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Analysis

Benefits of community fisheries management to individual households in the floodplains of the Amazon River in Brazil

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ABSTRACT

We study the incentives of households in the floodplain of the Amazon River (*várzea*) to comply with community fisheries management efforts. The local manifestation of fisheries management in the study region, fishing accords are community-level agreements that emerged starting in the 1980s in response to increased fishing pressure and fisheries stock depletion. We examine empirically the effects of fishing accords enforcement efforts on individual household time savings. The amount of time savings represents an incentive for, and a predictor of, continued participation in enforcing fishing accords. We quantify the time savings associated with the enforcement of accords by estimating a system of simultaneous factor demand equations that account for different periods in the flood regime of the Amazon River. We find that, in the short run, there is a cost to households from enforcing fishing accords. In the long term, however, the enforcement effort employed generates substantial time savings in fishing that frees scarce time to be allocated to other household activities, such as agriculture and cattle grazing.

1. Introduction

The perception of the net benefits accruing to individual households from common pool resource management schemes determines the effort these households expend to protect the resource. However, assessments of such schemes frequently ignore individual benefits and instead often focus on resource health (Defeo et al., 2016; Evans et al., 2011). In this article, we study individual incentives to participate in community fisheries management efforts by households located in the Amazon River floodplain (*várzea*) surrounding the city of Santarém, state of Pará, Brazil. We define fisheries management enforcement effort performed by an individual household as the sum of the time dedicated to the participation in the negotiation and discussion of community fisheries management (which usually take place in community meetings) and the time spent in patrols or fishing site monitoring activities to guarantee community fisheries management rules compliance. The main question we seek to answer is: what effects do household-level fisheries management enforcement efforts have on these same households? Our main hypothesis is that there are positive net benefits from fisheries management enforcement undertaken at the household level through fishing time savings generated by such efforts in the long run. This effect attests to the importance of continuing community efforts to not only protect local fishery resources per se, but also to guarantee the benefits individual households draw from it.

Historically undervalued by scientists and policy makers due to their geographic, socioeconomic, and political remoteness (see Pauly, 1997),[1] small-scale fisheries have only lately received more attention given their role in the livelihoods of millions of people and their potential for poverty reduction (Kolding et al., 2014; Béné et al., 2010). In contrast to industrial fisheries, small-scale fisheries are characterized by

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[1] Pauly (1997) explain that small-scale fisheries are undervalued by society in general (he uses the term "marginalization" to refer to this phenomenon) due to their remoteness, which may take three forms. Geographic and physical remoteness refer to the fact that fishing landings are spread across the space, far from commercial and political centers, besides the lack of infrastructure to reach and monitor them. As for social remoteness, the author explains society's low status perception towards fisher households and fisheries manager groups, who often present little or no education and belong to unfavored or minority groups. This makes communication with this public often difficult. Finally, political remoteness refers to the lack political power from the part of small-scale fishers, resulting in low participation in the political process. An economics explanation to this phenomenon described in Pauly (1997) is that the opportunity cost of a public dollar invested in monitoring small-scale or artisanal fisheries and fisher households is too high to justify the amount of investment, especially in situations of financial constraints as is the case in many developing countries where small-scale fisheries are located.

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the predominance of small fishing vessels mostly employed close to the household, by being less intensive in capital and energy compared to industrial fisheries, and by the fact that they are largely restricted to developing regions (Kolding et al., 2014). Moreover, in small-scale fisheries, fisher households often dedicate part of their time to other economic activities, such as agriculture and grazing, among others, as a means of reducing risk, meeting their subsistence needs and generating some cash income (McGrath et al., 2007; Almeida, 2006).[2] Another main characteristic of small-scale fisheries is the low investment in monitoring of fishing activities, exacerbated by difficulties in using conventional landings-based monitoring methodologies (Pauly, 1997). So, even when financial, political and human resources are invested in community fisheries management projects and programs, little effort is dedicated to long-term results assessments (Defeo et al., 2016; Gutiérrez et al., 2011; Evans et al., 2011).

One cannot expect a conservation policy to be effective if it does not include an understanding of the incentives driving the decisions of the actors in direct contact with the natural resource in question. The literature on benefits assessments from community fisheries management uses a variety of indicators of performance, which Evans et al. (2011) classify as either process indicators (participation level, resource control, destructive fishing activities, etc.) or outcome indicators, the latter of which household wellbeing falls into. However, most existing assessments of fisheries rely on resource users' and managers' perceptions of improvement (for example, see Lawson-Remer, 2013 and Donda, 2017) rather than on quantifiable measures.[3]

In the floodplain of the Amazon River surrounding the municipality of Santarém, the local manifestation of fisheries management takes the form of fishing accords (Oviedo et al., 2015). These constitute agreements among users of well-defined fishing territories seeking to limit access to the fishery resource (of both outsiders and members of the community), to establish rules of use of the resource (usually associated with restrictions on fishing gear, catch quantity and size, and/or fishing seasons) and to define punishment measures to those who violate such agreements (McGrath et al., 1999; Almeida, 2006; Oviedo et al., 2015). The literature concerning the success of fisheries management specifically in the *várzea* of Santarém is largely composed of analyses of the institutional and social arrangements that constitute the community management of fisheries (for example, see Castro and McGrath, 2003). Measures of success are mostly related to resource health and assessed in terms of physical catch per unit effort, such as in Almeida et al. (2002) and Almeida(2006).

McGrath et al. (1994) present a theory of fishing accords enforcement effort and household wellbeing based on the comparison of data collected in two communities of Santarém: Aracampina and São Miguel. Fisher households living in the former are more oriented towards commercial fishing and attempts at a functioning community fisheries management scheme have not been successful. However, São Miguel is considered a "model" of fisheries management in the region. McGrath et al. (1994) argue that there is a transition between the "no fishery management" and the "managed fishery" ends of the fisheries management spectrum: when fisheries management effort first starts, households go through a phase of reduced fish catch and income, making them rely on other activities (for example: agriculture) until fishery management efforts allow for increased fishery productivity and greater total household income (McGrath et al., 1994).

Without formal study, McGrath et al. (2007) follow along similar lines, arguing that fishing accords may change household strategies depending on its costs and benefits, and they emphasize the need to look at households' individual behavior in enforcing community fisheries management. If individual fisher households invest time and physical effort enforcing community fisheries management, then they incur a series of costs in the short run (Meshack et al., 2006).[4] These costs are related to the attendance of meetings to negotiate and discuss fishing accords, that is transaction costs, and the monitoring of fishing sites against outsiders and/or against practices deemed illegal in these agreements, diverting time from other household activities. In the long run, however, these efforts are expected to lead to a better fishery and may generate a net benefit if fishing accords enforcement time results in the reduction in fishing effort per unit catch (or increase in fishery productivity) and consequent reduction in the overall necessary time to attain a given catch level, which we call "time savings" in this article. Whether this long-term benefit outweighs the short-term cost of enforcement remains an open question; the answer ultimately determines the success of resource management (Coase, 1960).[5]

Our work in this article assesses individual incentives for community fisheries management enforcement among developing country fisher households. For the *várzea* in particular, there is no work we are aware of that formally and empirically examines the question of the benefits and costs accruing to individual households as a result of their fisheries management enforcement efforts. Viewing the individual fisher household as a decision unit of production, we use a production factor demands approach to understand fishing effort and fishing accords enforcement effort choices. We formally test our theoretical results using data collected through a 2015 survey of nearly 650 families taken at two periods of the year and spread across 23 different *várzea* communities of Santarém with differing degrees of community fishery management. Our results show that, in the short run, there are costs incurred by individual fisher households from enforcing fisheries management. However, these are offset by positive and significant long-term benefits generated by a history of fisheries management enforcement throughout the years that translates into fishing time savings in the present.[6]

2. Fishing in the Amazon floodplains

Our study area comprises the floodplain of the Amazon River within a 100 km straight distance upriver and downriver from the city of Santarém. The *várzea* extends through approximately 180,360 km^2 of abundant and diverse biota, yielding high fish production year-round (Bayley and Petrere, 1989; Bayley, 1995). Its dynamics is dictated by the "flood pulse"; the ever-changing interaction between land and water environments, inundating the land surrounding the main river channel for part of the year (Bayley, 1995), and generating a range of habitats that are connected according to the water level, forming "lakes systems" (Arantes et al., 2018).

