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Fisheries or aquaculture? Unravelling key determinants of livelihoods in the Brazilian semi-arid region

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Abstract

In impoverished semi-arid regions in the world, reservoirs serve multiple purposes, including food provision through fisheries and aquaculture. Yet, the socio-economic benefits of promoting both activities remain unclear. We independently assessed the socio-economic benefits generated from fisheries and aquaculture, in two reservoirs in the Brazilian semi-arid region (June 2013 to June 2014). These reservoirs produced 27.75 ton of farmed tilapia over a year (USD Purchasing Power Parities [PPP] 88,778.73) and provided at least 16.5 ton of fish through fisheries (USD PPP 37,557.81), based on data from four farmer associations. Our input–output model revealed that the local economy depends on both activities, which, therefore, contribute similarly to providing goods and services to different branches. Aquaculture generated much higher revenues (seven times) than fisheries, but also much higher losses (the most successful farm yielded an average income of USD PPP 592.41 monthly). Still, there were no statistical differences in income among the compared associations. Fisheries provided very but guaranteed income (USD PPP 311.02 ± 82.94) and employed over three times as many people and contributed much more (>3 times) to food security than aquaculture. Encouraging aquaculture through specific policies while overlooking fisheries is not advisable because poor fishers would not be able to deal with unpredictable outcomes and it would put their food security at risk. However, if initial external support is provided to fishers in order to buffer large losses, aquaculture could represent a way out of poverty by generating an opportunity for larger gains, as long as potential negative ecological impacts of aquaculture are accounted for.

KEYWORDS
Brazil, fisheries, food production, food security, poverty alleviation

1 | INTRODUCTION

Globally, the production of edible aquatic animals increased by more than fourfold between 1970 and 2015, when it reached an estimated 168.8 million ton (FAO, 2015). Even in developing countries, fish and seafood consumption increased by twofold between 1970s and 2001, reaching 14 kg per capita per year (Delgado, 2003). In 2008, this figure had already reached over 17 kg/year (FAO, 2010). Meanwhile, fish stocks around the world have declined: in 2011, 28.8% of fish stocks analysed were overfished, while 61.3% were fully fished (FAO, 2014). To meet the growing demand for seafood, aquaculture has been proposed as a solution, which over the last decade has corresponded to most of the net growth in fish production (FAO, 2013).

However, fish and seafood farming have brought about controversial debates and criticism surrounding their impact on food security, economic development (Béné, 2005; Béné et al., 2016; Vandergeest, Flaherty & Miller, 1999) and the environment (Diana, 2009). Critics of these activities highlight negative impacts ranging from violence against those who oppose farming, and community displacement (EJF, 2003), to the direct consequences on fisheries and human health. The latter include fry by catch and mangrove destruction (Lopes, 2008), harvesting of wild species from developing countries to feed global seafood markets in developed countries (Villasante, Rodríguez-González, Antelo, Rivero-Rodríguez & Lebrancón-Nieto, 2013), the dependence of aquaculture on freshwater and land (Troell et al., 2014), and the runoff of toxic inputs into water sources (Frankic & Hershner, 2003). Clearly, the extent of such impacts varies depending on the species being farmed, the methods being used and the ecological setting (Black, 2001). Over the years, new aquaculture practices have been developed and recommended to minimize negative social and environmental impacts (Frankic & Hershner, 2003). Nevertheless, such changes have occurred slowly and traditional and unsustainable approaches are still commonly employed without careful consideration of the environment where they are being developed. This is particularly common in developing countries with limited technical, financial and human resources. The alternative, organic aquaculture in 2000 responds for a modest 0.01% of production. Although projections estimate that it should reach 0.6% of global aquaculture production, an amazing 240-fold increase, it remains derisive in the grand total (Tacon & Brister, 2002).

The main appeal of aquaculture is its promise to contribute to poverty alleviation and food security, and it has indeed contributed to improving incomes and job offer indexes in various regions, such as Asia, Africa and Latin America (Outeiro & Villasante, 2013; Silva & Davy, 2010).

In Brazil, the practice of aquaculture can be found in places as diverse as the Amazon (Gomes et al., 2006) and semi-arid regions (Albinati, 2006; Moura, Valenti & Henry-Silva, 2016). In the latter, reservoirs created primarily for drinking water and for agriculture and animal husbandry are also used for cage aquaculture, especially for the exotic Nile Tilapia (*Oreochromis niloticus* Linnaeus). Tilapia cage aquaculture has been presented as an important alternative and is supported by state and federal governments as a means of improving poverty indexes and food security levels in this Brazilian region, which is marked by low social development indexes and by harsh environmental conditions (Gunkel, Lima, Selge, Sobral & Calado, 2015; Sampaio & Batista, 2004). However, reservoirs have historically been used for fisheries, which depend on previously stocked native and exotic species (Attayde, Brasil & Menescal, 2011).

In this study, we evaluate the economic and social outcomes of having artisanal fisheries and tilapia cage aquaculture together in Brazilian semi-arid reservoirs. We adopt a comprehensive approach that includes a conventional and a socio-economic assessment of the potential of each activity as a source of income generation, job creation, food supply and, consequently, poverty alleviation. We complement our approach with a theoretical discussion on the need to assess the ecological impacts of fisheries and aquaculture in order to promote steady long-term benefits. This is the first socio-economic assessment of integrated fisheries and aquaculture in reservoirs of the Brazilian semi-arid region. Ideally, the findings shown here could be used to guide initial policies, decision-making and future studies regarding where, how and if aquaculture should coexist with fisheries.

