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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, which was used as a model for inland pond fish farming in tropical South America. We assessed how farm size affects intermediaries, 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. We identified 7 downstream supply/value chains, which can be grouped into farmer-controlled and intermediary-controlled supply/value chains. The first group includes small farms selling their fish directly to consumers, while the second encompasses medium, large, and extra-large farms relying on intermediary trading. These two types showed different impacts on wealth creation and the number of wealth beneficiaries. The first group generates significant wages concentrated in the farmers' segment. This permits small farms to compensate for their low production level and to obtain economic outcomes sufficient to have a decent life and it allows wealth distribution. This model makes small fish farms (around 1 ha or less) an interesting business to alleviate poverty, provide food security and decent jobs, and reduce inequalities. The intermediary-controlled chains consist of non-vertically integrated farms composed of supply chains with intermediaries that transport and trade fish, mostly in remote markets. Thus, various stakeholders share the gross revenue. This was found to result in poor economic outcomes for the livelihoods of small farms and small intermediaries. Therefore, this model is more suitable for large farms or intermediaries, resulting in fewer wealth beneficiaries.

Keywords Tambatinga · Cachama · Wealth creation · Supply chain · Farm size · Tropical pond aquaculture

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Introduction

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 87.5 million tonnes worth USD 265 billion in 2020 (FAO 2022). Most production comes from inland small-scale fish pond farms in rural areas (FAO 2020; 2022). Nevertheless, the way in which this primary category of fish culture is associated with its social and economic surroundings is poorly understood (Fonseca et al. 2022).

Similarly to other production systems, fish farms are connected to a set of linked elements that constitute a production chain. This chain includes the farms themselves, together with a complex web of pre-production and post-production elements. The production chain involves, among others, its infrastructure; policies; the suppliers of feeds, seeds, and fertilizers; processors; distributors; traders; and consumers (Valenti and Tidwell 2006; Valenti and Moraes-Valenti 2010). Each production chain includes supply and value chains of the 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 elements of each product's distribution channel (supply chain). The upstream includes every player that provides supplies for production. The downstream includes the farming itself and its distribution channels; these comprise the chain of firms (or individuals) a product passes through to reach the end consumer. Therefore, we can separate the upstream and downstream supply chains. 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. Retailers include market sellers, fishmongers, supermarkets, restaurants, and others. Dealers are not value-added sellers; they only buy and sell the fish without altering their condition and are the end step of the distribution channel. Most of value chain literature focuses on transnational chains, i.e., global value chains (Bush et al. 2019). Some recent papers focus on the marine net-cage salmon industry (e.g., Holmena et al. 2018; Opstad et al. 2022; Svanidze et al. 2022). Studies on supply and value chains of inland fish culture are scarce and concentrated in some Asiatic countries, such as Sri Lanka, Bangladesh, Myanmar, Cambodia, and Indonesia (Jayantha and Silva 2010; Islam and Habib 2013; Pomeroy et al. 2017; Filipski and Belton 2018; Hernandez et al. 2018).

Fish is a perishable product that requires special care from the production phase to the end-consumer (Islam and Habib 2013). Slaughtering and storage facilities, suitable transport, and maintenance in proper conditions until consumption are specialized and complex. In many regions of the world, the ice chain is deficient and handling protocols are non-existent. Many small farms in various countries have poor processing conditions.

Therefore, the downstream value chain is critical to ensure the quality and security of its products and to meet market expectations. Another factor is that intermediary activities often generate more income and employment than the production itself (Beveridge et al. 2010), and fish prices are frequently determined by their distribution (Islam and Habib 2013). However, the number and roles of intermediaries and their impact on the local economy and the generation of wealth in developing countries are poorly understood. The effect of farm size on the distribution channel choice is also unknown. These gaps have impaired effective actions to strengthen the downstream process of the fish culture production chain. Understanding the dynamic factors that drive fish flow from farms to customers is essential in order to increase competitiveness, income, and sustainability (Islam and Habib 2013; Pomeroy et al. 2017). Unfortunately, studies on the supply and value chains of inland-farmed fish are still scarce. Innovative value chains are keys for aquaculture expansion and response to market requirements (FAO 2022). Thus, research effort is essential to understand the structure and dynamics of these value chains to allow innovative management and sound policymaking.

Brazil is suitable for studying the value chain of fish produced in inland small-scale pond farms. This vast country has a growing inland fish culture sector that reached ~ 550,000 t in the year 2020 (FAO 2022). The potential for expansion is high because of Brazil's huge freshwater availability, tropical climate, and strong internal market. Production is dominated by freshwater fish raised in ponds in various sizes of farms using different technology levels (Valenti et al. 2021). Tambaqui (*Colossoma macropomum*) and its hybrids are the second most highly farmed fish group in Brazil (Valenti et al. 2021). The tambatinga, a crossbreed with the pirapitinga (*Colossoma macropomum* x *Piaractus brachypomus*) has been increasingly produced. Tambatinga are characterized by their robustness, omnivore/filter-feeding habits and the large size that can be rapidly reached (2 to 3 kg in 1 year of production). This hybrid is produced in small, medium, and large farms, using various-sized earthen ponds operated in semi-intensive systems. Tambatinga is mainly farmed in monophasic or biphasic systems, starting with 2–5 g fingerlings and harvested at sizes of 0.8 kg to 3 kg (Valenti et al. 2021). Productivity ranges from 0.5 to 1.2 kg/m^2/year. All medium and large farms sell their fish to intermediaries, while most small farms participate in fish supply chains involving fish production and sales to retailers or final consumers. Therefore, the culture of tambatinga in Brazil is an excellent model for studying the value chain of freshwater fish produced in ponds.

In this paper, we used the tambatinga farming sector in Midnorth Brazil to study the downstream supply and value chains of fish raised in inland ponds in tropical South America. The main objective was to describe the downstream supply and value chains originating from commercial fish farms of various sizes. We have also assessed how farm size can affect the intermediaries—and consequently job creation, income generation, and the number of wealth beneficiaries.