The rhythm of the flood pulse provides a series of opportunities for

[2] The focus of our article is small scale fisheries, which, in our understanding, encompass subsistence and artisanal fishing activities as per the classification of fishing activities by type listed in the Brazilian Fishing Code (Article 80 of Law n. 11, 959 from June 29th 2009).

[3] Some exceptions do exist in development economics showing that community management of forests afford households with significant time savings in fuel collection (Köhlin and Amacher, 2005; Arnold et al., 2006). However, there are no comparable studies for small-scale artisanal fisher households.

[4] Unlike Meshack et al. (2006), we do not consider the household time commitment to actually enforcing fishing accords, that is, monitoring lakes, as a transaction cost related to fishing accords. This enforcement decision by the household constitutes a specific choice of time allocation that affects time allocated to other household activities such as fishing time, agriculture and cattle grazing. Moreover, the parties involved in fishing accords do not include outside fleets. However, distinguishing transaction costs from actual enforcement effort is quite difficult, as seen in the discussion of our empirical model below.

[5] An important element in the ability of households and communities to enforce fisheries management is the existence of well-defined property rights, without which transaction costs associated with enforcement would make fisheries management unfeasible (Coase, 1960).

[6] A main contribution of this work is to quantify the short and long-term effects of fishing accords enforcement in households.

subsistence and income generating activities for local households (Crampton et al., 2004; Moran, 1989; McGrath et al., 2007). Families usually engage in more than one economic activity (for example: agriculture, cattle and buffalo ranching, gardening, timber and non-timber forest products extraction, and fishing), following a "multiple resource use" living strategy (McGrath et al., 1993a; McGrath et al., 1993b; Almeida, 2006). Fishing, however, is the main source of income (Almeida, 2006).

The importance of fishing as an income-generating activity for the households of the *várzea* grew especially after the collapse of the Santarém 'jute' market in the 1980s (McGrath et al., 1993a; McGrath et al., 2007).[7] Associated with an increase in the demand for fish protein (as a result of immigration into the Amazon region) and with technology development,[8] there was a perception of ever-increasing pressure on local fisheries due to the presence and practices of local and outside fleets (McGrath et al., 1993a; Almeida, 2006; McGrath et al., 2007).[9] In this context, communities started organizing with the intent of averting the presence of outside fishers and of regulating fishing among their members (McGrath et al., 2007; Oviedo et al., 2015).

A number of community fishing agreements, locally known as "fishing accords" (Oviedo et al., 2015), resulted from the process described above. Fishing accords establish rules of access and use of the fishery resource, such as restrictions of fishing gear, catch size, individual size, and fishing seasons, as well as punishment measures to those who violate such agreements (McGrath et al., 1999; Almeida, 2006; Oviedo et al., 2015). At first informal, these agreements within and between communities gradually evolved into a regional fisheries co-management system in the 1990s during the *ProVarzea* project, implemented by the *Instituto Brasileiro de Meio Ambiente e Recursos Naturais Renováveis* (or IBAMA, the Brazilian environment regulation agency) and involved several governmental and non-governmental actors in addition to the communities themselves. Later on, fishing accords were incorporated into "Resource Use Plans" for each Agroextractivist Settlement Project (called PAE or *Projeto de Assentamento Agroextrativista*) created in the early 2000s during the land legalization process of the *várzea* by the Federal Government through the National Institute for Colonization and Agrarian Reform or INCRA (Benatti, 2011).[10] However, Brazilian Law considers all water bodies public (McGrath et al., 1999; Castro and McGrath, 2003; Almeida, 2006; Benatti, 2011; Oviedo et al., 2015). This fact combined with the still recent land tenure legalization process in the *várzea*, the also recent transfer of the fisheries management responsibility from the federal to states governments in 2011,[11] and the lack of resources by government institutions to support enforcement and monitoring of fishing accords (Oviedo et al., 2015) makes the fisheries of the *várzea* of Santarém a traditional example of common pool resource, that is rival and non-excludable. However, they present different levels of "openness" according to the ability of the households and communities to enforce fishing accords and keep outside fishing fleets from fishing in community lakes.[12]

3. Conceptual model of the small-scale fishing household

We first present a model of an individual fisher household that chooses the production factors necessary to perform its fishing activities, with a focus on variable factor demands, that is, inputs that may be changed in the short run: fishing time, fuel and time enforcing fishing accords. The household allocates time across other economic activities and leisure when not fishing nor enforcing fishing accords. Any effect of fishing accords enforcement on the household's time allocation represents an effect on wellbeing (for example, see Köhlin and Amacher, 2005 for a fuel collection example).

Our model of a developing country small-scale fisher household therefore differs from the traditional models in the fisheries economics literature (such as Smith, 2012). In the context of developing regions, as is the case of the *várzea*, insufficient data available over time on fishing catch and effort restricts the inclusion of population dynamics to assess household benefits in terms of catch per unit effort (Kolding et al., 2014). Additionally, the decision on the amount of certain cost factors are dependent on household characteristics, which differs from the problem modeled in commercial fisheries (Donda, 2017; Lawson-Remer, 2013; Evans et al., 2011; Milner-Gulland, 2011).

Assume that the household seeks to maximize the net benefits from all activities it engages in, including fishing. The household optimally chooses the level of fishing time that equates marginal returns across all its activities, a standard result in household-based rent maximization problems similar to ours (e.g., Sills et al., 2003; Jacoby, 1993; De Janvry et al., 1991; Singh et al., 1986). As a result, the optimal volume of fish catch defined by a household in a given time period maximizes the net benefit it derives from fishing. From duality theory, by maximizing its benefits or "profits", a fisher household is also minimizing its costs (Mas-Colell et al., 1995), which is the basis of our approach.

Let the household cost of fishing be defined by the function, $C(c, w, d)$, where $\frac{\partial C(.)}{\partial w} \geq 0$ and $\frac{\partial^2 C(.)}{\partial^2 w} \leq 0$. Let time spent fishing, f, and labor time allocated to enforcement of fishing accords, e, be variable production factors. The cost of fishing is a function of the market wage rate w defining the cost of time (measured per unit of time), and the market unit cost of fuel, represented by c, both of which are exogenously taken by the household. Variable d is the distance to a fishing site measured as the average time it takes to get there, and is exogenous in our specific data.[13] Formally, the decision problem faced by the individual fisher household is to allocate time between fishing and enforcement of fishing accords to minimize the cost of fishing:

[7] The jute (*Corchorus capsularis*) is a plant from which fiber is extracted to produce a rustic type of fabric. Introduced in Brazil by Japanese immigrants in the 1930s, it became an important part of the economy of Santarém and other municipalities of the Low Amazon region between the 1940s and the 1970s (Souza, 2008).