2 | MATERIALS AND METHODS

2.1 | Study area

For the comparison intended in this study, we chose two reservoirs, namely Santa Cruz and Umari, where fisheries and tilapia aquaculture are carried out simultaneously. These reservoirs are located in the state of Rio Grande do Norte, northeastern Brazil, in the catchment basin of the Apodi/Mossoró river (Figure 1). This basin covers an area of 14.276 km^2 or 26.8% of the state of Rio Grande do Norte. The Santa Cruz reservoir was filled in 2002, and it is the second largest in the state. It can store up to 600 million m^3 of water (Moura et al., 2016), irrigates just little over 14.000 ha and serves 108.000 people in 27 municipalities. The Umari reservoir was also filled in 2002 and is the third largest in the state. It can store approximately 293 million m^3 of water and can irrigate up to 3.000 ha. This particular reservoir does not provide drinking water.

2.2 | Aquaculture data

In the reservoirs we studied, there are four different aquaculture associations that set their tilapia cages on a regular basis (number in parenthesis are the total number of fish farmers at the time of the study): Fish Farmers and Fishers Association-APAFA (10), Association of Fish Farmers from Apodi-AQUAPO (10), Fisher Association (3) and Cooperative of Fish Farmers from Rio Grande do Norte-COOPIRN (12). Apart from COOPIRN, all the associations are formed by artisanal fishers, who divide their time between aquaculture and fisheries in the reservoirs. Cooperative of Fish Farmers from Rio Grande do Norte is formed by outsiders, who are locally called “businessmen” by the fishers, as they own capital and can afford better infrastructure and to maintain permanent staff. The three associations formed by fishers rely on their own labour on a cooperative basis, which is not always easy to maintain. For example, these three associations started with a larger number of participants, who slowly gave up along the way for believing the workload did not compensate due to uncertain profits.

We visited the four associations monthly in order to obtain their data on costs and revenues between June 2013 and June 2014. However, in only 6 months, farmers actually sold adult Tilapia. The number of cages with adult fish in the water varied from 4 to 142 within the studied period, while the number of fry cages varied from 0 to 10. Such variation was partially due to demand: associations sometimes sell fish that has not been produced yet, especially if they