Materials and methods

The survey began by visiting 16 commercial farms of tambatinga (*Colossoma macropomum x Piaractus brachypomus*) in the states of Maranhão and Piaui in the Brazilian Midnorth (Fig. 1) in 2016. This region contains many tambatinga producers, attaining about 2000 farms. The survey covered a purposive sample of commercial farms with a pond size range of 0.1 to 220 ha. These extremes are the minimum and maximum commercial farm

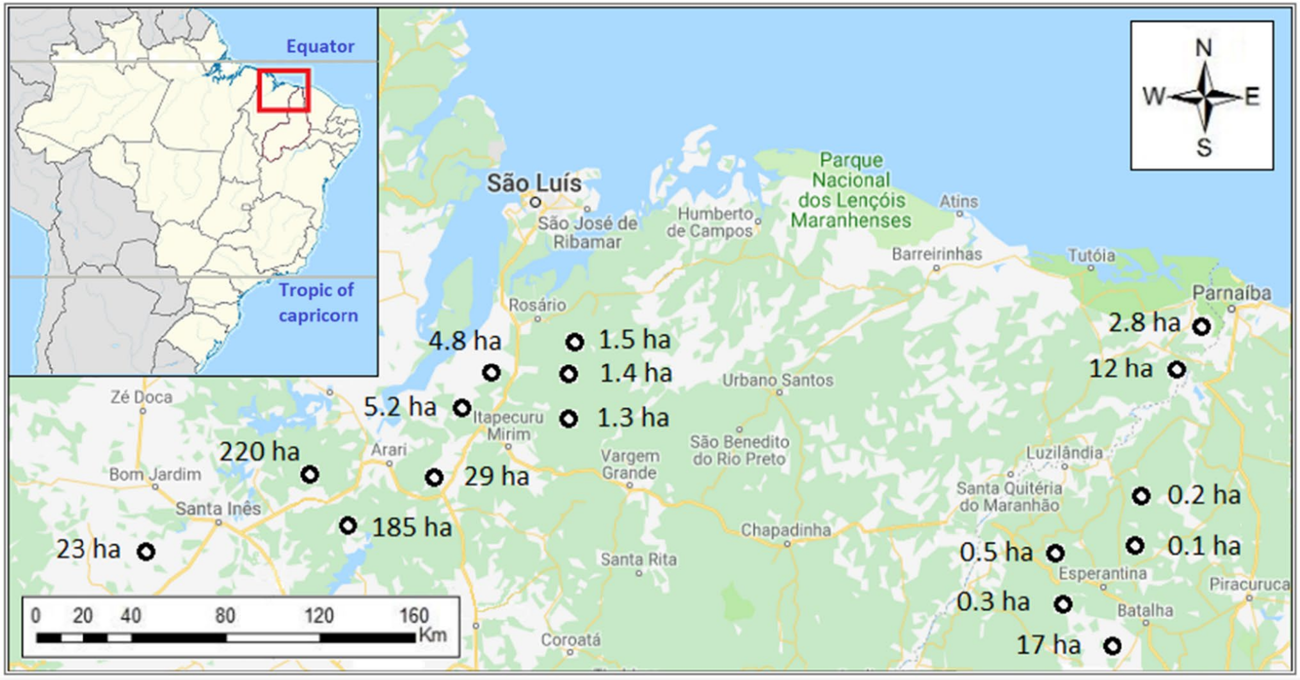

Fig. 1 Map of the Brazilian Midnorth showing the location and sizes of the farms studied, together with the location of São Luis city, where the intermediary sale supply chain occurred

sizes encountered in the region. Farms were chosen to represent the different groups of farm sizes and supply/value chains observed in the 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 local rural extension services experts. 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/m^2 during ~ 8 months. They use balanced feed with feed conversion ratios ranging from 1.3 to 1.8, and achieve production of 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 costs, 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. The distribution channels of these five farms varied: one farm sold farm-gate; two farms sold directly to customers' homes; another sold in a market; and the remaining farmer only undertook transport to a market.

The survey continued in early 2017 by examining the supply/value chain of the 11 farms selling to intermediaries. This phase of our study 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, i.e., the intermediary traders that buy fish in the farms and sell to wholesalers (distributors) or supermarkets; 7 distributors, i.e., the wholesalers that buy fish from the first middlemen and sell to other intermediaries; and 10 s 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 supply/value chain stakeholders as intermediaries.

Interviews were conducted with the owners and employees of farms and intermediary traders, 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. The information collected includes sensitive data that the farmers do not like to provide. Therefore, we visited the farms many times to check the data, using different techniques. As much as possible, the same information was obtained from other respondents or by direct observation. Some information was unknown even by the farmers and traders. Thus, we observed the daily movements, talked informally with owners and workers, and checked the farms' accountability. For small farms, we also obtained data from stores about how much feed or other supplies they sold to the respective farmers and the prices. At farms, we observed owners' and employees' functions and took notes on the total working hours of all involved (owners, family, and employees) during the entire fish production cycle and trade (labor-h). The quantity and value of fish sold and the operating costs were estimated based on the farmers' records in previous years. Sometimes we were able to observe the harvested fish. Data validity was verified on every occasion possible by comparing the same information obtained in different ways.

The investments in assets and operating costs of the farms were recorded. Investments included ponds, canal construction, pumps, buildings, electrical installation, equipment, and vehicles. The major farm equipment consisted of nets, aerators, weighing scales, and a wheelbarrow. The operating costs included labor, social security, feed, fingerlings, fuel, electricity, and expenses involved in water transference and quality.

During the various visits to São Luis, we obtained information on the structural organization of the various supply/value 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 for each stakeholder trading the fish. We also obtained data on the quantity and value of the fish sold and their operating costs, which included labor, social security, fuel for fish transport, and ice for fish storage. Data on the investment costs of equipment and vehicles were also obtained.

The working time of permanent workers was about 44 h/week during 48 weeks per year. The annual salary of temporary workers was calculated on an annual basis by multiplying their hourly pay by 44 (hours worked per week) and 48 weeks. In the smallest farms, feeding tasks are carried out by the owner or a family member who was 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 solely for harvesting.

Labor costs were calculated by multiplying the hourly labor wage by the labor-h required, plus the benefits, deductions, and taxes. These social benefit costs, which included paid vacation time, social security, and insurance, totalled approximately 42% of the gross income of a regular employee. Asset depreciation was included in the operational 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 to an annual basis (labor-h/year). In order to compare farms of different sizes that produce different quantities of fish, we divided the annual labor-h/year of each farm by their respective annual fish production (t/year) as follows:

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

In the second stage of our study, 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 towards 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 who 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 (2112 h/year).

To compare wealth creation and the number of wealth beneficiaries in each supply/value 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 among the various supply/value chain stakeholders studied. This was the average of the annual production of the two largest farms, namely 550 t. Therefore, we standardized 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:

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

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/value chain, we obtained the total wealth creation and the total number of wealth beneficiaries by summing the relevant data for each stakeholder involved. In other words, we summed employee earnings and the net income of farms and intermediates involved in each supply/value 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 among 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. Thus, the greater number of small farms necessary to produce 550 t of fish contributes to more self-employment, while the lower number of large farms required to produce the same 550 t contributes more employees. The same occurs 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 traders, 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.

