Effect of fish downstream supply chain on wealth creation: the case of tambatinga in the Brazilian Midnorth

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Abstract

We describe the downstream supply and value chains originating from commercial tambatinga farming in Midnorth Brazil. We assessed how farm size affects intermediaries and job creation, income generation and the number of wealth beneficiaries. We surveyed 16 commercial farms from 0.1 to 220 ha and their supply chains. To compare wealth creation and the number of beneficiaries we established a baseline annual production of 550 t. Labor hours per tonne tended to rise in medium and extra-large farms. There were two main types of fish downstream supply chains: small farms selling their fish directly to consumers and large farms relying on intermediary trading, where gross revenue was spread among the different parts of the supply chain. Large supply chain stakeholders enhanced net income, typically through supermarket sales. However, the few farms and intermediaries involved resulted in low, poorly distributed, wealth creation. Intermediary trading through markets resulted in high global wealth creation but incomes below the minimum salary of most market sellers. Market sellers shipping from the wholesale market showed improved income. Fish trading undertaken by small farms produced the best gross revenue per traded fish, providing considerable wealth creation, especially in the case of selling at consumers' homes and markets. This supply chain also permitted good wealth distribution. Net incomes of self-employed farmers exceeded the regional minimum salary by a factor of 3 to 5. Direct selling was thus more appropriate for lifting people out of poverty.

1 Background

Aquaculture is one of the fastest-growing food-producing sectors, increasing about 6% yearly in the past three decades and employing more than 20 million people (FAO 2020). This activity has been cited as essential to feed a growing world population in the present century (Béné et al. 2015). Worldwide aquatic animal production surpassed 85 million tonnes worth USD 259 billion in 2019 (FAO 2021). Most of the aquaculture production comes from inland small-scale pond farms in rural areas (FAO 2020). Despite this overall scenario, the way in which small-scale freshwater pond aquaculture is connected with the surrounding social, economic and environmental systems is poorly investigated (Fonseca et al. 2022).

The success of aquaculture depends on a set of linked elements that constitute the production chain. This chain includes the farms themselves, together with a complex web of pre-production and post-production elements. The production chain involves, amongst others, the infrastructure, policies, the suppliers of feed, seed and fertilizer, processors, distributors, traders and consumers (Valenti and Tidwell 2006; Valenti and Moraes-Valenti 2010). Each production chain includes supply and value chains of materials and goods provided to farms and for farm outputs. The supply chain is defined as the group of companies through which a product or service moves from producer to the end consumer, while the value chain is the set of market functions provided by the companies in the supply chain (Engle 2019). Supply chains describe the product path towards the consumer, while value chains refer to the way in which a product or service increases in value as it moves through the different elements to the consumer. Both are linear chains, in which a product moves step by step from one stage to the next.

The total process can be divided into upstream and downstream. Upstream refers to the material inputs needed for production, while downstream includes the production and the elements of each distribution channel (supply chain) of any product. The upstream includes all players that provide all the supplies for production. The downstream includes the farming itself together with the distribution channels; these are comprised of the chain of firms (or individuals) a product passes through to reach the end consumer. Therefore, we can separate the upstream supply chain and the downstream supply chain. The businesses between production and the final consumer are called intermediaries. The intermediaries may improve the products, adding value, and reselling it; or they may merely move the product through the channel (supply chain). The post-harvest downstream supply chain in aquaculture may include middlemen, wholesalers (distributors), retailers and dealers (the end of the distribution channel). Dealers include market sellers, fishmongers, supermarkets, restaurants, etc.

The contribution of aquaculture to food security and the reduction of poverty in developing countries is well-recognized. Brazil has the potential to become one of the major aquaculture producing countries in the near future (FAO 2018). Currently, Brazilian aquaculture represents less than 1% of worldwide aquaculture production (FAO 2020). However, this sector increased by 123% in the past decade (Myhre et al. 2017), reaching ~ 800,000 t worth US $ 1 billion in 2019 (Valenti et al. 2021). Production is performed mainly in freshwater ponds in farms of various sizes (Valenti et al. 2021). Brazilian aquaculture has considerable potential for expansion because of its huge availability of water, its tropical climate and its strong internal market.

Tambaqui (*Colossoma macropomum*), a native species in the Amazonian region, is the second most highly produced farmed fish in Brazil (Valenti et al. 2021). This species is mainly produced in the Midwest, North and Northeast Regions because of their tropical climatic conditions (Woynárovich and Van Anrooy 2019). The production of tambaqui and its hybrids, such as the tambatinga (*Colossoma macropomum x Piaractus brachipomum*), a cross breed with the pirapitinga (which is also a native species from the Amazonian region), reached 142,890 t in 2020 (Valenti et al. 2021). Tambaqui are characterized by their robustness, omnivore/filter-feeding habits and the large size that can be reached rapidly when effectively managed (2 to 3 kg in one year of production).

Tambaqui and tambatinga production is mainly carried out in monophasic or biphasic systems starting with 2–5 g fingerlings and harvesting at sizes of 0.8 kg to 3 kg. Farmers generally operate without aerators, resulting in a low production intensity, from 0.5 to 1.2 kg/m²/yr. The production of tambatinga is concentrated in the Midwest, Northeast and North Regions of Brazil and is carried out in earthen ponds in small, medium and large farms, (Valenti et al. 2021). In the Midnorth Region, tambatinga farms are smaller than in the other producing regions. Farms rarely reach 100 ha. Most of the small farms participate in fish supply chains involving fish production and sales to retailers or final consumers; this increases the margin of benefits from their activities.