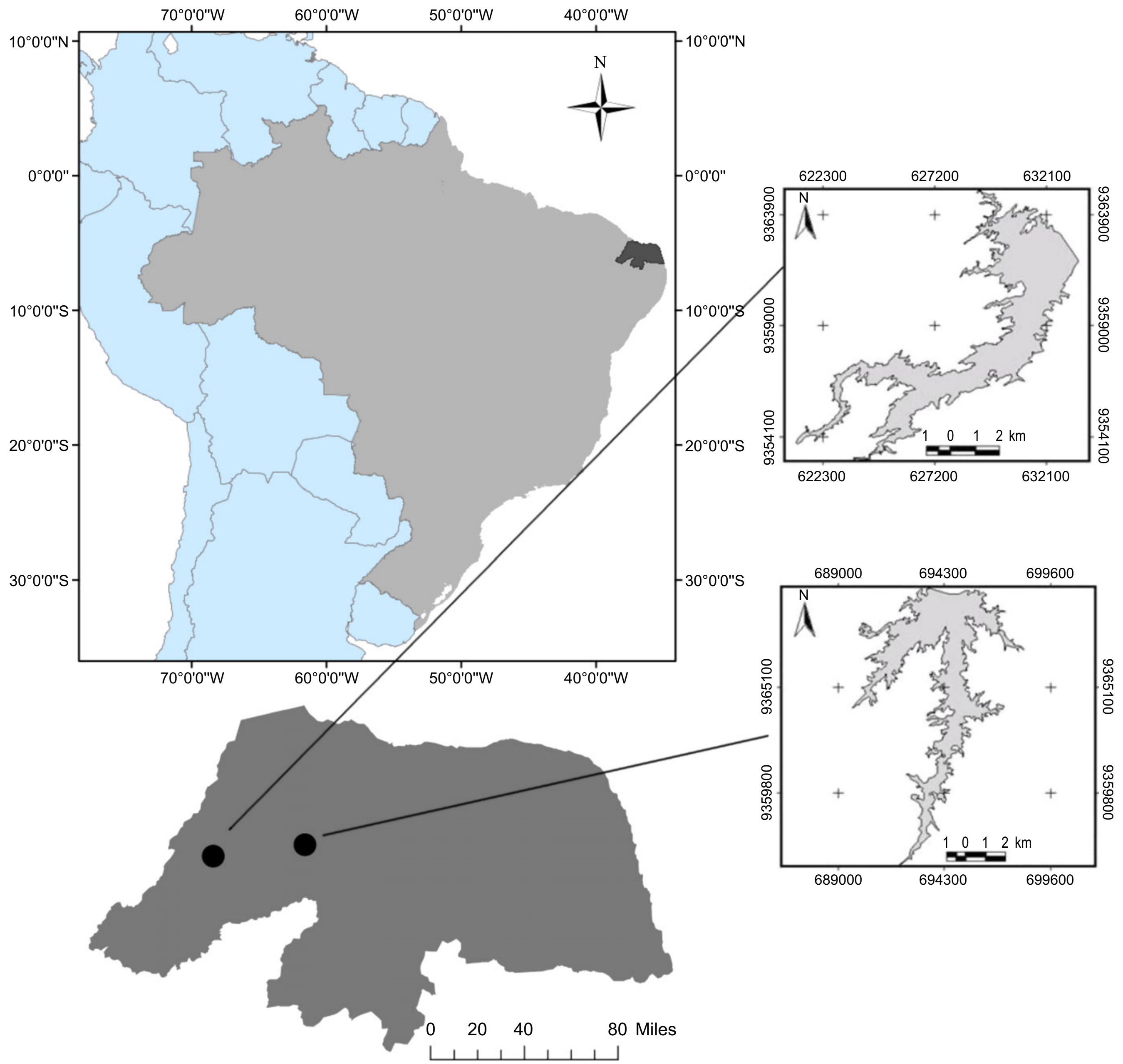

FIGURE 1 Map of the study area with the reservoirs (on the right). Santa Cruz reservoir is shown on top and Umari on the bottom

have contracts with the government; therefore, they set more cages to be able to deliver the amount of fish requested at a certain date. The data are presented together for both reservoirs, highlighting possible discrepancies between associations.

We collected data on the number of cages in the water, number of fry per cage, number of adult fish, use of fish food, revenues and costs due to staff, utilities and maintenance.

2.3 | Fisheries data

We actively tried to identify the fishers who use these reservoirs on a regular basis, by visiting local markets and through name suggestions from other fishers. Once a fisher was identified and approached, we explained the project to him or her and asked about their fishing frequency and level of dependency on this activity. We identified 72 fishers during this phase, and the remaining ones (47) during fish landing sampling. We used the total number of fishers (N = 119) to infer fisheries costs and profits from each reservoir by using an input–output model, assuming we had identified all fishers. Thus, the estimates are likely underestimated.

Given the geography of the reservoirs, it is basically impossible to sample all the fish landed. There are no harbours or ports: people land virtually anywhere around the reservoirs (Figure 1). Circling the reservoirs regularly is not possible because there are no roads; there are only a few access points for cars to specific areas. To overcome such difficulties, we used two sampling strategies to record landing data: fish landing monitoring by locals (resulting in 405 landings) and data supplied by one middleman fisher (resulting in 498 landings).

2.3.1 | The local monitoring system

We trained two local assistants living in the two main urban agglomerations around the reservoirs. These two people visited all the fishers known in the area once a day for 7 days a month to identify who had gone fishing. Once somebody was identified, the assistant would weigh the fish if it had not been sold yet. Otherwise, he/she would only ask about the species caught (local names, estimated amount, price and consumption). The costs were always estimated by the fisher, and they usually included oil for their motor canoes, fish food (fishers use a tiny amount of feed to attract fish) and food for their own consumption while fishing. This resulted in 405 fish landings sampled. For the results presented here, we only used catch, which did not vary statistically between months ($p > .05$).

2.3.2 | Data recorded by the middleman fisher

We had the support of a fisher who also works as a middleman and who provided information on his catches. This fisher hires a team of 5–8 fishers, who fish on a daily basis and sell him their entire catch. It was impossible for us and our assistants to reach this fishing team on a regular basis, as their camping site was on an island in the middle of the reservoir. Therefore, we trained the middleman fisher, who was illiterate but familiar with numbers, to record all of their landings, which did not include fishing costs due to the limitations of our pictogram form (Fig. S1). This fisher provided information on 498 landings because he chose to register landings every day over 10 months, except for August and September 2013.

We used two types of sampling to extrapolate monthly catches. The 7-day sampling was multiplied by four within each month for each of the two locations, whereas the 2 months that were not registered by the voluntary fisher were estimated to have catches equivalent to the average of the 10 months he sampled.

2.4 | Input–output model

We used a conventional input–output model to show how the interdependencies of fisheries and aquaculture affect the overall national and regional economies, due to the products they demand (input) and the outcomes they generate (output) (Dyck & Sumaila, 2010). The table is broken down into branch-by-branch and product-by-product consumed or provided by each activity.

2.4.1 | Input

Once we identified the gross products and services required for the performance of aquaculture and fisheries in the studied reservoirs, we accessed the Brazilian National Classification of Economic Activities (CNAE). Using this database, we refined the products and services into their official subcategories and generated an online market price for every item identified. Whenever available, we used public price databases (e.g. *Instituto de Economia Agrícola*) that provided the price paid by the consumer. In some situations we assessed the closest and most similar information available online, which could be information for the whole country or for major metropolitan areas, such as São Paulo. We double-checked the information by looking for prices on online stores that delivered the same products as in the state studied. We also collected information on prices provided by fishers and farmers regarding the depreciation of their boats and gear, given that some activities refer to local services that may or may not pay taxes. All prices are for May 2015. Although prices were collected in Brazilian Reais (BRL), figures are presented in USD PPP (Purchasing Power Parities), considering the average price of 2013 and 2014 (BRL 1,000 = USD PPP 1,688). Each input was calculated as described below. We only present equations when they involve more than a simple multiplication of variables:

Gear price: (i) Gillnet prices were estimated by fishers (USD PPP 148,10) and by fish farmers (R$600.00). The interviewees also estimated that nets would last, on average, 25.4 months (2.12 years), if given appropriate maintenance. Such maintenance had a different estimated annual cost for the fisher (USD PPP 44.14) and for the fish farmer (USD PPP 17.78). (ii) Canoes were estimated to cost R $600.00 for both fishers and farmers and they were estimated to last on average 7.3 years. All fishers ($N = 119$) had owned their own canoes and each association had one canoe. Their estimated monthly maintenance was cheap (USD PPP 1.23 monthly or 14.79 annually per canoe), as most people did not assign a cost for it as they fix their own canoes. Hook and line costs were only estimated for fisheries (USD PPP 3.55 and USD PPP 23.70/year respectively) and were multiplied by the number of fishers. Finally, food containers to carry fish feed to the cages had a one-time cost of USD PPP 68.13 per container and each of the four associations had an average of three containers. Interviewees could not estimate their depreciation, but we conservatively assumed it would last 3 years because they were made out of plastic and were constantly exposed to the sun.