[8] For example, the development of synthetic material that now composes fishnets and make them more durable and less costly, the use of motors and fridges in boats, and the invention of coolers (McGrath et al., 1993b).

[9] Many of outside fishing fleets are industrial in nature and come from as far as Belém (700 km in a straight line east of Santarém) and Manaus, Amazonas (nearly 600 km in a straight line west of Santarém). However, some fleets also come from smaller urban centers, including Santarém.

[10] The land legalization process refers to the act of the government of conferring a private party with the private usufruct rights to public land through an administrative contract – a concession contract, in the case of the *várzea*. These contracts were celebrated between the Brazilian government and the associations representing communities and they include a natural resource management plan (the Resource Use Plan) for which all inhabitants of the land are responsible. They were motivated at least in part by the conflicts in the floodplain related to fishing and cattle grazing. See Benatti (2011) for more details.

[11] Complementary Law n° 140, of December 8th 2011.

[12] Currently, there is an overlap of fisheries regulations by different government agencies that have distinct objectives (i.e. land tenure for INCRA and conservation for the State Environment Agency). Since the responsibility for fisheries management has been transferred to state governments in 2011, the government of the State of Pará has been leading the discussion of a decree with the rules for fisheries management and related government responsibilities as this paper is written (A. Cardoso 2019, personal communication, 19 August).

[13] The reason for exogeneity of this variable is that households fish mostly in rivers and within the "lake system" that belongs to the PAE in which they are located. Here we only consider variables related to fishing in lakes. Choices of fishing sites within the lake systems do not usually change in the short run. So, we assume distance to fishing sites to be sunk from the perspective of the short run cost function.

$$\min_{e,f} C(c,w,d) = w*f + w*e + c*g(f,e;d)$$
$$s.\ t.\ h(f,e;q,B) \geq H^*$$
$$f = f(e)$$
$$T \geq f + e + o$$
$$B = B(P) \tag{1}$$

Further, assume that c, w, d, f, e, q, B, $H^* \geq 0$ and $T > 0$.

In problem (1), labor time allocated to fishing, f, is affected in a given time period by current time spent in enforcement of fishing accords, e, to the extent that it averts illegal activity at the fishing sites. Also in Eq. (1), function $g(f,e;d)$ represents fuel use, another variable fishing cost. Function $h(f,e;q,B)$ represents the fishing production function, and H^* is the optimal harvest or catch decided upon by the household for a fixed time period – in household modeling, this is typically considered to be a subsistence constraint that must be met by the household.[14] Costs are minimized subject to the constraint that the representative household fisher is fishing at its optimal level, H^*, and subject to a constraint on the household's time endowment, T, where o is the time devoted to activities other than fishing and enforcement of fishing accords and is determined through the given time endowment and the choices of f and e.

In problem (1), fuel use is a short run choice and is completely determined by the decisions on time spent in fishing-related activities and by the total distance traveled to different fishing sites, d, in the period under consideration. The amount of fuel chosen by the household, through the time choices, also depends on the type of boat motor and size of the vessel. However, this is a long-run decision in nature and, therefore, a sunk cost. Most vessels across different small-scale fisher households in the study region under consideration are similar in size and technology. Thus, these aspects are not important to the empirical realization of Eq. (1).

The production function $h(f,e;q,B)$ in problem (1) depends not only on time allocated to fishing and enforcement, but also on exogenous fishing technology, q, and biomass health, B, both of which are fixed in the short run. The mechanism through which greater cumulative fishing accord enforcement through past time leads to more successful trips is likely to be through the impact on biomass health in fishing sites, represented by B. We define P as accumulated pressure on the fish population in the past, which is related to how long fishing accords have been in place and enforced (reducing pressure on the resource), such that $B'(P) < 0$. Variable P reflects all past enforcement of the fishing accord, which we represent by variable A and taken as given in determining the current period level of fishing and enforcement effort.

From problem (1), the factor demand functions for fishing labor time and fuel, conditional on production of harvest level H^*, are given by:

$$f(w,c,d \mid H^*) = \frac{\partial C(c,w,d \mid H^*)}{\partial w} - e \tag{2}$$

$$g(w,c,d \mid H^*) = \frac{\partial C(c,w,d \mid H^*)}{\partial c} \tag{3}$$

Eqs (2) and (3) are determined simultaneously and are linked together through the various factors that determine time allocation choices. Thus, if fishing accords makes households better off, we expect the optimal factor demand for labor to decrease as the household saves time.

Whereas time spent by a household in fishing accords enforcement may affect the labor allocation in the short-run directly, in the long run, enforcement enters through the biomass term in the production function. Therefore, the cumulative effects from past years of enforcement effort manifest through responses of the resource stock. In other words, the effect of biomass health in the cost minimization problem depends on how much pressure the fishery has suffered in the past and the length of fishing accords enforcement (measured in terms of number of years). We expect an extra year of fishing accords enforcement, A, to have a positive change on biomass health (abundance).[15] In turn, a positive change in biomass should generate a decrease in the time spent fishing in the present for a given level of catch defined by the household. This constitutes a time savings that may be used by the household towards other economics activities to increase its income (McGrath et al., 1999). That is, we expect the history of fishing accords enforcement to reduce pressure over the fishery resource, leading to healthier biomass and increasing household wellbeing:

$$\frac{\partial f(w,c,d \mid H^*)}{\partial A} < 0 \tag{4}$$

We provide a description of the econometric strategy and of the data used to empirically estimate factor demand Eqs. (2)–(3) and partial effect Eq. (4) below. Ultimately, we test the hypothesis that whereas current fishing accords enforcement effort at the individual household level leads to longer periods of time devoted to fishing activities in the present, a longer history of fishing accords enforcement effort leads to overall net household time savings.

4. Empirical estimation

Our main question is how fishing accords enforcement effort undertaken at the level of the household translates into benefits to the household itself. To test the hypothesis proposed above, we estimate a three-stage least squares (3SLS) system of simultaneous structural equations reflecting the system of simultaneous factor demand Eqs. (2)–(3)[16]:

$$y_1 = \boldsymbol{X_1\beta_1} + \varepsilon_1$$
$$y_2 = \boldsymbol{X_2\beta_2} + \varepsilon_2$$
$$y_3 = \boldsymbol{X_3\beta_3} + \varepsilon_3 \tag{5}$$

In the system of simultaneous equations above, scalar y_1 represents the demand for fishing labor time, y_2 represents the demand for fuel and y_3 represents fishing accords enforcement effort. Vectors $\boldsymbol{X_1}$, $\boldsymbol{X_2}$ and $\boldsymbol{X_3}$ contain our explanatory variables, and ε_1, ε_2 and ε_3 are the error terms for each equation, which are correlated.

The first-order conditions derived from the fishing cost minimization problem presented above lead to a system of equation in which the choices of fishing labor time, fishing accords enforcement effort and fuel use level are made concurrently and are closely linked through the household time constraint. The 3SLS estimation procedure is an appropriate method in this case because the error terms in Eq. (5) associated with these decisions are correlated due to the fact that the three variables (fishing labor time, enforcement effort and fuel use) play the role of both dependent and explanatory variables in our system of equations (Greene, 2012). Johnson et al. (2010) show that 3SLS is the best model to estimate parameters in situations such as this.

