between 2010 and 2017, and the increased volatility may be a joint effect of the hydrological variation and the decline in landings.

The scores of the harvest performance dimension declined from 3.75 in 2010–3.25 in 2017. The addition of the dams has transformed the ecological conditions of the Madeira River, and the yield of fish that can be sustainably harvested has declined as a result of this. The inefficiency of regulated open access in restricting effort prevents management from reducing effort to sustainable harvest rates under the new environmental conditions, and as such landings were expected to be at the maximum sustainable yield in 2010 (score of 4), but constraining stock recovery (score of 2) in 2017. Similarly, the management system's inability to restrict the number of fishers has led to overcapacity in the fishery and more so after the dam was installed.

The Madeira River fishery scored low in the other three economic dimensions, harvest assets, post-harvest assets and product form, and they remain unchanged between 2010 and 2017. There is no indication of wealth accumulation in harvest assets, boats or fishing gear, or in post-harvest assets which is likely due to the open access nature of the fishery. Other factors contributing to the poor asset score includes the capital lending and loyalty relationships between fishers and middlemen. Fishermen often borrow money interest-free from intermediaries but then are obligated to sell their catch to the lender and sometimes at a discounted price.

The economic dimension of trade is among the lowest scoring output dimension for the Madeira River fishery and the only dimension to show improvement between 2010 and 2017. The improvement reflects the higher prices achieved by the fishery in 2017 rather than an increase in actual trade. Limited infrastructure and high costs of travel has deterred fishers from selling catch at different landing sites where higher prices could be attained. Moreover, sanitation and hygiene standards prevent artisanal landings from being traded across state boundaries.

The scores for 3 out of the 7 social output dimensions, managerial returns, labor returns, and health and sanitation, declined between 2010 and 2017. Intermediaries or middlemen and boat owners to a lesser extent earned higher wages than the regional average and non-fishing alternatives in 2010. Boat owners receive an extra part of vessel earnings relative to their crew and as such the crew received lower wages than boat owners and are typically within 10% of the regional average income in 2010. Prior to the dams, the average earnings for fishers was R$631 (±750) with a high variation depending on the fishing sites [14] and is lower than the average per capita income of R$ 881.25 in Porto Velho [13]. Overall, the average regional fishing income declined 30–50% following installation of the dams as a result of reduced catch and despite increases in fish price [28]. The decline in wages of fishers and middlemen is reflected in the decrease in managerial return and labor return dimensions from 4.00 and 3.00 in 2010–3.67 and 2.67 in 2017, respectively. In the later observation, fishers received average or below average wages relative to regional income. Beyond reduction in wages, fishing has become a more dangerous occupation and harvest safety declined from a score of 4 in 2010–3 in 2017. Fishers' access to basic community services, such as health care and education, was limited but did not change with the decrease in wages, suggesting a potential disconnect between performance of the fishery and the broader functioning society [2]. Given the poor economic performance of the fishery, it is not surprising that it does not attract outsiders to the fishery.

3.3. *Performance by main dimension and sector*

Fig. 5 compares the performance by the three sustainability pillars and by sector for the Madeira River fishery in 2010 and 2017. The scores declined for all indicators between 2010 and 2017 with the largest difference occurring in the environmental pillar with much smaller differences in the economic and post-harvest sector indicators. This is important for recognizing that the three pillars of sustainability are correlated, and poor performance in one pillar implies poor performance in the other pillars [5]. The environmental indicator decreased from a score of 3.38 in 2010–2.88 in 2017, reflecting the declining state of the fish stocks and important habitats. The differences in the economic and community indicators between 2010 and 2017 were smaller. In the case of the economic indicator, it is likely the result of increases in fish price offsetting reductions in catch. In the case of the community indicator, declines in fishery income indicates livelihoods are threatened, however, the broader community services have yet to be affected. Moreover, the larger difference in the harvest sector (0.31) compared to the post-harvest sector (0.01) indicates that fishers have been disproportionately affected relative to middlemen and intermediaries. This is an important result for defining dam mitigation strategies.

4. Conclusions

Small-scale fisheries make important contributions to health, livelihoods and poverty alleviation. For the small-scale fisheries of the Amazon, there tends to be a unidimensional focus on environmental sustainability, and the economic and social benefits to local riverine communities are largely overlooked. Furthermore, data limitations constrain proper management for fish conservation much less socio-economic objectives. The FPIs are a valuable tool to evaluate the sustainability of data-limited fisheries and fisheries projects such as riverine hydropower projects and provide quantitative measures of the impacts to the economic, social and environmental dimensions of fisheries.

The FPIs were developed to improve insights to the economic and social dimensions of fisheries because these dimensions are often understudied and more difficult to assess. In this paper, the FPIs are used to evaluate the impact of a major hydropower project on the small-scale fisheries of the Madeira River, at two time points (before and after dam construction).

The results show declines in ecological health, and some economic and social dimensions and improvement in one economic dimension following installation of two hydroelectric dams on the Madeira River. Sharp declines in catch and revenue were observed following installation of the dam, while market prices increased by nearly 25% but were more volatile. The yield of fish that can be sustainably harvested has declined as a result of the altered environmental conditions and deterioration of habitat, however, the inefficiency of regulated open access management to restrict effort has led to an increase in overfishing.

Often the most challenging objective to measure in fishery assessments are the social objectives. Fishing income declined following installation of the dams, and the decline was greater for fishers compared to market intermediaries. However, it is important to note that fishers and intermediaries' access to basic community services, did not change with the decrease in wages as the facilities and services have existed and did not have any major changes before and after the dams. It is also outside the fishery management scope.

The FPI tool worked well to evaluate and track the changes in the Madeira River fisheries by collecting data at two time points, one before and one after the hydroelectric project. Future research may focus on defining specific metrics to evaluate more specific environmental changes resulting from the construction of dams, such as changes in hydrological regime, a key factor controlling fish production in large riverine systems, and additional socioeconomic metrics that are important to understanding changes to small-scale fisheries at broader scales.

Funding

This work was supported by a post-doctoral fellowship to CRCD (National Council for Scientific and Technological Development / Science without Borders (CNPq/CSF): 201457/2014-8); the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – International Cooperation Project (Coordination for the Improvement of Higher Education Personnel (CAPES) / COOPI Project No.38/2013); and the Pró-Amazônia / CAPES (Project No 21/2012).

Acknowledgements

We thank the Fishermen's Colony for the long-term monitoring data, and CNPq, CAPES for the support and fellowship to CRCD.

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