All calculations here assumed the following format:

$$I_i(\$) = \left(\frac{IP_i}{D_i}\right) * N \tag{1}$$

where $I_i(\$)$ is the total expense with item IP is the value provided for a new item $_i$, D is duration in years (some estimates were already given for an entire year), and N is the number of fishers ($N = 119$) or farmers ($N = 35$) or the total number of a given item considering all associations (e.g. the four associations owned four canoes in total).

Fuel: The average price for gasoline and diesel in the state of Rio Grande do Norte during the study period was used to estimate fuel expenses. These expenses were known from interviews. Fishers were estimated to fish 20 times a month. This was multiplied by the estimated number of fishers ($N = 119$) and then by 12 months. The calculation was a simple multiplication of all these factors. Farmers did not use any gas during the studied period and accessed their cages with rowboats. However, they incurred costs to transport their fish to distributors or dealers. In that case, they provided information on their actual use of fuel per month, which we averaged out across associations and multiplied by the number of associations and then for the year.

Ice: From the fish landings, it was estimated that fishers spent USD PPP 0.34 with ice per trip, a value that was again multiplied by the number of fishers and by the number of trips per month and then extrapolated per year (by 12). Farmers did not report the use of ice, probably because they transported the fish for processing at a different facility (e.g. store), with costs included in the analysis.

Feeding: For aquaculture, we used the monthly average expenses with feeding calculated for the associations multiplied by 12. We did not use a fixed value because the number of cages in the water varied widely throughout the year, as did the size of each cage, which had implications on the number of fish in each one. Although farmers only commercialized fish during 6 months of the study period, they incurred expenses to keep growing fish in the water throughout the year. Fishers incurred small costs with feeding, which they sometimes used to attract their target fish. Fishers' expenses per trip were calculated from fish landings (USD PPP 0.98 per trip per fisher) and again multiplied by the estimated number of trips per day, the number of fishers and the number of months.

Fish fry: The total sum per month of the different companies was averaged out for the 12-month period (many months had zero fry). Ideally, the real number of cages with fry should have been used, but the companies did not provide this information monthly. Therefore, we assume that the data used are a good proxy of fish fry used by different companies.

Cages: The price of a new cage was estimated at USD PPP 238.15 and to last 8 years, therefore depreciating USD PPP 29.77/year. On average, there were 94.6 cages in the water per month. Maintenance was mostly done by fishers or farmers themselves and also set at USD PPP 29.77/year/cage (expenses with thread and nylon). This was multiplied by the average number of cages in the water per month (94.6). The equation follows the principle of equation 1 above.

Packaging: This was a one-time cost (USD PPP 10.66) throughout the year, therefore computed as such.

Facility maintenance: This included each association's monthly expenses with water, electricity and rent (one of the associations had its own store to commercialize its fish). Fishers did not include any such costs. We averaged out the costs paid by each association for water and electricity to fill in the months that we did not have access to this information (USD PPP 152.25). This value was multiplied by 12 months. The rental expense was computed as its value (USD PPP 207.35) multiplied by 12.

Personnel expenses: This was divided by legal (expenses with accounting and staff salary and benefits) and expenses with personnel maintenance, which was only food. The legal expenses were exclusive to the associations, and represented fixed costs per month (USD PPP 1210.85), with the exception of accounting, which was a one-time cost per year (USD PPP 414.69). Food expenses were calculated based on typical regional staples of meat, rice and beans, and their price per kilogram in the local market (intake multiplied by price kg). The value found was multiplied by the average number of days a fisher works a month (farmers incur this expense everyday) and then by the number of fishers or farmers.

2.4.2 | Output

We did not perform a thorough output analysis, such as the extent of economic activities that are sourced from fisheries or from aquaculture (Dyck & Sumaila, 2010). To estimate profits, we simply calculated the revenues, by using ex-vessel price and its equivalent in aquaculture (price of the first sale) and the auto-consumption value (fish taken by the fisher or farmer for his or his family consumption), as follows:

$$R_l = L_l * P_l \tag{2}$$

where R is revenue per landing $_l$, L_l is landings of each fisher in a given day in kg and P_s is either the ex-vessel price or price of the first sale of each species per kilogram. Prices per species were collected during fish landing or during interviews with fish farmers. In the case of farmers, the price would be obtained for the whole or filleted fish, depending on how they had processed their production. Then, profit was calculated as follows:

$$P_s = R_l - TC_l \tag{3}$$

where R_l is revenue per landing and TC is total cost per landing $_l$. Total costs were obtained from direct interviews with fishers.

The auto-consumption value refers to the cost of all the fish that were directly consumed by the fisher/farmer or their families had they bought them from a first middleman (again, equivalent to the ex-vessel price).