In the first equation of the system of simultaneous equations ((5), household demand for fishing labor time, measured by the time the household spent fishing in *várzea* lakes, is a function of fishing accords enforcement effort, the length of the household involvement in fishing accords, and the daily wage level in the community where the interviewed household is located, all included in vector $\boldsymbol{X_1}$. We expect the

[14] This subsistence includes the catch necessary for the household's protein needs and for the generation of cash income for goods the household cannot produce and for services it needs. That does not exclude the possibility of the household making a surplus.

[15] As is explained below, biomass abundance in our econometric model is lagged two years in relation to our survey (Arantes et al., 2018).

[16] We do not apply a panel methodology in this article because there were only two rounds of data collection and they were very close to one another in time. We include a dummy variable that controls for water level effects.

demand for fishing labor time to increase with current fishing accords enforcement (as it reduces time availability for all economic activities) and to decrease with length of household participation in fishing accords, which considers past fishing accords enforcement and, in turn, we expect it would support higher biomass availability. Daily wage represents the unit cost of fishing time, an opportunity cost of fishing were household fishers to spend their time in a paid job instead. We expect higher daily wages to reduce the demand for fishing labor.

Vector $\boldsymbol{X_1}$ also includes a set of control variables that reflect the diversity of physical, social and economic contexts we find among sampled communities in the *várzea*. Since we collected data in two different seasons of the flood pulse, we include a dummy variable to indicate whether the data were collected during high or low water levels. We include the household's elevation in relation to sea level in feet as a control variable given that the extent to which the flood pulse affects households depends on how much its surrounding land is inundated (where other activities besides fishing happen) and how access to fishing sites change (affecting routes and fuel use through *d*).

Through $\boldsymbol{X_1}$, we additionally control for several opportunity costs of fishing such as prices related to agriculture and cattle grazing to capture the incentive to allocate labor to these activities, as well as for distance to the mostly well-developed market in the region, Santarém. We follow the literature (for example, see Caviglia-Harris, 2004; Kassie et al., 2014; Schons et al., 2019) in using the time it takes to reach the market as a measure of how remote a household is not only from the market (where it will sell and buy goods), but from basic services that the family does not have access to in the community and employment opportunities, all of which affect household time allocation decisions. We also take into account other pressures to graze cattle instead of fishing by including a sunk cost decision variable, herd size. Cattle grazing has been identified mostly as a savings-related activity for the credit-constrained *várzea* household; the cattle herd composing an investment that is liquid enough for times of family struggle (Merry et al., 2004).

Recognizing the interactions between commercial and small-scale fisheries,[17] we include a dummy variable for whether the household owns a larger vessel or not and the total value of the vessels a household owns in $\boldsymbol{X_1}$. As with herd size, these variables are wealth indicators. However, they also assist controlling for the higher technology used (size and potency of motors) that would be a characteristic of households that play the role of middleman as well. Higher technology is mostly for storing fish caught by other households and not for fishing per se. Individual fishermen selling to that boat use smaller vessels to fish.

In the set of controls in the demand for fishing labor time equation in system of equations (5), we include dummy variables for the location of the PAE where the household is located. This controls for the level of social organization and socioeconomic development (including infrastructure) found in the proximity of the household, which should influence the household's decision on the time spent fishing and time enforcing fishing accords.

In the second equation of of the system of equations (5), the fisher household's demand for fuel while fishing in local lakes depends on the distance of the fishing sites in relation to the household, included in $\boldsymbol{X_2}$. The demand for fuel should increase the greater the distance traveled. Additionally, the demand for fuel needed must also depend on the fishing labor (measure in time units) at the fishing site and on fishing accords enforcement effort. We expect both of these to affect fuel demand positively.

As is the case with vector $\boldsymbol{X_1}$, vector $\boldsymbol{X_2}$ includes a series of controls variables that affect the household's demand for fuel. Although the technology used by different fisher households is relatively homogenous and technology choice does not represent a problem in this specific analysis,[18] the dummy variable for whether the household owns a larger vessel and the total value of vessels the household owns are also included here. Vector $\boldsymbol{X_2}$ also includes the dummy variable that controls for the water level period when the interview took place as we expect it to be relevant as the level of water influences how spread out the biomass is and where it is concentrated (Oviedo et al., 2015) as it also determines the paths, and thus, distance to fishing sites. For the same reason we include elevation in $\boldsymbol{X_2}$ and we control for household community location.

The last equation in system (5) refers to the factors that determine fishing accords enforcement effort, which is included in this system of simultaneous equations because it is endogenous to the household fishing production process.[19] Vector $\boldsymbol{X_3}$ contains a series of variable determining the level of fishing accords enforcement effort by the household. It includes the probability that the household will participate in the community association,[20] the locus of fish accords negotiation. We expect a higher probability of participation to lead to higher fishing accord enforcement level. We expect the same result with regards to the length of household engagement in fishing accords, capturing not only the experience but the imputed value of the time spent enforcing accords through the years to the household. The decision on the level of fishing accords enforcement effort is also determined by illegal fishing activity, as households should be more willing to protect their natural and subsistence resource if they observe the presence of illegal fishers. In $\boldsymbol{X_3}$ we control for the distance to the market in Santarém and the distance to the community center, which provides information on access to participate in fishing accord discussions promoted by NGOs and government agencies involved with fisheries management. Finally, we control for period of data collection and elevation as well, as those affect the "natural" access to fishing sites and, thus, the need for higher or lower enforcement effort.

We estimate two different specifications of the system of simultaneous equations (Eq. (5). The main difference between specifications is the inclusion, in specification (2), of a variable capturing biomass health or abundance, which represents average biomass level in the community two years prior to our own survey in terms of catch per unit of effort. Biomass health should affect a household's fishing time as well as the decision to enforce fishing accords.

System (5) is identified given the number of endogenous variables, namely fishing labor demand, fuel demand for fishing, and fishing accords enforcement. The order condition for identification is satisfied, as is the rank condition, which ensures that the model has unique estimated values for the structural coefficients. To address

[17] Almeida (2006) and McGrath et al. (1993b) present discussions on the interaction between artisanal and commercial fishing in the Santarém region. In this study, we focus on small-scale artisanal fisher households and consider commercial fishing to the extent that a fisher household may also play the role of a middleman and that communities organize to keep industrial fleets outside of their lakes.

[18] Even if a few households own vessels with higher engine power or length, small-scale fishing activity in the region of study is still very labor intensive and the type of vessels used for specific fishing sites is similar among households due to the specificities of the fishing site, to fuel constraints and the generally low catch volumes. It is common to find households that will not use any fuel for fishing as they will row their canoes to the fishing sites and, in the low water or dry season, they may even walk to those sites. This may be the case even if the household owns a small horsepower motor, which they use for other purposes (for example, going to the city or meeting other basic transportation needs).

[19] Consistent with household economics theory, the decision on time spent in enforcement of fishing accords belongs to the household. This decision happens in detriment of the time spent in other income generating activities, including fishing. It thus affects and is endogenous to the fishing time decision.

[20] The decision of whether to participate or not in a community association is an important endogenous variable. We follow convention and use predicted probabilities, estimated through a Probit model (available upon request), instead of a dummy variable.