This paper refers to all players from post-harvest to the end consumers as intermediaries. This category includes middlemen, wholesalers (distributors), retailers and dealers. Intermediary activities often

generate more income and employment than production itself (Beveridge et al. 2010). It is possible that farm size may influence the choice of distribution channel. However, this effect has been poorly understood until now. The number and roles of intermediaries and their impact on the local economy of developing countries are also poorly understood. These gaps in knowledge have impaired effective actions to strengthen the downstream process of the aquaculture production chain.

Therefore the goal of the present study was to describe the downstream supply and value chains originating from commercial fish-farms of various sizes. To provide this information we studied the tambatinga farming sector in Midnorth Brazil as a model. We have assessed how farm size can affect the intermediaries and consequently job creation, income generation and the number of wealth beneficiaries.

2 Materials And Methods

The survey began by visiting 16 commercial farms of tambatinga (*Colossoma macropomum x Piaractus brachipomum*) in the states of Maranhão and Piaui in the Brazilian Midnorth (Fig. 1) in 2016. This region contains a large number of tambatinga producers; attaining about 2,000 farms. The survey covered a purposive sample of semi-intensive commercial farms, with a pond size range of 0.1 to 220 ha. These extremes are the minimum and maximum commercial farm sizes encountered in the region. Farms were chosen to represent the different groups of farm size observed in Brazilian Midnorth region. Farm categories were divided into small (< 1.5 ha of ponds), medium (from 2.8 to 5.2 ha of ponds), large (from 12 to 29 ha of ponds) and extra-large (from 185 to 220 ha of ponds). Farm selection was assisted by stakeholders in the tambatinga supply chain, including experts from local rural extension services. We selected the most representative production systems of each farm size. The farms sampled represent about 0.8% of all tambatinga farms in the Brazilian Midnorth. All farms operate a semi-intensive system, stocking 0.4 to 1.7 fingerlings/m2 during ~ 8 months. They use balanced feed with feed conversion ratios ranging from 1.3 to 1.8, and productivity from 3 to 16 t/ha/crop. Water sources are precipitation, rivers or wells. The farms studied have diverse channels to sell their output; this results in differing supply chain structures.

For each farm, data on the culture schemes, amount of labor, productivity, production cost and trade strategy were obtained. Among the 16 farms studied, 11 farms sold their output to intermediaries, while 5 (all are small farms) included distribution channels resulting in vertical integration. These distribution channels of these five farms were also studied: one farm sold farm-gate; two farms sold direct to customers' homes; another sold in a market and one farmer only undertook transport to a market.

The survey continued in early 2017 by examining the supply chain of the remaining 11 farms. This phase involved various stakeholders in the city of São Luis, the main trading point of the region. In that city we visited the wholesale market to interview 5 first middlemen (the intermediary trades that buy fish in the farms and sell to wholesalers (distributors) or supermarkets); 7 distributors (the wholesalers that buy fish from the first middlemen and sell to other intermediates); and 10 second middlemen that buy from

wholesalers and sell to retailers (markets). In addition we visited the 2 supermarket chains in São Luis to interview their sales directors. We also visited 2 different markets to interview 5 market sellers. In the present study, we refer to all these various stakeholders in the supply chain as intermediaries.

Interviews were conducted with the owners and employees of farms and intermediary trades, using semi-structured questionnaires by personal visit, i.e., face-to-face. Direct observations “in loco” and phone calls were also conducted to check and complete the information. At farms, data was obtained about owners’ and employees’ functions and the total working hours of all involved (owners, family and employees) during the entire fish production cycle and trade (labor-h). Information was also obtained about the quantity and value of fish sold and the operating costs. The latter included labor, social insurance, feed, fingerlings, fuel, electricity and water costs.

Investments in assets, including ponds, canal construction, pumps, buildings, electrical installation, equipment and vehicles were also recorded. The major equipment used at farms consisted of nets, aerators, a weighing scale and a wheelbarrow. During the various visits to São Luis we obtained information on the structural organisation of the different supply chain stakeholders (intermediaries), data on the owners’ and employees’ functions and the labor-h. In this case, labor-h was defined as the total hours of all workers (owner and employees) required at each stakeholder that was trading the fish. We also obtained data on the quantity and value of the fish sold and their operating costs, which included labor, social insurance, fuel for fish transport and ice for fish storage. Data on the investment costs of equipment and vehicles was also obtained.

The costs of permanent workers were calculated based on their annual salaries composed of 12 monthly wages plus 1 monthly wage of vacation pay. The working time of permanent workers was about 44 hours a week during 48 weeks per year. The annual salary of temporary workers was calculated on an annual basis by multiplying their hourly pay by the 44 (hours worked per week) and 48 weeks. In the smallest farms, feeding tasks are carried out by the owner or by a family member who is not paid. In this case, we calculated the feeding costs by multiplying the working hours spent in feeding by the relevant hourly wage paid to the people hired to work only for harvesting.