Figures shown in the output table differ from direct observations and calculations from fish landings and sampled aquaculture information because we also included estimated missing data. For fisheries, for instance, we observed that from all the regular fishers we had previously identified, only 49.5% showed up in at least one fish landing sampled. We interpreted that we missed 50.5% of the landings probably because they occurred outside our sampling area (two urban agglomerations and island fishing team). We, therefore, multiplied the fisheries output by 1.505.

2.5 | Comparing incomes

We tested possible variations within the mean income generated from farmers from different associations through the Kruskal–Wallis test. For fisheries, although we could not directly compare incomes, due to differences in sampling methodology, we estimated fishers' incomes based on their average net profit per fishing trip. For that, we simply defined the RPUE (Revenue per Fishing Effort) as the total landing in a fishing trip (in kg), and standardized it per number of fishers and per haul duration (in hr). For the large majority of the trips, there was only one fisher per canoe, which is why we did not include the crew size in the RPUE formulae. We estimated the monthly fishing frequency per fisher at 20, based on previous interviews. Therefore, to estimate the average income from fisheries, we took the average monthly RPUE and multiplied it by 20.

It was difficult to determine whether a fisher or farmer was working full- or part-time, because most of the people in the region depend on unstable or seasonal employment. Whereas 1 week they may just fish, the subsequent week this could change substantially. Therefore, to compute income we did not take into account if a person was working full or part-time and for the sake of simplicity we calculated fishing or farming-exclusive income disregarding other potential sources of wages. This simplification could have affected the estimates of auto-consumption, as months with fewer economic alternatives would probably make fishers rely more on fish protein and vice versa. However, this is likely a minor problem due to the high variation in income sources between fishers and throughout the months.

3 | RESULTS AND DISCUSSION

3.1 | Fisheries and aquaculture in reservoirs in a semi-arid region

Considering both reservoirs, 119 fishers and 35 fish farmers (23 of which are also fishers, but who never landed during our sampling) were identified. Although the number of fish farmers is accurate, the number of fishers is likely to be underestimated, as we may not have met all of them.

The two reservoirs farmed 27,75 ton of tilapia throughout the sampling period. The largest production was registered in the Umari reservoir (87.4%), where the business association formed by non-fishers is in charge of farming. The large majority of tilapia produced from both reservoirs (94.8%) was traded as whole fish, without any additional processing at an average price of USD PPP 3,92. The revenue generated by this trading was USD PPP 88,778.73 over 6 months. We could not get information on the revenue for two of the months we sampled. The final destination for the farmed fish varied depending on the fish farmers association and where they traded their product (to larger markets or local consumers). Two associations sold their fish to public schools due to official incentives that guarantee contracts with the government. Indeed, public support for private businesses has previously been shown to occur towards aquaculture, especially as a way to fight unfair competition or dumping practices or to stimulate innovation (Jarvinen & Magnusson, 2000). Even though aquaculture is a recent activity in the studied area and, therefore, could qualify as local innovation, there should be appropriate training and support for their future independence and business sustainability. This is also important given that these associations are formed by fishers with no previous business training, which can deter their full achievements (Isaacs, Hara & Raakjær, 2007).

As for fisheries, we sampled the catch of 2.9 ton, corresponding to 7-day sampling per month in each reservoir plus continued sampling done by the voluntary fisher over 10 months (total of 903 landings). All fishing was done with hook and line. Peacock cichlid (*Cichla ocellaris* Bloch & Schneider) responded for 90% of all the fish landed, followed by curimatã (*Prochilodus brevis* Steindachner, the only native species), trahira (*Hoplias malabaricus* Bloch) and tilapia (*O. niloticus*). The presence of exotic species in these fisheries is not surprising, given that the Brazilian government, through multiple institutions, has deliberately introduced non-native species to reservoirs (Agostinho, Pelicice & Júlio, 2006). Farmers, fishers and sport fishers have also done so, suggesting that from top institutions to final stakeholders people are not aware of the consequences of introducing exotic species (Novaes, Freire, Amorim & Costa, 2015; Pelicice, Vitule, Lima Junior, Orsi & Agostinho, 2014). Moreover, the introduction of exotic species, specifically in the Brazilian semi-arid region, has affected the local fish without necessarily resulting in clear social benefits (Attayde et al., 2011).

The fish sampled in this study amounted to USD PPP 6,601.07. We conservatively extrapolated that had we sampled the three locations continuously, the two reservoirs would have provided over 16.5 ton of fish per year and USD PPP 37,557.81. Fishers did not process their fish prior to sale, but rather always sold them whole, neither did they benefit from any specific contracts. Fishers could have benefitted from similar contracts with farmers to provide fish to public schools (e.g. the Brazilian Program of Food Acquisition that buys specifically from small/family farming, including artisanal fishers). However, this was not observed in the study, the fishers' low organizational level probably works as a hindrance to achieve such level of formalization. Therefore, incentives to fisheries should actually start by helping them organize themselves in order to better compete in the market with farmers.

3.2 | Aquaculture provides higher economic profits than fisheries

The general annual input in the society (all the expenses required to maintain the activity) is similar between fisheries and aquaculture. This means that both sectors contribute in a similar way to the economy before their product is put in the market, by interacting with other value chains for their functioning (Table 1). However, while the main input for fisheries (54.7%) is in the petroleum/gas value chain, as most of its costs are related to the little fuel they use in their activity, seconded by gear costs, the main input for aquaculture is in the animal feed/fry purchase value chain (46.3%). This is because most of its costs relate to the purchase of tilapia feed. Feed tends to be the largest variable cost in aquaculture, and this is especially true for carnivorous species (Goldburg & Naylor, 2005). Tilapias are omnivorous species and tolerate feed that is mostly plant based, especially soybean (El-Saidy & Gaber, 2002; Lin & Luo, 2011; Mzengereza et al., 2016), which decreases costs and pressures on marine environments where fishing for fish food occurs (Aldhous, 2004).