Results

We found that the tambatinga farming sector in Midnorth Brazil used similar stocking densities, feeds, and feed management (except for the largest farm that used an automatic feeder). However, harvested size (1 to 1.5 kg/fish) and harvesting and commercialization strategies were essentially different. The pond sizes and harvest management reflect the wide variation in farm size. We observed ponds ranging from 0.12 to 28.9 ha. Small ponds were harvested partially or totally on the same day. In the first case, the fish were traded, either live or very fresh, directly to consumers. Large ponds showed a more complex harvesting procedure which occurred over many days or weeks. During this time, fish stay alive inside the pond and thus this complex harvesting process did not affect fish freshness. However, freshness did decrease because of the greater number of steps to the end-consumer.

The labor-h/t was similar in farms up to 1.5 ha, averaging 59 labor-h/t (Fig. 2). This variable sharply increased in farms from 2.8 to 5.2 ha, averaging 96 labor-h/ha, slightly decreased in intermediate farms and increased again in farms from 29 ha onwards (Fig. 2). The labor cost per tonne produced increased substantially in farms of 29 ha or higher

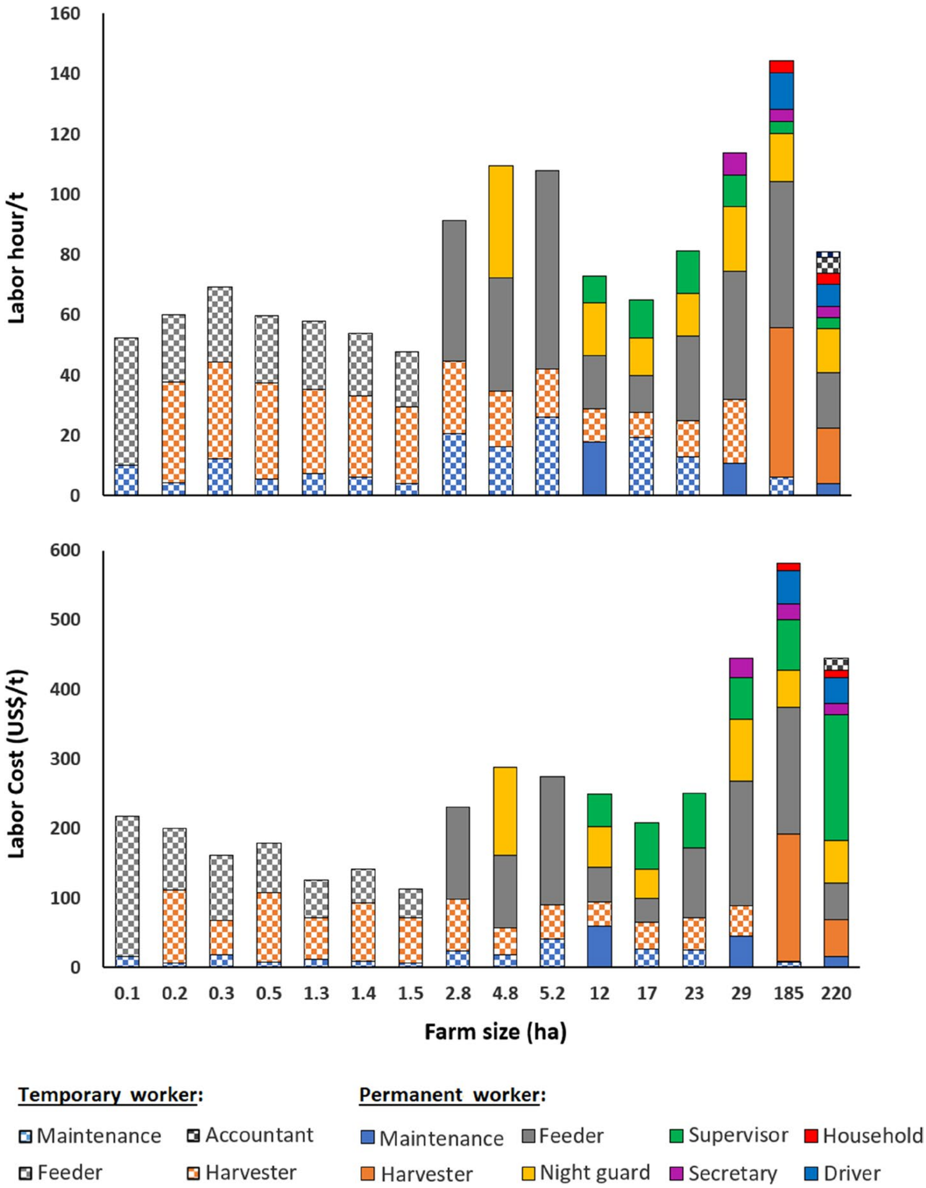

Fig. 2 Labor-h/t (top figure) and labor cost (lower figure) per tonne of fish produced, showing employee functions. Patterned histograms represent the temporary workers and full color shows permanent workers. Labor-h/t means the number of hours of work necessary to produce 1 tonne of fish. Labor cost represents the sum of workers' pay plus social security spent to produce 1 tonne of fish

(Fig. 2). The smallest farms studied (0.1 to 1.5 ha) relied exclusively on temporary workers (shown as patterned bar diagrams in Fig. 2) for feeding, harvesting, and maintenance activities. From the 2.8 ha farm upwards, farms hired permanent workers for feeding activities. From the 4.8 ha farm upwards, 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, temporary workers carried out harvesting, their wages ranging 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 h. 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 1 h, 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$ 3280/year, which corresponds to U$ 1.55/h based on a working time of 44 h per week. Secretaries, night guards, and drivers were paid between US$ 3240 and 5484/year. Supervisors had the largest salaries, especially in the two largest farms (185 ha and 220 ha), receiving a mean salary of US$30,864/year.

We identified 7 downstream supply/value chains characterized by different distribution channels (Fig. 3). All steps rely on the private sector; no government involvement was identified. Some farmers have horizontal links, such as cooperatives or associations. Four channels were undertaken by small farm owners, representing vertical integration (Fig. 3 (1, 2, 3, 4)). They were selling fish to nearby farms and incorporated the functions of distributors, retailers, and dealers or transporters to markets. Three distribution channels relied on intermediary traders and were used mainly by medium, large, and extra-large farms. In these channels, the retailers were markets and supermarkets in places that were remote from the farms (Fig. 3 (5, 6, 7)). 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/value chain of fish to the final consumer. The 1.4 ha farm transports to the local market and sells to retailers (Fig. 3). The larger farms and the 0.3 ha farm relied completely on intermediary traders.