Labor costs were calculated by multiplying the hourly labor wage by the labor-h required, plus the extra month’s wages for vacation and the labor insurance necessary for permanent workers. Asset depreciation was included in the operation costs; this was calculated by dividing the asset values by their useful life (Engle, 2010). The total operating costs of supermarkets were calculated based on the study performed by Laureth et al. (2018) for small supermarkets in Brazil.

The figures for gross revenue were obtained by multiplying the quantity of fish produced and/or traded by the fish value per kilogram. Net Income (NI) was computed by the gross revenue (GR) minus the total operating cost (TOC). All monetary values were converted from Brazilian Reals (R$) to US dollars (US$), based on the average exchange rate for the month of May 2017 (US$ 1.00 = R$ 3.22).

The labor-h at each farm studied was converted into an annual basis (labor-h/yr). In order to compare farms of different sizes that produce different quantities of fish, we divided the annual labor-h/yr of each farm by their respective annual fish production (t/yr) as follows:

$$\textbf{Labor-h/t} = \frac{Labor-h/yr}{t/yr}$$

In a second stage we assessed the labor-h/t of each intermediary in the various supply chains. Then we summed the labor-h/t of the whole downstream supply chain, i.e., each farm and its relevant intermediaries to the end-consumer, creating the total-labor-h/t. Finally, we assessed wealth creation in each supply chain. We defined wealth creation as the sum of employee earnings (salary plus labor insurance, i.e. direct plus indirect earnings) and the net income generated to produce and to trade the fish. Wealth beneficiaries were defined as all those that benefitted financially through their activities at all stages of the value chain. The quantity of workers was calculated by dividing the number of labor-h required per year by the hours of a permanent worker (2,112 h/yr).

To compare the wealth creation and the number of wealth beneficiaries in each supply chain pathway, we had to establish a baseline production because the supply chains start at farms of different sizes. Thus we used the highest volume produced and traded amongst the various supply chains stakeholders studied. This was the average of the annual production of the two largest farms, namely 550 t. Therefore, we standardised all the produced and traded quantities of fish at 550 t. To do so, we divided the wealth creation and the number of wealth beneficiaries of each stakeholder by their respective quantities of fish produced or traded and multiplied it by 550.

$$SWC = \left(\frac{\mathrm{WCS}}{PTQS}\right)\mathrm{x}550$$

in which:

SWC = Standardized wealth creation

WCS = wealth creation of the supply chain stakeholder

PTQS = production or traded quantity of the supply chain stakeholder

In each supply chain, we have obtained the total wealth creation and the total number of wealth beneficiaries by summing the wealth creation or the number of wealth beneficiaries of each stakeholder involved. In other words, we summed employee earnings and the net income of farms and intermediates involved in each supply chain to produce and/or to trade 550 t of fish. The number of wealth beneficiaries was defined by summing the number of employment positions and the number of owners. In the case of employees we summed the number of jobs generated. In the case of owners we summed the number of all the stakeholders required to produce and trade 550 t of fish.

The wealth produced is distributed amongst the people that work in farms and the intermediaries. The owners of farms and intermediaries are self-employed and are also beneficiaries; thus they should also be included in this account. Therefore, to obtain the number of wealth beneficiaries we summed the quantity of farm and intermediate trade owners and employees required to produce and trade 550 t of fish. Therefore, the higher number of small farms necessary to produce 550 t of fish will contribute more self-employment, while the lower number of large farms necessary to produce the same 550 t will contribute more employees. The same will occur with the stakeholders involved in the commercialization of each part of the sale supply chain.

The data from each supply chain stakeholder (such as the intermediaries and the farms selling directly to customers' homes and in markets) that occupied the same function were averaged. Furthermore, data from medium farms [2.8–5.2 ha], large farms [12–29 ha] and extra-large farms [185 and 220 ha] were also averaged. Intermediary trades, composed of three potential supply chains, were combined with the three farm size ranges mainly involved (medium, large and extra-large) to obtain 9 scenarios.

3 Results

There was a sharp increase in labor-h/t at the 2.8 ha farm size and a slight general tendency for it to decrease in intermediate farms and increase in farms from 29 ha onwards (Figure 2). Labor cost per tonne produced increased substantially in farms of 29 ha or higher (Figure 2) The smallest farms studied, from 0.1 to 1.5 ha, relied exclusively on temporary workers[1] for feeding, harvesting and maintenance activities. From the 2.8 ha farm onwards farms hired permanent workers for feeding activities. From the 4.8 ha farm onwards the number of worker positions and functions increased as the farm size increased. These positions included night guards, supervisors, secretaries, drivers, householders such as permanent workers and an accountant as freelancers. Apart from the two largest farms, harvesting was carried out by temporary workers, whose wages ranged from US$ 2.00 to 4.28/h, depending on the farm. According to the level of production, harvesting was performed weekly, monthly or quarterly by a team of 4 to 16 persons working for 4 to 12 hours. Maintenance was mainly carried out by temporary workers, hired occasionally for a whole day to clean the pond area. Their wages lay between US$ 1.14 and 1.42/h. In the small farms, feeding was carried out daily for periods between ¼h and 1h, mostly by one family member who received no pay. Therefore, our computation of their hourly wage was based on the hourly pay of harvesters. Permanent workers, such as feeders, harvesters and domestic employees earned the minimum legal salary of US$ 2,537/yr, which corresponds to U$ 1.20/h based on a working time of 44 hours per week. Secretaries, night guards and drivers were paid between US$ 3,240 and 5,484/yr. Supervisors had the largest salaries, especially in the two largest farms (185 ha and 220 ha), receiving a mean salary of US$ 30,864/yr.