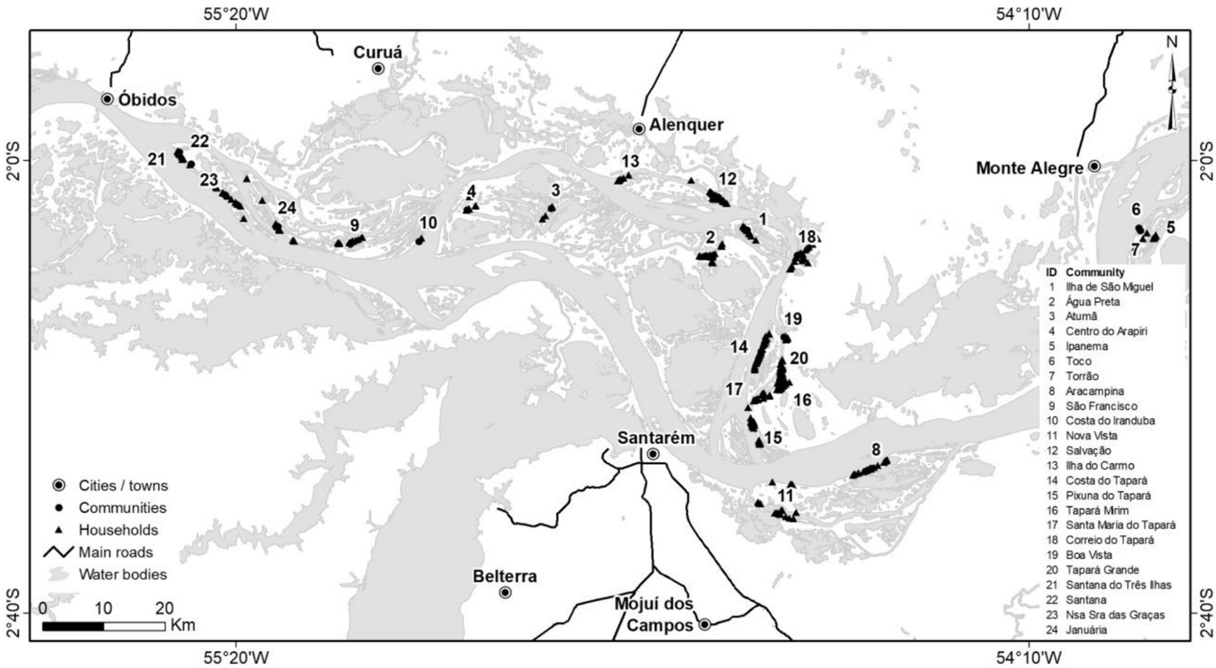

Fig. 1. Map of study region and interview locations.

heteroskedasticity, we run a 3SLS model with bootstrapped errors. Lastly, a note should be made on the fact that selection into groups of those households engaged in fishing and those not engaged in fishing is not a problem in the model. Households that are not engaged in fishing in our sample are those whose members have retired, those who receive a monthly minimum salary from the government (as they work as teachers or services personnel in the community school, for example), or those with members who work outside of the household, for example, as merchants. These households are not accounted for in the model when we estimate it because their fishing labor demand is equal to zero.

5. Data

We collected the data using a randomly stratified sample and a recall-based survey instrument applied in 23 communities surrounding the city of Santarém, state of Pará, Brazil (Fig. 1), in the second quarter of 2015 in two rounds of approximately 30 days each (mid-August to mid-September and mid-November to mid-December). The data include 1292 total observations of 646 households sampled three months apart, capturing households' behavior for periods with both high and low water levels.

The survey instrument was based on three months' worth of recall questions and contained questions on household demographics, plot information, income sources and wealth, economic activities, community and fishing accords. Surveyed communities cover a wide variation in the variables used in the empirical analysis, composing a representative sample of the fishing household of the Santarém *várzea*. Descriptive statistics for relevant variables are provided in Table 1 by round of interviews and refer to the three-month period prior to each round of interviews. There are statistically significant differences in most of variables between data collection periods.[21]

Fishing is by far the dominant subsistence and income generating activity, undertaken by over 92% of interviewed households in our sample in both seasons of the year.[22] Referring to Table 1, time spent fishing, which is our measure of demand for fishing labor, reduced considerably between seasons for most of our sample. Considering only fishing labor dispensed in the lakes within the outreaches of the communities, the average fisher household in the sample spent an average of 30.6 days fishing during three-months of high water season versus 15 days in the dry season.[23] This result is reasonable since the dry season is the time of the year when the fish biomass is more concentrated as it is trapped in floodplain lakes, which implies that it takes less time per unit catch to fish the optimal harvest level (Almeida, 2006; Oviedo et al., 2015).

On average, households spent less time for the three-month period before each interview traveling to fishing sites in the dry season relative to the high-level water season. For the overall sample, the average total distance traveled by a household to reach community lakes over the three-month period covered by the interview was 2.6 days in the first data collection round and 1.8 days in the second. This probably means that fishers go further away during the high water season, when traveling long distances is easier and biomass is widely spread. During the dry season, water levels are low, which means that the obstacles to traveling through water across the region are more numerous.[24]

We use the number of "occasions" in which a household was involved in enforcing fishing accords in the three months before the interview as a proxy measure for the household's short-term fishing accords enforcement effort. An "occasion" refers to a particular event that the person interviewed recalls having participated in activities related to fishing accords enforcement, such as monitoring patrols, or related to the discussion and negotiation of the accords at community association

[21] We provide descriptive statistics per round of data collection on Table SM 1 and Table SM 2 of the Supplementary material.

[22] We assume there is no jointness in production even though households

(*footnote continued*)
devote time to other activities in addition to fishing due to the fact that other economic activities, such as agriculture or cattle ranching, are undertaken in different environments (on land versus water).

[23] We have decided to scale the fishing labor variable in this analysis in terms of eight-hour-long days of work so that the analysis is clearer, but we understand that an actual fishing day is usually much longer.

[24] Because it is more cumbersome to travel during low water levels season, it takes almost 30 more minutes on average to travel from a household in our sample to Santarém and it also takes longer to travel to the community center. These travel times vary significantly across communities.

Table 1
Relevant descriptive statistics.

Round of data collection	Round 1 (high water season)		Round 2 (dry season)		Total	
Variables	Mean	sd	Mean	sd	Mean	sd
Site-specific variables						
Elevation (feet)	35.65	26.09	35.57	26.97	35.65	26.52
Time to market in STM (min)	210.92	101.19	238.71	173.78	224.63	142.36
Time to community center (min)	14.74	18.09	16.93	20.04	15.80	19.08
Economic variables						
Herd size (n. heads)	8.20	35.98	6.68	20.85	7.45	29.69
Adult cattle head mean value (R$)	1243.46	675.52	1249.95	820.49	1246.58	748.34
Gas price (R$)	4.50	0.49	4.85	0.56	4.67	0.55
Daily wage (R$)	37.21	4.11	37.57	6.20	37.38	5.22
Watermelon price (R$)[a]	5.59	1.16	5.48	2.55	5.53	1.96
Fishing variables						
Total distance traveled to fishing sites (8-h-days)	3.30	4.81	2.69	3.96	3.01	4.43
Distance traveled to fishing sites – local lakes systems (8-h-days)	2.62	4.41	1.84	3.37	2.24	3.96
Total time spent fishing (8-h-days)	47.62	50.16	34.38	44.71	41.26	48.06
Time spent fishing in local lakes systems (8 h/day)	30.63	38.40	15.06	26.91	23.15	34.26
Fishing accord/enforcement variables						
Number of fishing accords “occasions”	1.86	4.43	2.64	4.78	2.24	4.61
Length of fishing accords enforcement (n. of years)	10.56	9.02	10.78	8.95	10.65	8.98
Total value of vessels (R$)	5769.21	11,127.77	5637.98	8854.26	5706.15	10,095.77
Highest n. illegal vessels spotted at once	1.89	5.86	2.05	6.91	1.97	6.38
Biomass (kg/h) collected in 2013/14 for a subsample of the data	1094.75	578.14	1094.38	582.35	1094.57	579.83
Affiliated to fisher's colony	77.78%		78.90%		77.32%	
Affiliated to community association	63.21%		62.50%		62.87%	
Owns a boat	36.36%		44.50%		40.27%	