The 0.1 ha farm sold its production of whole fish at the farm gate to neighbors at US$ 2.50/kg (Fig. 3 (1)); this was the cheapest price recorded for consumers. This farm sold 1.6 t/year of fish, generating an income of US$ 1805/year. The 0.2 and 0.5 ha farms sold fish to consumers' homes (Fig. 3 (2)). Once a week, a crew of 4 people harvested around 100 kg of fish. After that, one or two sellers passed round the neighborhood with a vehicle (a motorbike or a car equipped with a trailer) for about 3 h, selling whole fish for US$ 3.10/kg. On average, they traded 5.0 t/year of fish for US$ 7585. After the fish grow-out, no transformation or process added any value to the product, and thus they both are characterized as supply chains.

The 1.3 ha farm sold daily in a market (Fig. 3 (3)). A crew of 4 persons harvests approximately 40 kg of fish each day and ships them to a local market. There, the famer's family members and two assistants remove the fish scales, degut, and sell the fish for US$ 3.10/kg over a 6-h period. They generally sell 12 t/year, 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 (Fig. 3 (4)). Whole fish were sold for US$ 2.50/kg to market sellers, who removed the fish scales, degutted them, and sold them for US$ 3.10/kg. This farmer traded about 15 t/year and generated US$ 12,512/year. The fish are processed, and value is added only at the retailer's level.

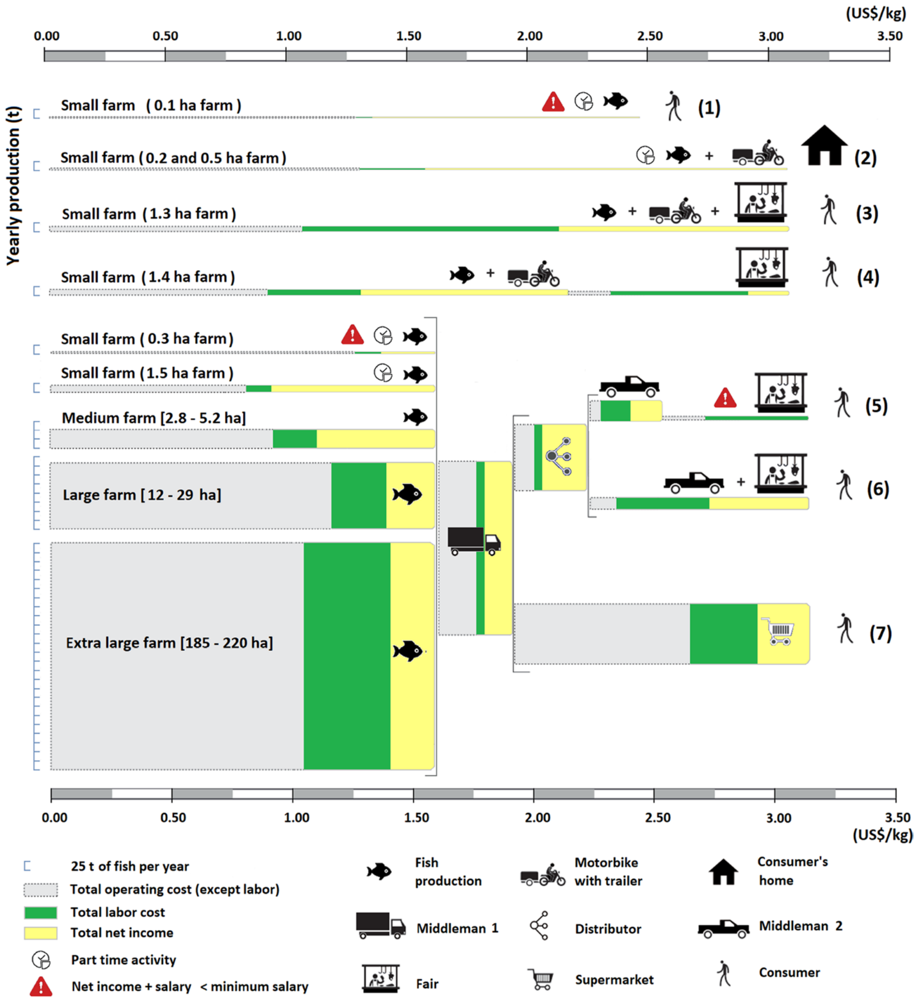

Fig. 3 Diagram representing the different stakeholders of the tambatinga supply/value chains from the production to the consumer. The *x*-axis (horizontal graduation) shows the trade value of tambatinga (US$/kg). The length of horizontal bars represents gross revenue, while the thickness of the bars is proportional to the yearly traded quantity (t/year). 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 security); and the yellow area represents the net income. Fourteen 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 transport to the market solely undertaken by the farmer; (5) intermediary trade through market sales; (6) intermediary trade through market sales with the market traders taking care of fish transport from the wholesale market; and (7) intermediary trade through supermarket sales. The word “Fair” refers to open-air markets

The 0.3 and 1.5 ha farms and those larger than 1.5 ha sold their fish to intermediary traders. The supply/value 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’s mean weight. These first middlemen took care of fish transport with trucks, using two drivers that alternated the driving during each trip. They mainly travelled from rural to urban areas over a 10 to 17-h 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 for around US$ 1.86/kg. Each first middleman generated an average income of US$ 48,183/year (Table 1).

The wholesale market, which is located in the city center of São Luis, consists of 30 traders. There, fish are displayed in boxes with ice in an open-air space. These traders sell around 10 t of tambatinga daily (~3600 t/year), according to the chairman of the wholesale market association. Tambatinga correspond to approximately one-third of the total seawater and freshwater fish traded in São Luis City and its suburbs. 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 also exchange information between offer and demand. They also take care of the unloading of fish from the first middlemen's trucks and the control of cargo weight; on average, this requires 3 temporary workers per day for 7 h. These intermediaries on average generate US$ 31,428/year of net income (Table 1).