We identified 7 different supply chains (distribution channels) (Figure 3). Four channels were undertaken by small farm owners, representing vertical integration. They were selling fish to nearby farms and incorporated the functions of distributors and dealers or transporters to markets. Three distribution

channels relied on intermediary traders and were used by medium, large and extra-large farms. In these channels, the dealers were markets and supermarkets remote from the farms (Figure 3).

Most of the small farms studied, such as the 0.1, 0.2, 0.5, and 1.3 ha farms, were involved in the supply chain of fish to the final consumer, while the 1.4 ha farm exclusively took care of the transport to the local market (Figure 3). The 0.1 ha farm sold their production of whole fish at the farm gate to neighbours at US$ 2.50 /kg of fish [Figure 3(1)], this was the cheapest price recorded for consumers. This farm sold 1.6 t/yr of fish, generating an income of US$ 1,805 /yr. The 0.2 and 0.5 ha farms sold fish to consumer's homes [Figure 3(2)]. Once a week, a crew of 4 people harvested around 100 kg of fish. After that, 1 or 2 sellers passed round the neighbourhood with a vehicle (motorbike or normal car equipped with a trailer) for about 3 hours, selling whole fish for US$ 3.10 /kg. On average they traded 5.0 t/yr of fish for US$ 7,585/yr.

The 1.3 ha farm sold daily in a market [Figure 3(3)]. A crew of 4 persons harvest 40 kg of fish each day and ship them to a local market. Here the famers' family members and two assistants cleaned and sold the fish for US$ 3.10 /kg over a 6 hour period. They sold 12 t/yr, generating US$ 11,554 of net income.

The 1.4 ha farm harvested around 40 kg of fish daily and sold its output only through the market [Figure 3(4)]. Whole fish were sold for US$ 2.50 /kg to market sellers where they were cleaned and sold for US$ 3.10 /kg. This farmer traded 15 t/yr and generated US$ 12,512/yr.

The larger farms and the 0.3 ha farm relied completely on intermediary traders. The supply chain started at the farm which sold whole fish at the farm gate to intermediary traders (first middlemen in the supply chain) from US$ 1.55 to 1.70 /kg, depending on the fish mean weight. These first middlemen took care of fish transport with trucks, using 2 drivers that alternated the driving during each trip. They mainly travelled from rural to urban areas over a 10 to 17 hour journey with an average load of 4 t of fish. They made the trip 2 to 3 times per week. First middlemen shipped the fish to a wholesale market or to supermarkets selling fish around US$ 1.86/kg in each case. Each first middleman generated an average income of US$ 48,183/yr (Table 1).

In the wholesale market, distributors hold a central position. They not only make the connections between the first middlemen and the second middlemen but also, to a lesser extent, with the final consumers, fishmongers or restaurants. Distributors have a function in fish sales, exchanging information between offer and demand. They also take care of the unloading of fish from the first middlemens' trucks and the control of cargo weight, on average this requires 3 temporary workers per day for 7 hours. These intermediaries on average generate US$ 31,428/yr of net income (Table 1).

Second middlemen transport fish from the wholesale market to smaller markets that are spread throughout the city and possibly to some fishmongers as well. They buy fish from distributors at US$ 2.17/kg and sell them at around US$ 2.48/kg to market-sellers [Figure 3(5)]. On average they generate US$ 5,719/yr of net income (Table 1). Sometimes the middlemen themselves handle part of the fish sales at the market [Figure 3(6)]. At the ultimate step of the supply chain market-sellers sell fish to consumers

at around US$ 3.10/kg. Market-sellers with small stalls sell an average of 70 kg of fish per week. Larger stallholders reach 300 kg per week, but they have 1 to 2 extra workers to clean and cut the fish. Market sellers with an average trade generate no net income and a low salary (US$ 2,234/yr) (Table 1).

The wholesale market, which is located in the city centre of São Luis, consists of 30 traders. These sell around 10 t of tambatinga daily, according to the chairman of the wholesale market association. In total, including seawater and freshwater fish, 90 traders sell around 30 t daily, supplying São Luis City and its suburbs. This amounts to more than 10,000 t/yr of fish.

Supermarkets [Figure (7)] have 6 to 7 permanent workers in the fish department. These take care of quality control, weighing, cleaning, cutting and wrapping. One supermarket, whose average daily sales of various fish species reach ~ 400 kg, sells tambatinga at ~ US$ 3.25/kg. The fish department of this supermarket generates an average net income of US$ 110,619/yr. In São Luis, two supermarket brands share the business with 28 supermarkets achieving total sales of 4,440 t/yr of fish.