TABLE 1 Summary of the input–output analysis

Cost/Revenue	Item	Fisheries	Aquaculture	% Fisheries	% Aquaculture
Fixed costs	Gear	−20,369.67	−12,589.89	−25.04	−14.78
Variable cost	Boat maintenance	−1,759.62	−59.15	−2.16	−0.07
Variable cost	Packing material/ice	−9,711.75	−10.66	−11.94	−0.01
Variable cost	Oil and gas	−44,472.73	−2,796.21	−54.68	−3.28
Variable cost	Animal feed	−2,199.53	−39,433.58	−2.70	−46.29
Variable cost	Fry	0	−1,082.85	0.00	1.27
Variable cost	Personnel expenses (legal)[b]	0.00	−14,944.93	0.00	−17.54
Variable cost	Personnel expenses (food)[b]	−2,819.34	−9,808.47	−3.47	−11.51
Variable cost	Facility maintenance	0.00	−4,454.98	0.00	−5.23
Total costs	–	*−81,332.64*	*−85,180.70*	–	–
Revenue	Governmental buyer	0.00	49,542.65	0.00	21.17
Revenue	Other buyers[a]	97,999.40	181,625.41	95.28	77.62
Revenue	Consumption	4,853.63	2,830.28	4.72	1.21
Total revenue	–	*102,852.43*	*233,998.34*	–	–
Net profit	–	21,519.79	148,817.63	–	–

Note that percentage values refer to the total contribution of an item to total costs (shown with a negative sign) or to total revenues. Values are shown in USD PPP (US$ Purchasing Power Parities).
[a]Other buyers include their own local store, final consumer, local and regional middlemen, and regional stores.
[b]Legal personnel expenses refer to employer's taxes for each employee, whereas personnel expenses for food refer to costs for providing food for the staff (aquaculture) or food expenses while fishing (fisheries).

Overall, aquaculture is a much more profitable activity, as its net benefits were estimated to be almost sevenfolds higher than local fisheries (Table 1, Data S1). Part of this is attributed to the dependence each activity on different market segments. Fisheries depend almost exclusively on direct deals with middlemen and consumers (95.3%), whereas 21.2% of aquaculture production is sold to the government. In addition, fisheries are multispecific, with some fish less valuable than tilapia and none more expensive.

3.3 | Fisheries provide higher social and nutritional benefits

Whereas aquaculture generates higher revenues than fisheries, such revenues are restricted to a smaller parcel of the population. Fisheries directly benefited at least 3.3 times more people than aquaculture, a value that is likely underestimated due to the difficulties of identifying fishers around the reservoirs. In addition, fisheries contributed 3.9 times more to fishers food consumption (auto-consumption: fisheries = 4.7%, aquaculture = 1.21%) in relation to the total percentage of the catch that goes for auto-consumption. In kilograms, on average, while farmers took 1.1 kg fish per month for consumption, fishers used 0.46 kg of fish per trip for their own consumption. Assuming that fishers have an average family of five and fish 20 days per month, this would imply the consumption of 22 kg/per capita/per year, which is above the world per capita fish supply in 2010 (15.4 kg/per capita) (FAO, 2014). Fishing communities do have a higher intake of fish than non-fishing ones living in similar places (da Costa, de Melo & Lopes, 2014; Isaac & de Almeida, 2011), even though such intake is directly affected by fish fluctuation, urbanization levels and market insertion (MacCord & Begossi, 2006; van Vliet et al., 2015). However, for the Brazilian semi-arid region, there are no accurate estimates regarding fish consumption, except for a few studies pointing out food insecurity driven by the climate usually observed in this region (Simões et al., 2010; Vianna & Segall-Corrêa, 2008), which reinforce the role of fish in such places. In these studies, fish is not a regular food item in the local families' diets (Silva et al., 2012), again supporting its nutritional relevance for the poor.

Aquaculture and fisheries also differed in income return and stability. Fisheries provided a low but stable income: the average monthly income varied from USD PPP 22986, in June 2013 to USD PPP 39218 in August 2013 (±USD PPP 8294) (Figure 2). As a comparison, the average Brazilian monthly minimum wage for the studied period was USD PPP 41528. Aquaculture, on the other hand, provided much higher revenues, but it also resulted in losses, which never occurred to fisheries. In addition, aquaculture showed wide variation, depending on the association considered. For the three associations formed by fishers, one performed reasonably better, with a mean income per member of around USD PPP 59241, while the others struggled most of the time with their losses (Figure 3). Despite some clear visual differences, the Kruskal–Wallis test did not detect significant differences between mean revenue among the associations, probably due to the wide variations around the standard deviations ($H = 1.23$; $p = .74$).