Second middlemen transport fish from the wholesale market to smaller markets spread throughout the city and possibly to some fishmongers. They buy fish from distributors at US$ 2.17/kg and sell them at around US$ 2.48/kg to market sellers (Fig. 3 (5)). On average, they generate US$ 5719/year of net income (Table 1). Sometimes, the middlemen handle part of the fish sales at the market (Fig. 3 (6)). At the ultimate supply/value chain step, market sellers sell fish to consumers at around US$ 3.10/kg. Market sellers with small

Table 1 Production or trade, labor-h/t required and mean intermediary wages, total labor costs and income for each stakeholder in the tambatinga supply chain. Values in red represent mean salaries or net incomes lower than the minimum annual salary in Brazil, which was US$ 3280 in 2016. The word "Fair" refers to open-air markets

	Production or trade (t/year)	Labor-h/t	Mean Salary (US$/year)	Labor cost (US$/year)	Net Income (US$/year)
Farmer trade:					
Farm sale (0.1 ha)	1.6	72	3734	176	*1805*
Home sale [0.2; 0.5 ha]	5.0	114	5117	1381	7585
Fair sale (1.3 ha)	12	591	3861	12,963	11,554
Farm + middleman (1.4 ha)	15	564	6554	5710	12,512
Intermediary trade:					
0.3 ha farm	3.9	69	3286	419	*811*
1.5 ha farm	14	47	4080	1313	10,918
Medium farm [2.8–5.2 ha]	45	103	3501	7701	23,205
Large farm [12–29 ha]	160	83	4024	37,323	31,404
Extra-large farm [185; 220 ha]	551	113	4144	210,744	111,507
Middleman 1	421	12	5764	13,885	48,183
Distributor	164	45	4186	14,390	31,428
Middleman 2	22	60	4373	3960	5719
Middleman 2 + fair	27	244	4108	14,571	17,477
Fair (following wholesale)	8.0	437	*2234*	8553	*None*
Fair (following 1.4 ha farm)	8.0	437	2920	8553	*1768*
Supermarket	142	109	5031	52289	110,619

stalls sell an average of 70 kg of fish per week. Larger stallholders reach 300 kg per week but have 1 to 2 extra workers to descale, degut, and sometimes cut the fish. Market sellers with an average trade generate no net income and a low salary (US$ 2234/year) (Table 1). Supermarkets (Fig. 3 (7)) have 6 to 7 permanent workers in the fish department. These workers take care of quality control, weighing, descaling, degutting, cutting, and wrapping the fish. 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/year. In São Luis, two supermarket brands with 28 supermarkets share the business, achieving total sales of 4440 t/year of fish. Fish are processed and packaged, generating product added-value, generally only by retailers—the last element of the value chain.

From farms to retailers, fish were transported in large boxes with ice, except when they were traded alive or at the farm gate. Hygiene and conservation techniques were acceptable, although the slaughtering, storage, and transportation did not match the local regulations. No plant processing is used to freeze or increase product shelf life. The freshness level decreased according to the supply/value chain extension. Retailers were the single added-value seller in all supply/value chains because they performed simple processing, including degutting, descaling, and packing the fish before selling to the end consumers. However, if we consider restaurants as intermediaries, they obviously also add value to tambatinga.

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 (Fig. 4). The 0.1 ha farm selling fish at the farm gate had the lowest score with 76 total-labor-h/t (Fig. 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 (Fig. 4 (2)). Sales of fish at the market from the 1.3 ha farm required 591 total-labor-h/t, mainly due to the amount of salespeople at the market ((Fig. 4 (3)). The supply chain through the 1.4 ha farm (Fig. 4 (4)) totalled 564 total-labor-h/t, also mainly due to the amount of salespeople at the market, while fish supply of the farmer through the market required 11 labor-h/t. Market sales required the highest amount of labor, reaching 437 total-labor-h/t (Fig. 4 (5)). Combined with the production of extra-large farms, market sales reached the highest score of 657 total-labor-h/t (Fig. 4 (5)). When market sellers buy and transport fish from the distributor, the total-labor-h/t decreased (Fig. 4 (6)). This decreased further when the first middlemen delivered fish to supermarkets (Fig. 4 (7)). Extra-large farms with supermarket sales required only 232 total-labor-h/t (Fig. 4 (7)).

Among the vertically integrated farms (the ones where farmers undertake the supply/value chain), the 0.1 ha farm shows the highest number of wealth beneficiaries with the creation of 16 full time equivalent work-positions (44 h/week during 48 weeks of the year) and 344 owner positions (farmers) (Table 2; Fig. 5 (1)). However, in this farm size, people worked as a part-time activity; this resulted in a low net income that was below the minimum salary in the region (US$ 3280 in 2016). On the other hand, the vertically integrated farms that sell their fish at consumers' homes (Fig. 5 (2)) showed good wealth creation (US$ 984,249) and generated an average of 30 worker positions and 110 owner positions (farmers) with good net incomes. The 1.3 and the 1.4 ha farms (Fig. 5 (3, 4)) showed high net income with many wealth beneficiaries. On average, they required 148 workers, 109 farmers, and intermediaries with wealth creation of US$ 1,112,967.

The downstream supply/value chains that started in medium, large, and extra-large farms and ended with non-supermarket retailers (Fig. 5 (5, 6)) showed large total wealth