The sum of labor-h/t of the farms and their respective supply chains (see data in Table 1) represent the total labor-h/t (Figure 4). The 0.1 ha farm selling fish at the farm gate had the lowest score with 76 total-labor-h/t [Figure 4 (1)]. Sales of fish at consumers' homes made by the 0.2 and 0.5 ha farms reached on average of 114 total-labor-h/t [Figure 4 (2)]. Sales of fish at market from the 1.3 ha farm required 591 total-labor-h/t, mainly due to the amount of salesmen at the market [(Figure 4 (3)]. The supply chain through the 1.4 ha farm [Figure 4 (4)] totalled 564 total-labor-h/t, mainly due to the amount of salesmen at the market, while fish supply of the farmer through the market required 11 labor-h/t. Extra-large farms required the highest labor-h/t of intermediaries, while the 1.4 ha farm required the lowest (Table 1). Market sales required the highest amount of labor, reaching 437 total-labor-h/t [Figure 4 (5)]. Combined with extra-large farms production, market sales reached the highest score of 657 total-labor-h/t. Extra-large farms with supermarket sales required 232 total-labor-h/t [Figure 4 (7)].

Table 2 and Figure 5 show the total wealth creation by the various supply chain stakeholders to produce 550 t of fish for each of the 7 supply chains. In Figure 5 the various supply chain stakeholders are represented by rows with square patterns. The quantity of boxes represent the required number of workers (44h/week) in green and the number of supply chains' intermediaries or farms in yellow. Wealth creation, expressed in millions of US$/yr, is represented by the sum of workers' salaries in green, social insurance in blue and farms and intermediaries' net income in yellow.

There is a slight tendency to increase the quantity of workers involved with intermediary trade and total wages as farm size increases (Table 2). On the contrary, medium farms showed more net income and more total wealth creation than larger farms. The supply chain that has the supermarket as an intermediary showed the lowest total wealth creation and the lowest distribution. This supply chain generates on average US$ 678,000 of total wealth with 56 workers and 11 stakeholders.

Market supply chains showed large total wealth creation (US$ 997,861) and generate a large quantity of workers (163) and supply chain stakeholders (104). However, market sellers with an average stall size do

not generate any net income. Conversely, market sellers that undertake shipping from the wholesale market show high net income with high wealth creation (US$ 1,160,000 on average) and lower supply chain stakeholders (30 on average).

Among the vertically integrated farms (the ones where the supply chain was undertaken by farmers), the 0.1 ha farm shows the highest number of wealth beneficiaries with the creation of 16 full-time work-positions (i.e., those employed for 44 hours/week during 48 weeks of the year) and 344 owner positions (farmers). However, in this farm size, people work as a part time activity, this results in a low net income that is below the minimum salary. On the other hand, the 1.3 and the 1.4 ha farms showed high net income with a high number of wealth beneficiaries. On average they required 148 workers, 109 farmers and intermediaries with wealth creation of US$ 1,112,967. As a part time activity, the vertically integrated farms that sell their fish at consumers' homes showed good wealth creation (US$ 984,249), only 30 workers positions were generated but 110 owner positions (farmers) were created with good net incomes.

[1] Shown as patterned bar diagrams in Figure 2

4 Discussion

The quantity of labor-h and the labor cost required per tonne of fish produced exclusively through farm activity shows two different patterns related to farm size. Firstly, farms from 0.1 to 1.5 ha show a low and regular score which decreases slightly as farm size increases. This relationship is explained by the fact that these farms rely exclusively on temporary workers. Their hiring flexibility induces low and regular labor-h per tonne produced; an average of 59 labor-h/t.

Farms from 2.8 ha onwards start to hire permanent workers (44 hours per week). This results in a sharp increase in labor-h and laborers' wages per tonne produced. This switch to worker type employment results in a second pattern with global higher values (an average of 96 labor-h/t) and irregular scores as farm size increases. In fact, the three first farms in this pattern show high labor-h/t mostly because of the full-time employment of one feeder for a relatively low production of fish. Larger farms (12 ha and 17 ha) also employ one feeder but for a fish production more than twice as large. This reduces labor-h and labor cost per tonne of fish.

The even larger farms show an increase in labor, which could at first be explained by an increase of management complexity. In fact these farms require other types of workers, such as supervisor, secretary, night guard, domestic employee, driver, lawyer and accountant. In addition we observed an increase of labor-h/t in feeding and harvesting, partly due to more difficult employee management and logistics but also to handling complexity related to larger pond size. In fact, pond size is proportional to farm size and the two largest farms have 45% of their ponds larger than 10 ha. With this pond size, harvesting is carried

out by two tractors which drag various coupled fishing nets from the banks of the pond. This requires a large number of men handling the nets and they are in the water all day long. With regard to feeding the 185 ha farm uses a boat to spread food properly throughout the large ponds; this requires more workers for a longer period. In consequence the full time employment, combined with the management complexity, results in a labor-h/t similar or higher (+ 62% on average) than smaller farms. However, we found that the largest farm (220 ha) had a much lower demand for workers principally because it used five feed spreader machines, thus accelerating the feeding process.

In the study of Filipski and Belton (2018) in Myanmar, large farms showed lower labor demand than small farms. The opposite result that was obtained in our study comes in part from the limited use of mechanization; the feeding processes of large farms increased the need for feeding workers. Furthermore, the region where the farms are has a small local market that cannot immediately uptake the large quantity of fish harvested per large pond farm; it also does not have large freezer storage facilities. Thus, large farms take several months to sell their fish. As the fish remain in the ponds, farm productivity is reduced; this increases the labor-h/t required.