Poor people tend to avoid risky economic decisions, that is, those that generate highly variable outcomes, unless this is the only

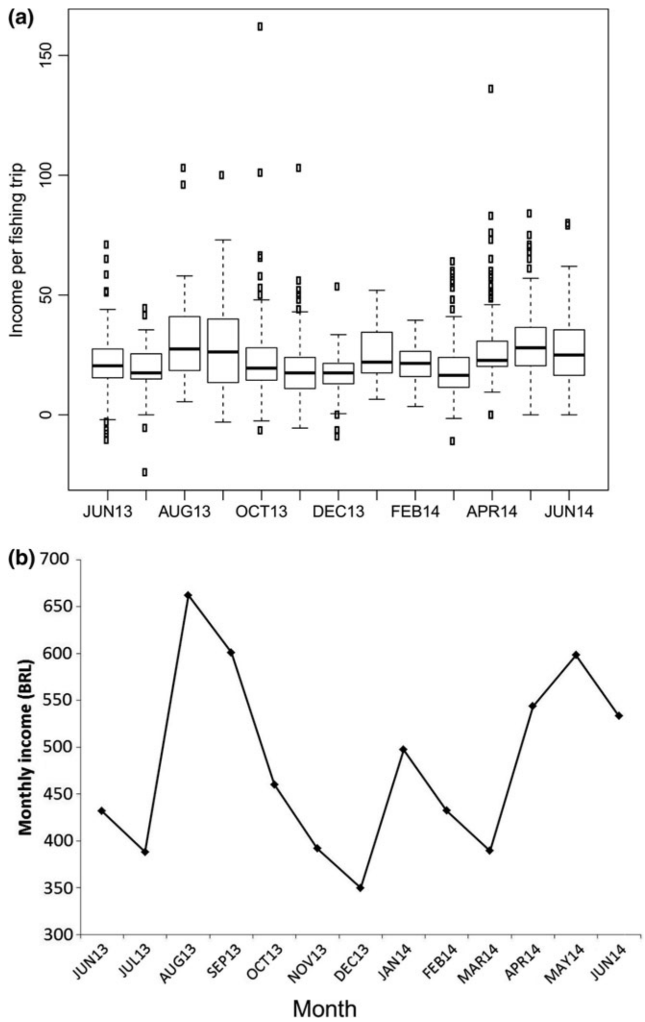

FIGURE 2 Estimated monthly income generated by fisheries in the studied reservoirs of the Brazilian semi-arid region. (a) On top shows the median income per fishing trip (line inside the box), minimum and maximum values (vertical lines), 25% and 75% quartiles (outer lines of the box), and outliers (dots), whereas (b) shows an estimate of how much such trips would generate per month, considering an average of 20 fishing trips per month per fisher

option (e.g. when not facing risks means they will not achieve their minimum needs for survival) (Winterhalder, 1990). Avoiding risks is expected given that in general poor people have not had a chance to secure their futures, through investments, for example, due to more urgent needs in the present (Banerjee & Duflo, 2012; Wood, 2003). This is consistent with empirical evidence obtained in poor countries where people, in particular women, develop local capacities to endure long months of droughts without fish to feed their families (Villasante et al., 2015). Therefore, even though the poor are the ones most in need, they are unable to undertake novel, but risky initiatives that could lift them out of the poverty trap, unless such risks are supported by external institutions, such as the government. In such a case, having the government buy their initial production may be a good alternative to decrease the initial risks while they build capital to undergo major profits and losses, as the "businessmen" association (COOPIRN) does. However, even then governmental support should not be seen as the only solution (Banerjee & Duflo, 2012), as every reservoir with its own surrounding socio-economic reality might respond differently.

Finally, it is important to acknowledge that we did not fully measure all the impacts on food security of having disposable income from aquaculture from time to time. With higher purchasing power, people might invest in different kinds of food other than fish. It is still not clear if such an investment is usually made towards better quality food or not (Ahmed & Lorica, 2002). Some suggest that with more disposable income and, given that a minimum of staple food has been acquired, people will invest in non-staples (e.g. meat and vegetables) for a more adequate calorie intake (Dawson & Tiffin, 1998) or for a varied diet from a taste perspective (Ahmed & Lorica, 2002). Therefore, future studies in semi-arid regions of the world should consider how eventual disposable income from aquaculture is used or invested by households, contributing to food security or not in different ways.

3.4 | Ecological impacts for fisheries and aquaculture in reservoirs

Any socio-economic approach that disregards its ecological background, especially in a context of direct use of natural resources, tends to be incomplete. Specifically, for the questions approached here, economic and social sustainability will only be ensured in the long term if an ecologically healthy environment is maintained. While the benefits provided by fisheries and aquaculture are easier to see, it is also necessary to acknowledge the risks posed by them.

Fisheries, for instance, can modify the ecology of the water column (Sarà, 2007), affecting the plankton that feed the fish. Fisheries also affect the food web directly, depending on how much fish is removed and on the trophic level of this fish (Fulton, Smith & Punt, 2005).