[a] Watermelon was the mostly widely grown crop across communities in our sample during our data collection, reason why is the agricultural price we have chosen to include in our model.

events and government office visits (the latter typically defined as transaction costs in economics). The average number of occasions enforcing fishing accords by a household for a three-month period was 1.9 for the first round of interviews and 2.6 for the second round (but the average per community varies from zero to almost nine occasions). Higher enforcement in the dry season is due to higher illegal activity during that time, when the most valuable species are concentrated in community lakes and, thus, more easily caught. In fact, the mean sample number of illegal vessels observed at once during the period covered by each interview was 1.9 in the first round and two in the second round, varying between zero and six illegal vessels.

The length of household participation or engagement in fishing accords is measured in number of years since a household first got involved in fishing accords. The average length of fishing accords engagement was approximately 11 years, but it varied greatly among communities, reaching as high as 22 years for households in the community of São Miguel and 16 years in the community of Pixuna. This is a long-term measure of the effort made by each household to enforce fishing accords. In the estimation that follows, we use an average of the stated accord length between the first and second round of interviews for each household.

Biomass health or abundance (for the subsample for which it is available) is expressed in terms of catch per unit of effort (kg/h) and also varied among communities. Our biomass data comes from Arantes et al. (2018), who collected biomass information in 16 of the 23 communities in our study region two years before our socioeconomic data collection. On average, this biomass was lower in the high waters season (630 kg/h), varying between 289.58 kg/h and 1719.13 kg/h, and larger in the dry season (1711 kg/h), varying between 173.46 kg/h and 5315.50 kg/h. Biomass in our model is used as a measure of ecosystem health.

Challenges with our dataset include the fact that variable on biomass health or abundance is available only for a portion of the communities in our sample and, as a result does not include three communities regarded as well-organized and engaged in fishing accords (São Miguel, Santa Maria and Tapará-miri). However, we estimate the model with this variable to determine whether the effect of fishing accords enforcement effort, in the short and long runs, on fishing labor demand is robust to the inclusion or exclusion of a measure of biomass abundance. Another challenge with our dataset is that, when collecting our data, households had difficulties recalling exactly how many hours each of them devoted to fishing accords enforcement in the three-month period before each interview. However, interviewees were able to recall how many “occasions” or events in which they were present to discuss, plan or enforce (for example, monitoring trips) fishing accords. Number of “occasions” engaged in fishing accords-related events is therefore used as our measure of fishing accords enforcement effort and includes the transaction costs related to the activity.

6. Results

6.1. Econometric results

Table 2 presents the results from the estimation of the system of simultaneous equations (Eq. (5) for specification (1), which does not include the variable related to biomass health, and specification (2), which includes biomass health and therefore has a lower number of observations. The results are consistent across both specifications.

In the demand for fishing labor time equation, the stage of the flood pulse in which the data was collected (round of data collection), the number of occasions the household devoted to fishing accords enforcement in the three months prior to the interview,[25] the length of fishing accords engagement (number of years since the household first engaged in fishing accords), the time that it took to travel to the market in Santarém, and the dummy variables for PAEs Tapará, Aritapera and Três Ilhas are statistically significant predictors of the time the household spends fishing in lakes. The number of occasions the household

[25] We use the natural log of the number of occasions in which the household was involved in fishing accords-related activities due to better fit.

Table 2
Three-stage least-squares regression[a].

Regressors	Specification (1)			Specification (2)		
	Fishing labor demand (time)	Fuel demand	Fishing accord enforcement effort[b]	Fishing labor demand (time)	Fuel demand	Fishing accord enforcement effort[b]
Data collection round (1 = round 1, high water season; 0 = round 2, dry season)	54.83*** (14.11)	−43.00** (15.5)	−0.235*** (0.0503)	69.74** (23.5)	−60.00** (21.18)	−0.307*** (0.0597)
Total time spent fishing in local lake system (8-h-days)		2.064** −0.753			2.335* −0.914	
ln n. of fishing accords "occasions" (accords enforcement effort)[b]	184.7*** (49.34)	−60.96** (23.58)		197.6** (72.43)	−60.52 (33.36)	
Length of fishing accords enforcement (n. of years)	−2.328** (0.887)		0.0133*** (0.00294)	−2.090* (1.014)		0.0104** (0.00368)
Probability household will participate in community association			−0.595** (0.224)			−0.00477 (0.00505)
Highest n. illegal vessels spotted at once			0.00112 (0.00263)			−0.003 (0.00431)
Distance traveled to fishing sites – local lake systems (8-h-days)		0.253 (2.618)			1.55 (3.169)	
Elevation (feet)	0.149 (0.0952)	−0.420* (0.186)		0.250* (0.121)	−0.530* (0.246)	
Watermelon price (R$)	0.0359 (1.769)			−0.0179 (2.019)		
Herd size (n. heads)	0.0352 (0.0992)			0.0765 (0.131)		
Adult cattle head mean value (R$)	0.00327 (0.0039)			0.00228 (0.00631)		
Daily wage (R$)	−0.728 (0.622)			−0.157 (0.465)		
Gas price (R$)		−0.0549 (5.318)			−7.508 (7.704)	
Time to community center (min)			−0.000878 (0.000866)			−0.000105 (0.00107)
Time to market in Santarém (min)	0.200** (0.0682)		−0.00154*** (0.000348)	0.184* (0.0737)		−0.00133** (0.00041)
Total vessels value of (R$)	−0.0000674 (0.000238)	0.000124 (0.000313)		0.00021 (0.000287)	0.000121 (0.000447)	
Household owns a larger vessel (1 = yes; 0 = no)	3.238 (5.004)	5.848 (7.504)		−4.157 (6.811)	2.774 (10.62)	
Biomass (kg/h)[c]				−0.0572* (0.0274)	0.00785 (0.012)	0.0114*** (0.0123)
Constant	−76.63* (35.74)	61.05 (35.49)	1.050*** (0.218)	−69.4 (39.72)	90.32 (46.14)	0.925*** (0.278)
N	1105			682[c]		
AIC	26,891			16,879.1		

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.
[a] Estimated coefficients for PAE location dummies are available in the Supplementary material, Table SM 3. PAE Salvação is the baseline. Accord length per household used in the model is the average reported between both periods of data collection.
[b] Natural log of the number of fishing accords enforcement occasions.
[c] Biomass abundance is only available for 16 out of the 23 communities sampled in the socio-economic survey.

was involved with fishing accords in the three months prior to the interviews, which measures fishing accords enforcement effort, is positively related to the amount of labor allocated by the household for fishing at the optimal catch level: a 1% increase in the number of occasions a household is involved in fishing accords-related activities means an increase of 1.85 fishing labor days within a three-month period under specification (1) and 1.97 fishing labor days under specification (2). In the short run, fishing accords enforcement leads to increased household fishing labor time.