We observed two main selling methods which characterize two patterns of downstream supply chain. Most of the small farms undertook a supply chain while farms larger than 1.5 ha relied exclusively on intermediary stakeholders to sell their fish. Post-harvest supply chains generally require more labor-h/t than fish production. They also show greater variation between their various distribution channels. Where fish production requires from 47 to 144 labor-h/t, the supply chain requires from 72 to 657 labor-h/t. The market selling channel requires the largest amount of labor (~ 600 labor-h/t), followed remotely by supermarket (~ 200 labor-h/t) and farm or home selling (~ 90 labor-h/t). As far as we know, no comparable data are available in the literature for other fish supply chains.

Job creation is particularly important as the poorest households in communities where fish farming occurs rarely have enough resources to participate in aquaculture directly as producers (Toufique and Belton 2014). Nonetheless, most job creation in the agricultural sector is based on the minimum salary, which may be too low to lift people out of poverty. The Brazilian Department of Statistic and Socioeconomic Studies (DIEESE) calculated that the minimum salary in 2016 would need to be multiplied by 4.38 to raise a four-member family (DIEESE 2017). Furthermore the state of Maranhão, one of the poorest in Brazil, has an average per capita income of US$ 2,220 per year; this is below the minimum salary which was fixed at US$ 2,537 per year in 2016 (IBGE 2017). This is due to the fact that workers without a formal contract or who are self-employed represent respectively 16.5% and 32.5% of those employed in the Brazilian agribusiness sector (Castro et al. 2020). Neither worker category receives a guaranteed minimum salary.

Our study showed that some supply chain stakeholders had very weak economic outcomes. As intermediary traders, market sellers working 6 to 7 hours a day, 6 days per week, selling an average of 156 kg of fish per week do not generate any net incomes. They generate just enough to recoup their costs and to draw a low wage for themselves of about US$ 2,234/yr. The smallest stands selling about 70 kg of fish

weekly barely reached US$ 1,235/yr [Figure 3 (path 5)]. The smallest farms selling fish to intermediary traders (such as the 0.3 ha farm) or the small farms selling at their farm gates (like the 0.1 ha farm) also show weak incomes. However, they have other potential sources of income; fish farming is a part-time activity in these cases (< 1 h/day).

In intermediary trading, the numerous stakeholders from the farm to the consumer results in a divided and thus reduced gross revenue per traded fish. Furthermore, profit margins in the main Brazilian aquaculture activity are poor, due to high operating costs caused by expensive unit fish feed prices (Pedroza Filho et al. 2016). Therefore, small farms and small intermediaries involved in intermediary trading are unable to earn a decent wage, such as that defined in sustainable development goal number 8 (UN 2015). This type of supply chain suits large farms and large supply chain intermediaries that are able to trade a large quantity of fish. This increases net income as shown by the extra-large farms and supermarket with net incomes over 40 times the minimum salary.

However, this type of supply chain shows the lowest wealth creation (below US$700,000 on average) with the lowest number of wealth beneficiaries. There were six and eighteen farms and intermediaries when fish was produced by the extra-large and medium farms respectively. Furthermore, the supermarket supply chain in São Luis is composed of 28 supermarkets belonging to two brands; this reduces the number of wealth beneficiaries even more. An alternative that we observed in intermediary trading was to take care of two functions in the supply chain to enhance the gross revenue per traded fish. An example was the market sellers equipped with a pickup truck or station wagon who also ship from the wholesale market [Figure 3(path 6)]. This was the best channel in intermediary trading with respect to providing the minimum salary and large wealth creation.

Supply chains undertaken by farmers in markets or at consumers' homes involve fewer or no intermediary stakeholders; this results in a concentration of the gross revenue per traded fish in a few stakeholders, increasing their gains. It creates a net income exceeding 3 to 5 times the minimum salary in the region. With a small quantity of fish traded by each farm, this supply chain channel requires a large quantity of farms to respond to the fish demand. Therefore this supply chain may result in large wealth creation which is widely distributed. Small vehicles with trailers allow farmers to undertake their own supply chain as market sellers. Vehicles allow the transport of fish from the wholesale market through intermediary trading, providing the greater creation and distribution of wealth. As small farms or ventures can hardly afford this equipment it is important to facilitate access to small credit lines; currently the paperwork requirement for credit access is a real bottleneck.

Farmers selling fish at their farm gates represent the simplest supply chain model in which their customers are close neighbours. As this supply chain does not require any vehicles it shows the lowest operating cost and the lowest sale value. To sell exclusively to neighbours in a rural area involves a low production, as observed in the 0.1 ha farm (1.6 t/yr); this results in a low net income of US$ 1,805/yr but it is obtained by part time activity (< 1h/day).

5 Conclusions

Two main types of fish supply chain were observed in the Brazilian Midnorth Region. The first group consisted of vertically integrated farms composed of a local supply chain undertaken by small farms (< 1.5 ha). The second group consisting of non-vertically integrated farms was composed by supply chains with intermediaries that transported and traded fish mostly in remote markets. These two types showed different impacts on the wealth creation and the number of wealth beneficiaries.

