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To fish or not to fish? Resource degradation and income diversification in Benin

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To fish or not to fish?

Resource degradation and income diversification in Benin

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Abstract

This paper looks at the relationship between natural resource degradation and income diversification for fishing communities in southern Benin. We find that the higher the degradation of the fishery stock, the more fishers diversify their income away from the fishery sector. However, given the rapid natural resource degradation, the level of income diversification that we find is surprisingly low and far from sufficient to relieve the stress on the lakes. In explaining the low level of income diversification, our results suggest that education plays a role.

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1. Introduction

Many natural resources are declining in the developing world, posing a threat to the economies depending on them (Millennium Ecosystem Assessment, 2005; UNEP, 2006). One way to alleviate the pressure on degrading ecosystems and enhance economic sustainability is to diversify income toward activities that rely less on scarce natural resources. This is formalized by Barbier (2010) in a model linking natural resource degradation and income diversification. He shows that, when faced with resource degradation, individuals will reallocate labour away from resource dependent activities – provided that outside options are accessible and markets operate well. If these conditions are not met, e.g. in the absence of well-functioning markets for labour, credit or products, a poverty-environment trap looms at the horizon.

We study the relationship between natural resource degradation and income diversification for 18 fishing communities located at the coastal lakes and lagoons of southern Benin. The communities depend on fishing, both for generating income and for animal protein intake. Resource degradation has however led to a severe decline of the fishing stock in the three main lakes, threatening the livelihood of the fishing communities (Gnohossou, 2006; Niyonkuru & Lalèyè, 2010). In this context, we analyse the profile of individuals who diversify their income away from the fishing sector, and how this diversification relates to the decline of fishery resources. Following the model of Barbier (2010), we conjecture that a degradation of the fishing stock decreases the labour productivity of fishing, lowering the reservation wage for activities outside the fishing sector. If this assertion is correct, a degradation of the fishing stock would give rise to increased income diversification towards non-fishing activities.

We expect income diversification to occur at the individual level, given that couples in Benin do not pool their income. For instance, LeMay-Boucher et al. (2007), show that the financial spheres of husband and wife are relatively disconnected and expenditure decisions are based on individual budgets rather than a common budget.

To measure income diversification, we rely on two standard measures. The first is simply the number of income sources. Second, we use the Herfindahl index of diversification which takes into account the number of income sources as well as the income share derived from each source (Barrett & Reardon, 2000). The level of natural resource degradation of the lakes is also measured in two ways. First, we use self-reported degradation by fishermen, which we collected for all the villages included in the sample. Second, we construct a degradation index based on physicochemical parameters of water quality [4]. It could be argued that both measures of natural degradation suffer from endogeneity issues, which may attenuate our results. For instance, if more (less) diversification leads to less (more) natural resource degradation, the positive link between degradation and diversification as predicted by Barbier (2010) is attenuated. To address this caveat, we use an instrumental variables approach that relies on the distance to the sea as an instrument for degradation.

The contribution of this paper is twofold. First, our results offer empirical confirmation for Barbier's (2010) theoretical model. We find robust evidence that the level of income diversification is higher in areas where natural resource degradation is stronger. Our quantitative analysis supports the conjecture that a degradation of the fishing stock lowers the reservation wage for outside employment and stimulates income diversification away from the fishing sector. A second contribution lies in shedding light on the magnitude and heterogeneity of this effect. We find that the effect is rather weak, in the sense that – despite rapid degradation – the level of income diversification is surprisingly low and far from sufficient to relieve the stress on the lakes. In explaining the low level of income diversification, our analysis suggests that education plays a role. While higher educational attainment leads to higher levels of income diversification, the median fisherman in our sample is illiterate and relies only on fishing.

One of the objectives of Benin's 2011 Poverty Reduction Strategy Paper was to link the sustainable use of natural resources to poverty reduction (OECD, 2012). In that respect, the findings of this paper suggest that one mechanism which could serve both goals would be enhanced education, including vocational training, combined with the creation of employment outside the fishery sector. Such a policy could enhance the fishermen's access to attractive outside options, and safeguard fishing communities from a poverty-environment trap.

[4] This data was collected by Gnohossou (2006)

2. Fishing in Benin

Benin is a small country in the coastal region of western Africa (see Figure 1). About half of its 9 million inhabitants live in the southernmost sixth of the country. The availability of natural resources partly explains the asymmetric population distribution; the coastal lakes and lagoons of southern Benin form the country's most productive ecosystems (USAID, 2007). The fishing sector is of great importance to both national and rural economic development as fish is the main source of animal protein consumed in the country and, in 2008, approximately 600,000 people were employed in the fishing sector (FAO, 2008; USAID, 2007).