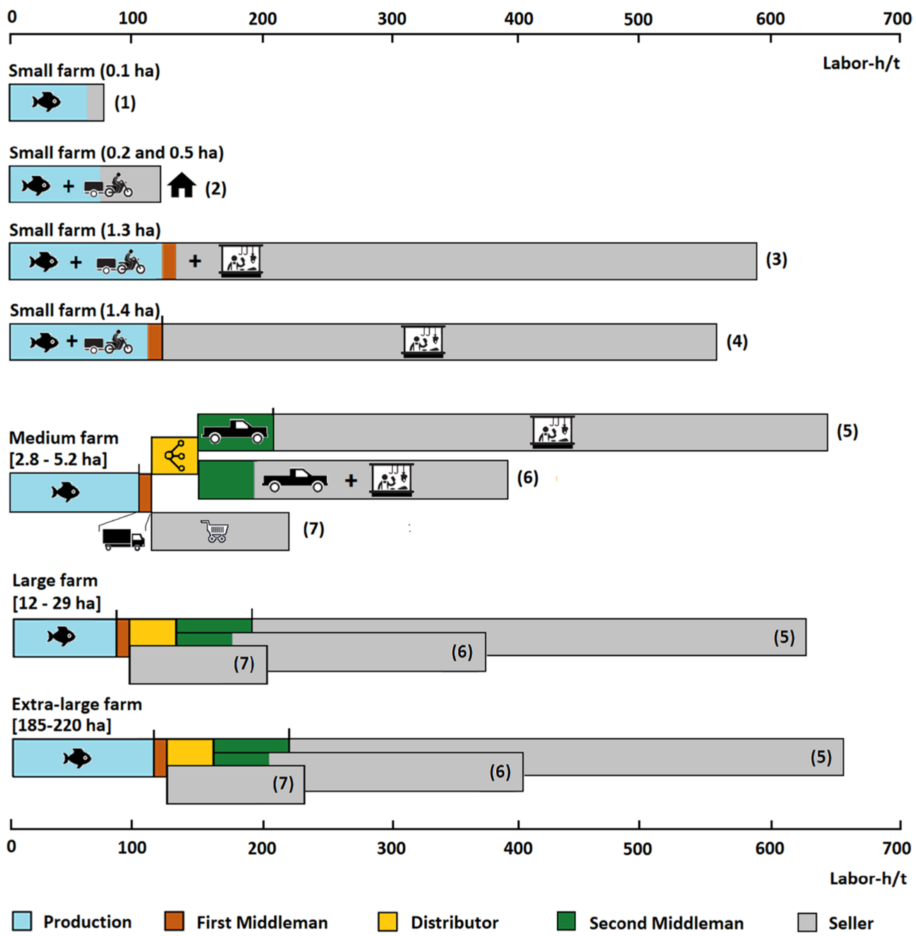

Fig. 4 Labor-h/t of fish produced and traded through the 7 supply/value chains observed in the present study. Vertical bars indicate that the fish move to another stakeholder, while the plus signal (+) indicates that the same stakeholder performs more than one step in the supply/value chain. The numbers 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. See Fig. 3 for the meaning of the symbols

creation, with a mean of US$ 997,861, and generated a large quantity of workers (averaging 163) and supply chain stakeholders (averaging 104) (Fig. 5). However, among this supply/value chain, market sellers with an average stall size did not generate any net income and drew a low wage that was below the minimum salary. Conversely, market sellers that undertook shipping from the wholesale market showed high net income with high wealth creation (US$ 1,160,000 on average) and lower supply chain stakeholders (30 on average). The supply/value chain that has the supermarket as an end-consumer distributor led to the lowest total wealth creation and the lowest distribution

Table 2 Economic outcomes to produce 550 t of fish through the 7 different supply/value chains. Worker quantity is the number of workers and owners working 44 h/week required to produce or sell 550 t of fish. Total labor cost is the sum of all the workers' salaries, including social security, computed as 42% of the total salary of permanent workers that is required to produce 550 t. Owner quantity is the number of farm and intermediary owners required to produce or sell 550 t. Total net income is the sum of the net income of farms and intermediaries required to produce or sell 550 t. Wealth creation is the sum of the total labor costs and the owner net income. Red numbers stand for chains that include steps in which workers' wages or owners' net incomes are below the minimum salary in the region (US$ 3280 in 2016). The word "Fair" refers to open-air markets

	Worker		Owner		Worker + owner	
	Quantity (N°/550t)	Total labor cost (US$/550t)	Quantity (N°/550t)	Total net income (US$/550t)	Quantity (N°/550t)	Wealth creation (US$/550t)
Farmer trade:						
(1) Farm sale (0.1 ha)	16	60,500	*344*	*620,386*	*360*	*680,886*
(2) Home sale [0.2; 0.5 ha]	30	151,642	110	832,607	139	984,249
(3) Fair sale (1.3 ha)	154	594,125	46	529,559	200	1,123,685
(4) Farm-supplier (1.4 ha) + fair	141	531,912	107	570,517	248	1,102,429
Intermediary trade:						
(5) M farm—fair	*163*	*470,182*	*111*	*595,984*	*274*	*1,066,166*
(6) M farm—middleman and fair	103	422,202	37	805,839	140	1,228,040
(7) M farm—supermarket	56	250,021	18	482,640	74	732,661
(5) L farm—fair	*160*	*503,711*	*102*	*417,625*	*261*	*921,336*
(6) L farm—middleman and fair	100	455,731	28	627,479	128	1,083,210
(7) L farm—supermarket	53	303,979	8.6	304,280	62	608,259
		-			-	
(5) XL farm—fair	*167*	*585,404*	*99*	*420,678*	*267*	*1,006,082*
(6) XL farm—middleman and fair	108	537,424	26	630,532	133	1,167,956
(7) XL farm—supermarket	61	385,672	6.2	307,333	67	693,005
Intermediary stakeholders						
0.3 ha farm	18	59,020	*141*	*114,211*	*159*	*173,231*
1.5 ha farm	12	50,391	38	418,930	51	469,321
M farm [2.8–5.2 ha]	25	95,108	12	286,594	37	381,702
L farm [12–29 ha]	22	128,637	3.4	108,235	25	236,872
XL farm [185 and 220 ha]	29	210,330	1.0	111,288	30	321,618
Supplier	3.0	17,466	1.3	62,985	4	80,450
Distributor	**12**	**48,841**	**3.4**	**105,445**	**15**	**154,286**
Middleman	16	68,323	25	140,960	40	209,283
Middleman-fair	63	260,787	20	350,815	84	611,602
Fair (following wholesale)	*108*	*240,444*	*69*	*None*	*177*	*240,444*

Table 2 (continued)

	Worker		Owner		Worker + owner	
	Quantity (N°/550t)	Total labor cost (US$/550t)	Quantity (N°/550t)	Total net income (US$/550t)	Quantity (N°/550t)	Wealth creation (US$/550t)
Fair (following 1.4 ha farm)	108	315,337	69	95,915	177	411,252
Supermarket	28	157,877	3.9	133,061	32	290,937

and generated an average of US$ 678,000 of total wealth with 56 workers and 11 stakeholders (Fig. 5 (7)).

Discussion

Tambatinga farming sector in Midnorth Brazil showed a wide diversity in farm and pond sizes, harvest strategies, and downstream supply/value chains. Farm size drives the definition of the farm organization, workforce structure, and distribution channels used. The amount of work created, number and the complexity of work positions, and wages distributed among the workers and owners showed different patterns in small, medium, large, and extra-large farms. We identified 7 different downstream supply/value chains, which may depend somewhat on the farm sizes. Small farmers can appropriate the main chain steps and adopt a vertical model from production to end-user. Thus, they compensate for their small size and generate fair wages for the owners' families and employees. Medium, large, and extra-large farms need intermediaries to transport and trade fish in urban markets. The latter two supply/value chain groups had different impacts on wealth creation and the number of wealth beneficiaries.