The intermediary trade supply chain was composed of various stakeholders that shared the gross revenue. This resulted in insufficient economic outcomes for the livelihoods of small farms and small supply chain intermediaries. Therefore, this model is more suitable for large farms or intermediaries, resulting in a low number of wealth beneficiaries.

Conversely, direct selling by farmers concentrated gross revenues. This permitted small farms to compensate for their low production level and to obtain economic outcomes sufficient to have a decent life. This supply chain model also allowed wealth distribution. This makes direct selling more appropriate to lift more people out of poverty. Further studies should be performed to demonstrate if this pattern is similar in other regions and for the supply chains of other fish species.

Declarations

6.1 Ethical Approval and consent to participate

All ethical approvals and consents for participation have been obtained.

6.2 Human and Animal Ethics

The authors have complied with all relevant human and animal ethical principles in conducting the research reported in this manuscript.

6.3 Consent for publication

Consent for publication has been obtained from all authors and participating institutions.

6.4 Availability of supporting data

Supporting data, if required, is available from the corresponding author.

6.5 Code availability

Not applicable.

6.6 Competing interest

The authors declare that they have no competing interests.

6.7 Funding

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6.8 Authors' contributions

F. Gilson: conceptualization, methodology, field work and writing.

M.B. New: reviewing and editing.

L. A. Rodrigues: field work.

W.C. Valenti: methodology, writing, reviewing and supervision.

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6.10 Authors' information

Relevant authors' information has been stated below the title to this paper.

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Tables

Table 1 and 2 are available in the Supplementary Files section.

Figures

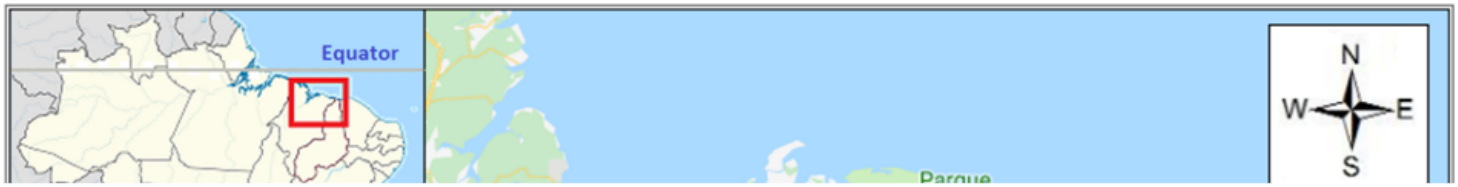

Figure 1

Map of the Brazilian Midnorth showing the location and sizes of the farms studied, together with the location of São Luis city, where intermediary sale supply chain occurred.

Figure 2

Labor-h/t (top figure) and labor cost (lower figure) per tonne of fish produced showing employee functions. Patterned histograms represent the temporary workers and full colour shows permanent workers Labor-h/t means the number of hours of work necessary to produce 1 tonne of fish; Labor cost represent the sum of workers' pay plus social insurance spent to produce 1 tonne of fish.

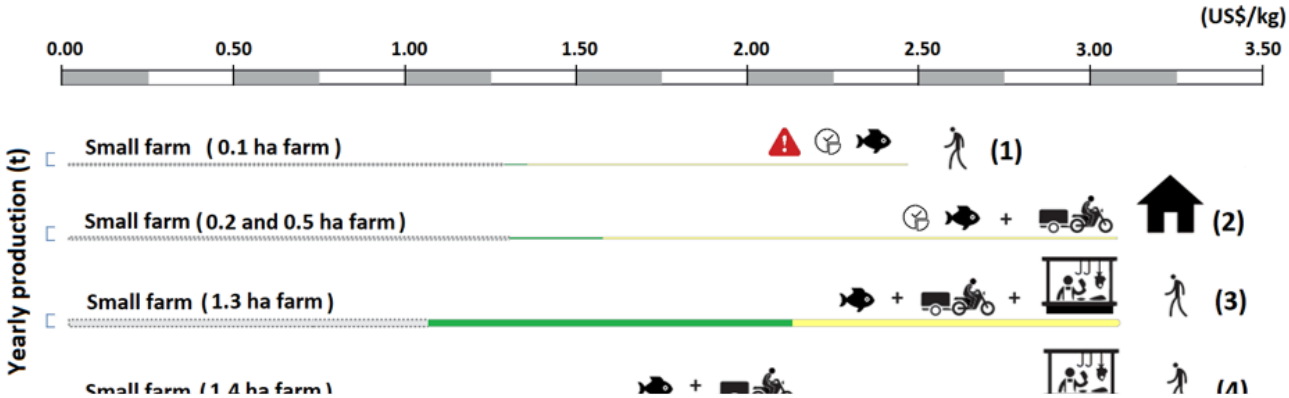

Figure 3

Diagram representing the different stakeholders of the tambatinga supply chain from the production to the consumer.