Aquaculture, however, can be responsible for tilapia escapees, which adds to the risk of disease transmission, especially to other cichlidae species (McCrary, Murphy, Stauffer & Hendrix, 2006). Also, the use of antibiotics in tilapia cultures could contaminate the water used for human consumption (Quesada, Paschoal & Reyes, 2013). Although the use of antibiotics in fish farming are regulated in Brazil (Quesada et al., 2013), enforcement is not always the rule, especially in the least developed areas, raising multiple issues, including the use of illicit antibiotics (Hashimoto et al., 2012). The concentration of tilapias in cages also increases waste in shallow reservoirs, which could lead to reservoir eutrophication (Starling, Lazzaro, Cavalcanti & Moreira, 2002), especially at the high stocking densities done in Brazil (100 kg of fish per m^3) (Garcia, Kimpara, Valenti & Ambrosio, 2014). Again, this also depends on cage density and their stocking, and on the reservoir depth and its connectivity with other water bodies. Studies with cage and pond tilapia farms in Ethiopia and in Brazil, for example, have hardly shown any evidence of a higher concentration of nutrients in the water (Degefu, Mengistu & Schagerl, 2011; Moura et al., 2016). In fact, tilapia could be used to control

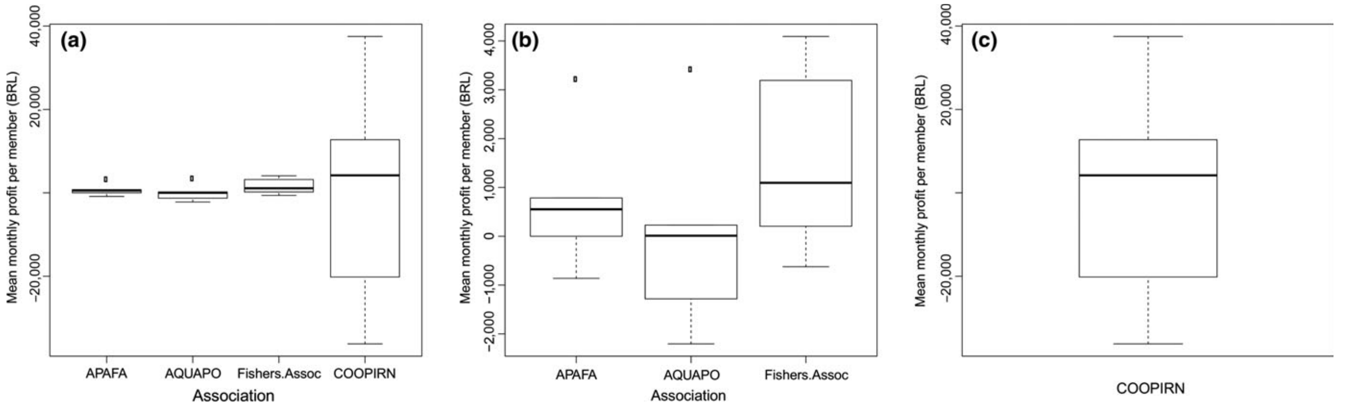

FIGURE 3 A fish farmer median monthly income derived from aquaculture from (a) all four fish farm associations together. (b) The three associations not managed by businessmen/entrepreneurs; and (c) the fish farm association controlled by outsiders (businessmen). APAFA = Fish Farmers and Fishers Association (10 participants), AQUAPO = Association of Fish Farmers from Apodi (10 participants), Fisher's association = managed by artisanal fishers (3 participants) and COOPIRN = Cooperative of Fish Farmers from Rio Grande do Norte (12 participants). All figures show median values (lines inside the box), minimum and maximum values (vertical lines), 25% and 75% quartiles (outer lines of the box)

cyanobacteria blooms that can affect human health (Attayde, van Nes, Araujo, Corso & Scheffer, 2010; Tucker, 2007). The effects of aquaculture on water used for irrigation could be either positive or negative, as the organic waste in the water can benefit agriculture to a certain extent (Cardoso Filho, Campeche & Paulino, 2010; El-Kady & Soluma, 2011).

Therefore, a thorough assessment of the impacts of the use of reservoirs for both fisheries and aquaculture is a necessary step to conclude if their benefits go beyond or are restricted to short-term socio-economic gains.

4 | CONCLUSIONS

Reservoirs are built to for multiple uses and are especially important in arid or semi-arid regions, where they can also provide drinking water and food for the poor, through fisheries and, more recently, aquaculture. Nevertheless, in some cases both fisheries and aquaculture carried out in reservoirs have been considered impacting activities. This is due to the fact that, in many reservoirs, fishing depends largely on exotic species, which have affected the local fish without necessarily resulting in social benefits for the surrounding population. Aquaculture has been criticized for the effects it generates by densely stocking exotic species, such as tilapias, in waters that serve human consumption and for being carried out without appropriate ecological impact studies.

In this study, we showed that the practice of both fisheries and aquaculture together in the reservoirs of the Brazilian semi-arid region generated similar benefits to the economy before their final product reached the market. Once in the market, aquaculture generated much higher economic revenues. However, such a conclusion tends to oversimplify the reality and underestimate the synergies and trade-offs generated by both activities, especially given that the post-harvest benefits are limited to total revenues. Using a more encompassing socio-economic approach, we showed that fisheries tended to be more socially fair for employing more people and for contributing to food security on a larger extent. Even though aquaculture provided larger gains, it also provided larger losses, which may not be affordable to poor people and could continue the poverty trap in which they are caught in, unless they have the support of stronger institutions.

In this study, fisheries were a more reliable alternative for food security and livelihoods, but its potential to generate income is limited, despite being more constant over time than aquaculture. Aquaculture, however, can potentially be a way out of poverty, as long as farmers can deal with wide profit and loss variations. The Brazilian semi-arid region, similar to many other impoverished semi-arid areas in the world, needs options to improve the local livelihoods; integrated aquaculture and fisheries could be one such option. Nevertheless, we suggest that, before implementation, fisheries and aquaculture should be analysed under a more integrative view whereby one activity does not compromise another presently or in the future, by disrupting the ecosystem they depend on.

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