The length of time, in years, since a household first participated in fishing accords is negatively related to the amount of fishing labor time demanded by the household in the three months prior to the interview as expected in Eq. (4) of our theoretical model. Given specification (1), each year of participation in fishing accords represents a time savings of 2.3 days of fishing labor time to obtain the optimal catch decided upon by the household within a three-month period. This marginal effect is 2.1 days of time savings for specification (2).

The distance to the regional market in Santarém is also a significant explanatory variable in the demand for fishing labor time equation. The greater the time it takes to travel to Santarém (the more distant the household is from the regional center), the more time the household will devote to fishing: a one-minute increase represents an additional 0.20 day of fishing labor in specification (1) and 0.18 in specification (2). An explanation for this effect may be that higher isolation of households makes fishing a more important economic and subsistence activity. Some interviewed households were closer to other markets, providing an opportunity to sell fish at higher prices. However, these other markets do not have the same employment potential as Santarém. The closer the household is to Santarém, the greater are the education and higher paying employment opportunities. Fishing for these households has a higher opportunity cost, leading them to allocate less labor time to fishing.

In the demand for fuel equation of system (5), the round of interviews and elevation of the household in feet are significant in both specifications (1) and (2), with high water levels meaning less demand for fuel. This reflects fewer obstacles to bypass and less time required to travel through a flooded *várzea*. Additionally, households located in higher elevations face fewer difficulties in reaching fishing sites and use less fuel.

The amount of time a household spends fishing, an explanatory variable in the demand for fuel equation, is significant in both specifications of the demand for fuel equation as well: fuel demand increases with the time household members spend in the fishing site. The number of occasions a household is involved in fishing accords (that is, fishing accords enforcement) is significant and negatively related to the demand for fuel. That means that current fishing accords enforcement effort reduces the amount of fuel a household uses for fishing. This suggests that, even in the short run, higher fishing accords enforcement levels mean higher biomass quality, translating into less fishing time and fuel needed to achieve the optimal harvest level.

In the third equation of system of equations (5), we estimate the coefficients for the variables affecting a household's decision on the number of occasions to be engaged in fishing accords enforcement. The round of interview is a significant variable in this equation, which means households decide to participate more in activities related to fishing accords enforcement when the water in floodplains is lower. This is due to greater vulnerability of fisheries in lakes leads to higher need of enforcement in that period.

The number of years since the household first engaged in fishing accords is also a significant predictor for the number of occasions in which the household is involved in fishing accords enforcement in the three months prior to each interview. Every year a household has been involved in enforcing fishing accords has a positive impact of 1.33% on the number of occasions enforcing fishing accords for model specification (1) and 1.04% increase in occasions for specification (2). Nonetheless, the higher the probability of a household participating in the community association, the fewer the number of fishing accords enforcement occasions it is involved in. The reason may be a reduction in expected benefits from participating in the community association due to relaxed income constraints allowed for by government cash transfer programs and other benefits.

The coefficient of the variable time to travel to the market in Santarém is negative and highly significant in both specifications of the third equation in system (5). Therefore, households located further from Santarém devote less time to fishing accords. Two factors may explain the relevance of distance to market in estimating this equation: communities closer to Santarém have greater access to work from NGOs and governmental institutions that support fishing accords, and being closer to a regional center means greater pressure on the fisheries both from “outsiders” of the community and community members.

In model specification (2), the variable measuring biomass health is statistically significant in the estimation of demand for fishing labor time and fishing accords enforcement effort equations of system (5). That is, a healthier biomass fishery means less time spent to obtain the optimal catch decided upon by the household and represents an incentive to continued fishing accords enforcement.[26] All estimated specifications remained similar in the magnitude of the marginal effects and retained the same direction, which leads us to believe our model is robust to the inclusion or exclusion of a measure of the fishery health.

In summary, based on the estimation of our system of fishing factor demand equations (5) for a representative household in our sample, in the short run fishing accords enforcement effort increases a household's fishing labor time but, in the long run, the length of fishing accords participation contributes to a reduction in time needed to fish a level of catch defined by the household. Next, we verify whether these time savings gains offset the short-term costs of fishing accords enforcement, in which case a net time savings represent a positive benefit to the household stemming from fishing accords enforcement as this is time the household may devote to either leisure or other economic activities, potentially increasing its overall household income (Köhlin and Amacher, 2005).

6.2. Benefits from fishing accords enforcement

We estimate net time savings from fishing accords implementation based on the coefficients for fishing accords enforcement effort and length of time implementing fishing accord in years (respectively, natural log of the number of occasions related to fisheries accords enforcement and the history of fishing accords enforcement in number of years) in the first equation of system of simultaneous equations (5) estimated under specification (1). We calculate how many fishing days the average household saves as a result of the number of years it has been enforcing fishing accords and subtract the extra fishing labor demand generated due to the short run implementation of fishing accords (in the three months prior to interviews).[27]

Table 3 presents the average household wellbeing effects from fishing accords enforcement, defined as the net amount of fishing labor saved in 8-hour-days within a three-month period, by group of communities and round of data collection. Table 3 also presents the average fishing labor time used in the three months before each round of interviews for comparison purposes. The three groups which the households were separated into represent different levels of community fisheries management: high management, medium management, and low management. Level of management per community was defined according to the average of reported household short and long run fishing accords enforcement effort per community. The list is consistent with the level of organization of communities observed in the field and described in part of the literature (Ferreira and da Silva, 2018; Oviedo and Bursztyn, 2017; McGrath et al., 1994), but the management level among communities within a group still varies significantly.[28] What distinguishes the communities in the high management level from the others is not only the fact that its members participate more in fishing accords as per our survey. At different intensities, these communities are known for organizing fishing site monitoring groups and effectively enforcing fishing accords rules (by, for example, expulsing outside fishers and apprehending illegal fishing gear) besides seeking for outside help (from local NGOs and government agencies) when they come across illegal activity. These communities are also known in the region for catching higher quality fish, that is larger and more numerous individuals of valuable species, such as *Arapaima gigas* and *Colossoma macropomum*.

According to our results, households that have devoted more time to enforcing fishing accords (through the years and in the short run) save more fishing labor time in the present, both in absolute terms as well as proportionally to the average current fishing labor time. This potentially means that household in communities that are highly organized realize the largest average household net time savings from fishing accords enforcement (for example, São Miguel and Pixuna). Moreover, the average household achieves higher net benefits from fishing accords

[26] As explained earlier, biomass health is included in the econometric model as a short-term indicator of ecosystem health and was collected two years earlier in a subsample of the communities where we collected our data. Thus, there is no reverse causality in specification 2 because biomass health is an exogenous variable. Although this variable may be related to accord length (reflecting a community's ability to enforce fishing accords through time), this is not likely to be a problem since we are using a system of simultaneous equations estimation procedure (3SLS) that allows for correlation between equation error terms.

[27] See the Appendix for a detailed explanation of the calculations performed and the supplementary material for Table SM 4 with the average wellbeing effects from fishing accords enforcement by community and round of collection.

[28] There is no published research we are aware of that presents an analysis of quality of community fishing accords enforcement for the same or similar group of communities of that in our sample. Such analysis is not the focus of this article.

Table 3
Average estimated wellbeing benefit in fishing labor time saved per period of three months.