Marine fishing accounts for 25% of national fishery production, while inland fisheries dominate, accounting for the remaining 75% (FAO, 2008). Lake Nokoué (150 km^2), lake Ahémé (85 km^2) and Porto-Novo lagoon (35 km^2) are the three main lakes of Benin. The Totché channel connects lake Nokoué and Porto Novo lagoon, making it the largest water body of Benin. The Cotonou channel and Ahô channel connect lake Nokoué and lake Ahémé to the Atlantic ocean. The connections are vital to the ecosystem as the inflow of marine water creates seasonal variations in the salinity, temperature and oxygen level of the water, which promotes diversity and reproduction of the aquatic fauna and flora (Amoussou, 2004; Gnohossou, 2006).

At each lake, villages are located along the border or on the water surface in the form of pile villages. They are inhabited by different ethnic groups which strongly depend on the fishing sector for their livelihood. This dependency is threatening the sustainability of their livelihoods, as in the past few decades the coastal lakes and lagoons of Benin have experienced dramatic environmental degradation leading to a loss of biodiversity and a decline of the fishing stock (Allan et al., 2005; Amoussou, 2004; FAO, 2008; Gnohossou, 2006; USAID, 2007).

The socio-economic changes associated with the colonization of Benin (1894-1960) gradually raised the pressure on the coastal lakes. The emergence of markets and transport systems enhanced the economic value of fishery resources beyond subsistence value with a consequent increase in the number of fishers (Dangbégnon, 2000; Maarleveld & Dangbégnon, 1999). In addition, both the number of fishers and the demand for fish increased due to high natural population growth as well as migration flows to the coastal region. For instance, Porto Novo and Cotonou which are both located at one of the southern lakes, grew to become the largest cities of Benin. As population increased and industries grew, water pollution worsened, with household waste, industrial waste and agricultural waste all flowing freely into the lakes (USAID, 2007). The inflow of pesticides, copper, lead and other chemical substances adds to the contamination of the water resulting in high chemical concentrations in fish tissues (Gnohossou, 2006; Roche International, 2000; USAID, 2007).

The colonization as well as the increased monetization and commercialization of the economy marked the breakdown of the traditional natural resource management system which was embedded in the Voodoo religion. The Voodoo governance system prevented overfishing and the use of damaging fishing instruments through a set of rules and sanctions. The rules were enforced by local spiritual leaders who gained legitimacy and trustworthiness from their religious status and their close association with the ancestors (Dangbégnon, 2000; Maarleveld & Dangbégnon, 1999; USAID, 2007; Briones et al., mimeo). The colonization and subsequent promotion of monotheistic religions in Benin reduced the influence of Voodoo and undermined the authority of local spiritual leaders.

New fishery institutions were introduced in the 1990's, but have not been able to effectively regulate fishing activities due to monitoring and enforcement difficulties (Dangbégnon, 2000; Maarleveld & Dangbégnon, 1999; USAID, 2007; Briones et al., mimeo). The weak monitoring and enforcement power of the new institutions eased the introduction of highly yielding but damaging fishing instruments from the 1960s onward (Dangbégnon, 2000). Especially the increased use of the two main damaging instruments, the acadja and the medokpokonou, has contributed to the problem of overfishing and resource degradation (FAO, 2008; Niyonkuru & Lalèyè, 2010; USAID, 2007).

The acadja resembles a fishing pond (see Figure 2). It is constructed by placing wooden branches in the lake and fencing them with fishing nets (USAID, 2007). The nets protect fish against predators and food is provided abundantly by algae and other micro-organisms which grow on the immersed parts of the branches. The acadja became a popular fishing instrument because of its high yield. From 1981-1996 the number of acadjas increased by more than 1500% in Benin's coastal lakes and lagoons (USAID, 2007). At present, 35% of lake Nokoué's water surface is covered by acadjas (Niyonkuru & Lalèyè, 2010). As mangrove wood is used to construct the acadja, the popularity of the fishing instrument has led to a decrease of mangrove cover with serious implications for the productivity and diversity of the coastal ecosystems (USAID, 2007). With the disappearance of mangrove cover, several fish species lose their natural habitat and the shores of the lake have become vulnerable to erosion and silting (Amoussou, 2004; Gnohossou, 2006; Pliya, 1980). The high concentration of acadja further causes an accumulation of mud and silt in the lakes, reducing oxygen levels and hindering water circulation (Amoussou, 2004; Gnohossou, 2006).

The medokpokonou is a fixed fishing installation with fine-mesh nets (see Figure 3). Contrary to the acadja, it is not closed by nets, but nets of several meters are set in such a manner that the fish get trapped. Initially designed for catching shrimp, its fine-mesh nets also trap young fish and fish eggs, thereby reducing the reproduction of the fishing stock (USAID, 2007). In addition, the medokpokonou is a direct source of conflict because, in order to make use of the water current to trap fish, the nets are usually set out close to narrow channels thereby catching basically all fish entering the lake and leaving few resources for fishermen further downstream.