The number of labor hours and the labor costs required per tonne of fish produced varied in different ways in the small and medium farm groups. Farms from 0.1 to 1.5 ha showed low and regular scores, decreasing slightly as farm size increased. This relationship is explained by the fact that these farms rely exclusively on family and temporary workers. Their hiring flexibility induces low and regular labor-hours per tonne produced. In Bangladesh, family labor is also mostly used in small farms, and hired labor is uncommon (Hernandez et al. 2018). In our study, farms from 2.8 ha onwards hired permanent workers (44 h per week). This shift resulted in a sharp increase in labor hours, laborers' wages per tonne produced, and irregular scores as farm size increased. The three first farms in this pattern showed high labor per tonne produced mainly because of the full-time employment of one feeder for relatively low fish production. Larger farms (12 ha and 17 ha) also employed one feeder, but for a fish production more than twice as large. This higher production reduced labor hours and labor costs per tonne of fish. In Myanmar, small freshwater fish culture generate more spill overs and labor demand than medium ones (Filipski and Belton 2018). This difference may be due to the fact that in the present study, we measured the labor and wage divided by the quantity of fish produced.

The even larger farms showed an increase in labor per tonne produced because of the rise in pond sizes and total production and the diversification of the functions required. Large farms need a supervisor, secretary, night guard, domestic employee, driver, lawyer, and accountant. In addition, we observed an increase of labor hours per tonne produced in feeding and

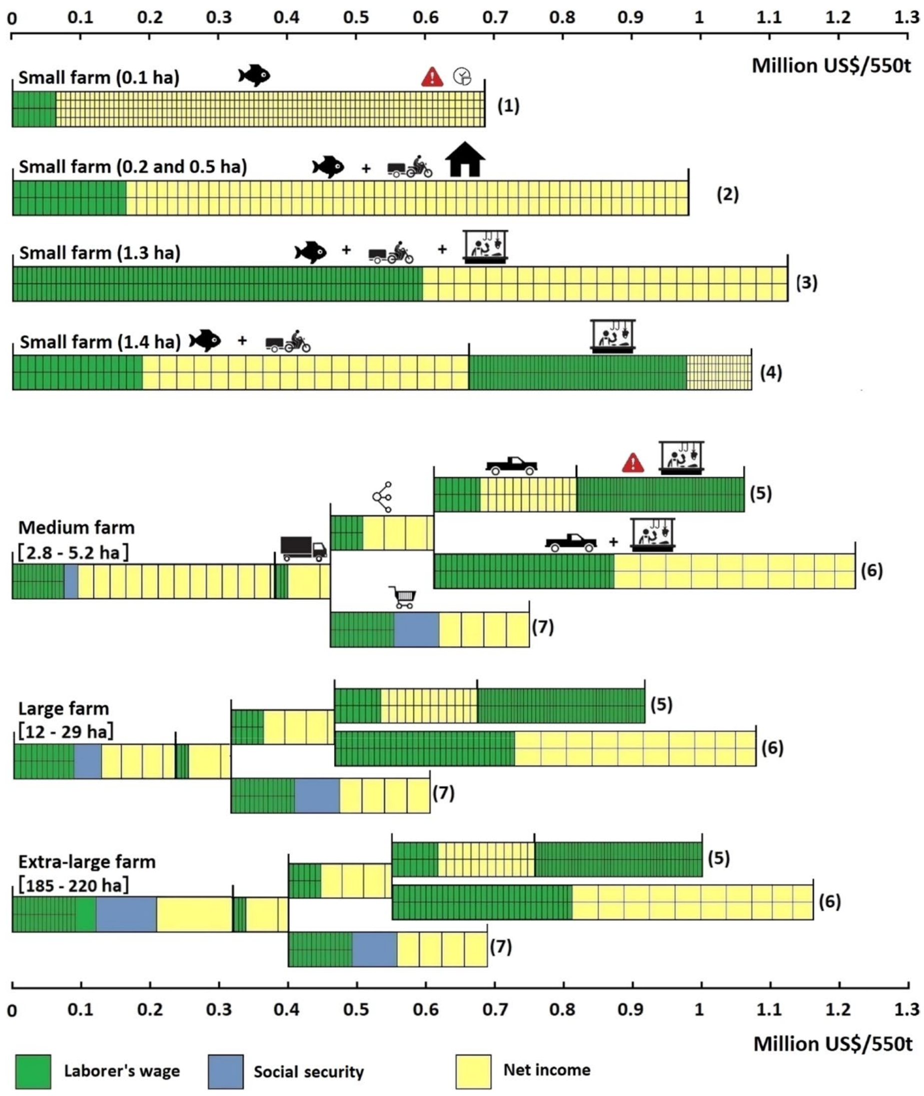

Fig. 5 Wealth creation (represented by the length of each bar) obtained to produce 550 t of fish based on different farm sizes. Vertical bars indicate that the fish move to other stakeholders, while the plus signal (+) indicates that the same stakeholder performs more than one step in the supply/value chain. The 7 supply chains, represented by rows with square patterns, include farmers and the other respective supply chain stakeholders involved. Wealth creation, represented by the horizontal bars in millions of US$/year to produce 550 t of tambatinga, is calculated by the sum of total worker salaries (in green), total social security (in blue), and total venture net income of the farms and the intermediaries (in yellow). Total worker salary is subdivided into rectangles that represent the quantity of workers (44 h/week) required to produce and trade 550 t of fish. Total farm and intermediaries net income bars are subdivided into 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, namely (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; and (7) intermediary trade through supermarket sales. See Fig. 3 for the meaning of symbols

harvesting because of the more difficult employee management and logistics and handling complexity related to larger pond size. Pond size was proportional to farm size in the Brazilian Midnorth; 45% of the ponds in the two largest farms were larger than 10 ha. With this pond size, two tractors carried out harvesting, dragging various coupled fishing nets from the banks of the pond. This harvest required many persons to handle the nets in the ponds all day long. The 185 ha farm used a boat to spread food properly throughout the large ponds, which required more workers for a longer period. Consequently, the full-time employment, combined with the management complexity, resulted in a labor-h/t 62% higher than smaller farms on average. However, we found that the largest farm (220 ha) had much lower worker demand because it used five feed spreader machines, thus accelerating the feeding process. In Myanmar, large farms showed lower labor demand than small farms (Filipski and Belton 2018) because of the mechanization of some tasks. The tambatinga sector showed minimal mechanization and automation, increasing human work demand. This situation improves social sustainability and may not decrease economic sustainability (UN 2015; Valenti et al. 2018).