Variable	Level of management					
	High water season			Dry season		
	High[c]	Medium[d]	Low[e]	High[c]	Medium[d]	Low[e]
Net fishing time savings[a] (wellbeing benefit)	26.54	17.23	6.88	27.07	21.15	14.31
Fishing time[a]	34.91	28.11	26.57	18.71	13.73	10.73
Proportion of Wellbeing benefit to Fishing time	76%	61%	26%	145%	154%	133%
Fishing accords enforcement (n. occasions)	2.84	1.56	0.60	4.15	1.91	1.08
Accord length (n. years)[b]	12.91	9.35	5.49	12.91	9.35	5.49

[a] In 8-hour long days.
[b] Six-month average.
[c] High management communities: Ilha de São Miguel, Pixuna, Santa Maria, Tapará-mirim, Costa do Tapará, Boa Vista, Água Preta, Aracampina.
[d] Medium management communities: Salvação, Costa do Iranduba, Centro do Arapiri, Atumã, Correio, Nova Vista do Ituqui, Ilha do Carmo (PAE Três Ilhas).
[e] Low management communities: São Francisco do Madalena, Nossa Sra das Graças, Ipanema, Santana do Três Ilhas, Ilha do Carmo (PAE Salvação), Toco-Torrão, Tapará-Grande, Januária.

enforcement in the dry season than in the high waters season. Fishing time savings are estimated to be, on average, 26 and 27 eight-hour long days in the high water season and dry season, respectively, for the group of high management level communities. For the group of medium management level communities, the average time savings is 17 days in the high water season and 21 days in the dry season, whereas, for the group of low management level communities we found 7 days of average time savings in the high water season and 14 days in the dry season.

In the high water season, when the fish biomass is wide-spread through the landscape, the proportion of fishing time savings in relation to total fishing time labor is 76%, 61% and 26% for high, medium and low management level communities, respectively. For the dry season, the proportion of fishing labor time saved is also on average much greater than total fishing labor demanded by the household in that same period, relative to the high waters season, a reflection of the fact that biomass is more concentrated then. Looking at the averages by community (Table SM 4 in the supplementary material), for 17 of the 23 communities in the sample, the average estimated wellbeing effect is larger in the dry season. Net time savings varies from 0.5 days to 44 days in the high water season and between 9 and 55 days in the dry season.

For our entire sample, between mid-June and mid-December of 2015, the households saved 22,288 days of fishing labor (20.17 days per family), which confirms our hypothesis that there is a benefit to individual households stemming from the fishing accords enforcement effort that they carry out and that these benefits are significant in magnitude.

The net time savings we estimate represent time that the household is able to redirect from fishing to other economic activities, such as agriculture, cattle ranching, honey production, gardening, among others, following the multiple resource use living strategy in the *várzea* (McGrath et al., 1993a), or in leisure. Since time is a scarce resource to the fisher household, any time savings represents value (Köhlin and Amacher, 2005); a concrete wellbeing benefit to the household because it means the possibility of increasing its overall income. This result is significant to *várzea* families and communities and policy makers in the region. If the reasoning for engaging in fishing accords was to guarantee fish protein for the food security of the families (Isaac et al., 2008) and conserving the natural resource, now fishing households will be aware that they also incur into time savings when participating of such collective action efforts.

7. Conclusion

Faced with the challenge of overexploitation of the fisheries that constitute their main source of subsistence and cash income, households in the floodplain surrounding Santarém, Brazil, have organized and created a series of rules and monitoring activities to enforce these rules through fishing accords. The overall goal is to prevent illegal fishing in communities for which property rights, even if recently well defined, are still not well enforced. Community management of common pool resources is a non-government mechanism to ensure that fisheries resources are protected and continue to provide benefits to the communities that use them. While community organization is fundamental for fisheries protection, these communities are composed of households that ultimately suffer if the resource is degraded. Hence, understanding how households benefit individually from fishing accords enforcement is imperative in understanding their incentives to participate in community fisheries management efforts.

We use an extensive survey-based data set to empirically test our hypothesis that fishing accords enforcement effort carried out at the level of the household generates a net time savings in fishing to those same households. Our fishing production factor demand analysis reveals that statistically important drivers of fishing labor time demand and demand for fuel include the short run level of dedication of a household, its history in implementing fishing accords, the *várzea* landscape, the flood pulse, and distance to the main regional market. Our results are revealing. For a six-month period that represents the time when most fishing activity occurs in the year McGrath et al. (1993a); Almeida, (2006), estimated benefits measured as time savings generated to the average household in the sample were 20.17 days for 2015, varying across communities.

This is the first empirical assessment of the incentives for individual households to participate in community management of fisheries in developing countries that we are aware of, going beyond measurements of resource stocks, perceptions of wellbeing and resource improvement from community leaders which are found in the literature or a comparison of descriptive statistics, as performed in McGrath et al. (1994). We focus on choices that households make and how those choices translate into a measurable benefit indicator as we control for a series of factor relevant to the individual decision of contributing to collective action efforts that fishing accords represent. This information is fundamental to support enforcement of fishing accords at the level of the household and a justification as to why households should participate and contribute to the organization of the communities so that those accords are effectively implemented. Beyond addressing their food security concerns, households also benefit from enforcing fishing accords because they are able to save time that is valuable to them (Köhlin and Amacher, 2005) in that they can devote it to other income-generating economic activities (McGrath et al., 1999). As described in McGrath et al. (2007), willingness to participate in collective action and comply with fishing accords depends on the impact of this effort on the household's basic functions. Additionally, this information is key for policy makers and the government as a participant of the co-management of fishing accords in the region and due to their concern with poverty reduction and food security in the Amazon region. Government support, after all, is one of the conditions for successful common pool resource management (Ostrom, 1990).

Possible extensions of this work are the development and inclusion in our model of a better measure of community management quality that allow for a more complete analysis of the relationship between the benefits accumulated by the household in terms of time savings and the level and quality of collective action in the community or PAE it belongs to. Additionally, a better measure of biomass health and the composition of a dynamic and spatial model that includes the appreciation of harvest and fishing accords enforcement effort through time and through space are also desirable and would constitute not only an extension of our model, but would also provide an additional tool for thinking different fishing accords arrangements and policies for the *várzea* of the Amazon River.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

On Table 3, we present the average net household wellbeing estimates for three groups of households in our sample separated by level of community management, which we established based on the average household fishing accords enforcement effort per community. Table SM 4 of the supplementary material presents the estimated net household wellbeing average figures for each community from the coefficients from the estimated system of equations (Eq. (5)) related to the length of fishing accords enforcement (in number of years) and the enforcement of fishing accords effort at the time of the interviews (in number of occasions), which are presented on Table 2 under specification (1).

Assume that $\widehat{\beta}_{LR}$ is the estimated marginal effect of the length of fishing accords enforcement (in number of years) on fishing time labor and that $\widehat{\beta}_{SR}$ is the estimated marginal effect of enforcement effort at the time of the interviews (in number of occasions, a short run measure of fishing accords enforcement) on fishing time labor. If A is the length in year of fishing accords enforcement performed by a household and e is the current fishing accords enforcement effort, as per our theoretical model, to find the average estimated household wellbeing benefit in fishing labor time saved per period of three months (eight-hour long days) presented on Table SM 4 we first performed the following operation for each household:

$$|\widehat{\beta}_{LR} * A| - \left|\frac{\widehat{\beta}_{SR}}{100} * \frac{1}{e}\right| = |2.328 * A| - \left|1.84 * \frac{1}{e}\right|$$

The first term represents the time savings to the household generated by the implementation of fishing accords in the long run and the second term is the time spent in enforcing accords during the data collection period (short run), giving us a net wellbeing or time savings per household. After performing this calculation for each household, we then took the household average for each community, which is found on Table SM 4.

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolecon.2019.106531.

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