The X-axis (horizontal graduation) shows the trade value of tambatinga (US$/kg). The length of horizontal bars represents gross revenue, while the thickness of the bars is proportional to the yearly traded quantity (t/yr.). In each horizontal bar, the grey area represents the total operating cost except for labor; the green area represents the total labor cost (including social insurance); and the yellow area represents the net income. One supermarket is shown in the Figure but 14 supermarkets of the same brand are present in São Luis city. The numbers in brackets represent the sales supply chains studied. i.e. (1) farm gate sales; (2) customer home sales; (3) market sales undertaken by the farmer; (4) market sales with only transport to the market undertaken by the farmer; (5) intermediary trade through market sales (6) intermediary trade through market sales with market trader taking care of fish transport from the wholesale market; and (7) intermediary trade through supermarket sales. The word “Fair” refers to open-air markets.

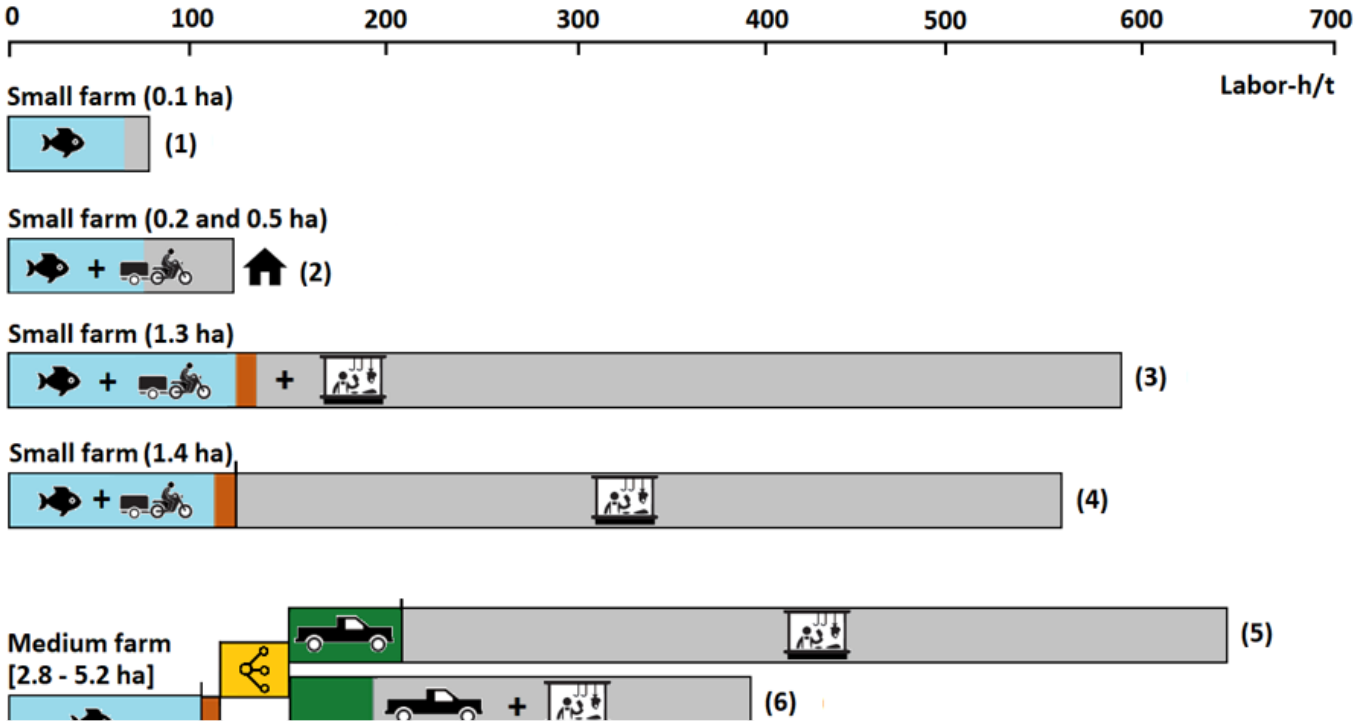

Figure 4

Labor-h/t of fish produced and traded through the principal supply chains.

The numbers in brackets represent the supply chains studied, namely (1) farm gate sales; (2) customer home sales; (3) market sales undertaken by the farmer; (4) market sales with only the transport undertaken by the farmer; (5) intermediary trade through market sales (6) intermediary trade through

market sales with the market trader taking care of fish transport from the wholesale market; and (7) intermediary trade through supermarket sales.

Figure 5

Wealth creation (represented by each bar length) obtained to produce 550 t of fish based on different farm sizes.

The 7 supply chains include farmers and the respective supply chain stakeholders involved. Wealth creation, represented by the horizontal bars, is calculated by the sum of total worker salaries (in green), total social insurance (in blue) and total venture net income (in yellow) of the farms and the intermediaries. Total worker salary is subdivided in rectangles that represent the quantity of workers (44h/week) required to produce and trade 550 t of fish. Total farms and intermediaries net income bars is subdivided in rectangles that represent the quantity of farms and intermediaries required to produce and trade 550 t of fish. The numbers in brackets represent the supply chains studied such as (1) sales at farm gate; (2) sales at customer homes; (3) market sales undertaken by the farmer; (4) market sales with only transport undertaken by the farmer; (5) intermediary trade through market sales (6) intermediary trade through market sales with market trader taking care of fish transport from the wholesale market; (7) intermediary trade through supermarket sales.

Supplementary Files

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- Tablestambatingasupplychain.docx