The 7 downstream supply/value chains identified can be grouped into farmer-controlled and intermediary-controlled supply/value chains. The first group included the smallest farms, which undertook a supply/value chain selling the fish directly to the end-consumer or a single retailer. The power in (control of) the supply/value chain was held by the farmers. The intermediary-controlled group included one small farm and farms larger than 1.5 ha. They relied exclusively on intermediary stakeholders to sell their fish. In this group, the power is held by one or two intermediary segments. Regardless of the model, most of the linkages seemed to be based on oral agreements between the actors rather than legal contracts. Lack of formal contracts and weak links were observed in small-scale fish aquaculture in Asia (Pomeroy et al. 2017; Hernandez et al. 2018). On the other hand, in Asia, links were found to be primarily between actors of the immediately prior or following paths, with low interaction between distant paths (Pomeroy et al. 2017). In tambatinga supply/value chains, the interaction is not totally linear and many farmers have direct interaction with consumers; this may improve the information circulating among all the stakeholders. Governance is undoubtedly essential to upgrade the linkages between actors.

The labor required per tonne of tambatinga produced or traded varied largely among the different paths in the 7 supply/value chains identified. The on-farm activities needed from 47 to 144 labor-h/t and the off-farm segments from 72 to 657 labor-h/t. Thus, post-harvest paths required more labor-h/t than fish production, corroborating the statements of Beveridge et al. (2010), Bush et al. (2019), and Nasr-Allah et al. (2020) who found that off-farm segments of supply/value chains created more work demand than the farming process. The market selling channel for tambatinga required the largest amount of labor, i.e., ~600 labor-h/t, followed remotely by supermarket selling (~200 labor-h/t) and farm or home selling (~90 labor-h/t). Thus, the final retail segment generated the most jobs. These results are similar to what was observed about fish retailers in Egypt by Nasr-Allah et al. (2020). Considering the relationships between retailers and end-consumers, we can assume that this may be the pattern for fish value chains that commence on semi-intensive culture farms.

Farmer-controlled supply/value chains involve no intermediary stakeholders—only the final seller; this results in a concentration of the gross revenue per traded fish by farmers alone or farmers plus the final retailer, increasing their gains. Farmers selling fish at their farm gates represent the simplest supply chain model, in which their customers are close neighbors. This model involves low production and net income, as observed in the 0.1 ha farm (1.6 t/year and US$ 1805/year) but they are obtained by part-time activities (< 1 h/day) through selling exclusively to neighbors in the same rural area. On the other hand, the farmers that operate a market stall and supply direct to consumers' homes create a net income exceeding 3 to 5 times the minimum salary in the region. With the small quantity of fish traded by each farm, this supply chain channel requires many farms to respond to the fish demand. Therefore, this supply chain may result in large wealth creation, which is widely distributed. This scenario was also observed in Myanmar by Belton et al. (2018). Small vehicles with trailers allow farmers to undertake their own supply chain as market sellers. Facilitating small farmers' access to this asset may be essential to enhance the supply/value chains.

Intermediary-controlled supply/value chains trade with 2 to 4 stakeholders, from the farm to the consumer. Only the final retailers add value to the product. Thus, the final revenues are divided among the stakeholders of each path, generating a poor income for each. Furthermore, profit margins in the tambaqui fish group are low mainly due to the expensive commercial diets used (Lima et al. 2020). Therefore, small stakeholders have fragile economic outcomes. As intermediary traders, some retailers who sell an average of 156 kg of fish per week to end-consumers, working 6 to 7 h a day and 6 days per week, generate a very low net income. This is just enough to recoup their costs and to draw a low wage for themselves of about US$ 2234/year. The smallest stalls sell about 70 kg of fish weekly, barely reaching US$ 1235/year (Fig. 3 (5)). Intermediary-controlled supply/value chains suit large farms and large intermediaries that trade large quantities of fish. This increases net income, as shown by the extra-large farms which trade through supermarkets, with net incomes over 40 times the minimum salary in the region. However, this type of supply chain shows the lowest wealth creation (US$ 677,975 on average) and the lowest number of wealth beneficiaries (62 to 74). Six extra-large and eighteen medium-sized farms and intermediaries produced and sold 550 t of fish per year. 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.

New and innovative technologies can improve the gains of all stakeholders. Very small farms frequently merely complement their owners' wages from other activities. 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) show poor incomes. However, they have other potential sources of income because fish farming is a part-time activity that takes about 1 h/day to operate. Innovative technologies can increase productivity, revenue, and profit margins in such small farms and larger farms. Improvements in technology to increase farming profit margins and/or add value to the product at each step are necessary upgrades to increase socioeconomic gains in all the downstream supply/value chains identified.

In the present study, we obtained sensitive data often unavailable or even unknown to farmers. The difficulties in obtaining precise data may be seen as a limitation of our work and we considered this when interpreting our results. Nevertheless, the data obtained have sufficient accuracy to allow the conclusions below. Although we have focused on the culture of a South American species, the approach and results of the paper are deemed relevant for regions and systems elsewhere to consider.

Conclusions

Our study of tambatinga farming shows a dichotomic pattern of downstream supply/value chains in tropical South America: the farmer-controlled and the intermediary-controlled chains. These two types have different impacts on wealth creation and the number of wealth beneficiaries. The first one generates significant wages concentrated in the farmers' segment. This permits small farms to compensate for their low production level and to obtain economic outcomes sufficient to have a decent life; it also allows wealth distribution.

This model makes small fish farms (around 1 ha or lower) an interesting business to alleviate poverty, provide food security and decent jobs, and reduce inequalities using aquatic resources. Therefore, small farms can contribute to reaching the sustainable development goals (SDGs) numbered 1, 2, 8, 9, and 14 of Agenda 2030 (UN 2015). The intermediary-controlled chains consist of non-vertically integrated farms; these are composed of supply chains with intermediaries that transport and trade fish, mostly to remote markets. Thus, several stakeholders share the gross revenue. This results in poor economic outcomes for the livelihoods of small farms and small intermediaries. Therefore, this model is more suitable for large farms or intermediaries, resulting in fewer wealth beneficiaries. Further studies should be performed to confirm if the patterns observed for the tambatinga sector in tropical South America are similar to those in other regions and the supply/value chains of other fish species.

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Author contribution F. Gilson: conceptualization, methodology, field work and writing.
M. B. New: reviewing and editing
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W. C. Valenti: methodology, writing, reviewing, and supervision

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

Code availability Not applicable.

Declarations

Competing interests The authors declare no competing interests.

Ethics approval and consent to participate All ethical approvals and consents for participation have been obtained.

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

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