The problem of inland fishery degradation is widespread in Africa, which is why the Sustainable Fisheries Livelihoods Program (SFLP) was established in 1999 with funding for seven years. SFLP was a partnership between the FAO [5], DFID [6] and 25 participating countries in West and Central Africa, including Benin. The program focused on assisting fishing communities to enhance their livelihoods and manage their natural resources by strengthening human and social capital and creating the appropriate political and institutional environment (Westlund et al., 2008).

Key recommendations of the program included: setting up partnerships between local and national governments (co-management of inland fisheries), making use of local knowledge in natural resource management, stimulating income diversification towards non-fishing activities, encouraging the use of more selective and environmentally friendly fishing methods, stimulating the development of microenterprises and offering microfinance support (FAO, 2001, 2004; Westlund et al., 2008). The program actively supported a better integration of inland fishery management into the poverty reduction strategy papers of the participating countries. Benin's

[5] The Food and Agricultural Organization of the United Nations

[6] The Department for International Development of the United Kingdom of Great Britain and Northern Ireland

2011 poverty reduction strategy paper explicitly follows this direction and aims to link the sustainable use of natural resources, including inland fisheries, to poverty reduction (OECD, 2012).

3. Natural resource management and income diversification: a brief literature review

Inland fisheries are characterized by a number of properties that challenge sustainable governance. First, fish are a mobile resource which makes it particularly difficult to control the number of resource users and the intensity of exploitation (Dietz et al., 2002; Feeny et al., 1990; Ostrom et al., 1999). Second, a lack of accurate information on the evolution of fishing stocks makes it difficult to design suitable access- and exploitation rules and to adapt them to changing circumstances (Dietz, et al., 2003). Third, the costs of preventing access and monitoring activities increase with the size of the fisheries. It may in fact be economically inefficient or unfeasible to fully monitor large inland fisheries (Ostrom et al., 1994). Finally, in many developing countries inland fisheries play an important role in the livelihoods of rural communities (Allan et al., 2005). While a strong dependence on the fishing resource may increase the perceived benefits of regulating exploitation and the likelihood of sustainable governance, strong dependence may also lead to a situation where users discount the future substantially and sustainable governance breaks down (Ostrom et al., 1999). Especially in the face of poverty and an immediate need for resources, highly dependent users may increase their resource exploitation despite the high cost in the longer term (Agrawal, 2001).

One way rural communities may relieve pressure on Common Pool Resources is by diversifying their income away from activities that depend heavily on the resource under pressure. Income diversification refers to the situation where individuals rely on multiple income sources (Barrett et al., 2001; Barrett & Reardon, 2000; Ellis, 1999). Empirical evidence shows that income diversification is specifically important in rural Africa where the average share of income from non-farm sources ranges between 30% and 50% (Ellis, 1999; Reardon, 1997).

The literature on income diversification discusses two broad sets of motives which may incentivize households and individuals to diversify their income: push factors and pull factors.

Push factors are generally negative impulses and imply actions taken to avoid potential negative outcomes. For instance, households may diversify to spread risk in order to avoid strongly negative income shocks, or they may diversify to smooth consumption once a negative shock occurred. Pull factors are positive impulses, characterizing situations in which households try to seek benefits and take advantage of opportunities. For instance, households may engage in several activities in order to realize strategic complementarities, or to bring out the best in each household member in terms of specialization according to comparative advantages (Barrett et al., 2001; Barrett & Reardon, 2000; Ellis, 1999).

In the push factor-logic, income diversification is one of the main strategies by which people in developing countries may reduce risk (Barrett et al., 2001). In the context of southern Benin, fishermen may diversify income in order to curb the risk of a future tension between needs and resources. They may also use income diversification as a way to cope with income shocks ex post, i.e. a kind of self-insurance strategy once fishers have been negatively affected (Barrett et al., 2001; Ellis, 1999). But if fishers are myopic, not sufficiently risk averse, or have access to more effective coping strategies, this mechanism may not lead to more income diversification. In that case, other push or pull factors need to come in, for example a dramatic degradation of the fishing stock that decreases the relative profitability of fishing activities tremendously, or an increased return to other non-fishery activities that makes fishermen switch sectors.

Even when switching sectors is attractive, it may not be feasible. In fact, there appear to be substantial entry barriers: the potential for non-farm income diversification is found to be positively correlated with income, education, access to credit markets, physical access to markets and being male (Barrett et al., 2001; Ellis, 1999; Feeny et al., 1990; Lanjouw et al., 2001; Smith et al., 2001). The policy challenge lies in tackling the entry barriers in order to make high-return non-farm activities more widely accessible (Barrett et al., 2001; Ellis, 1999).

The World Commission on Environment and Development coined the idea that poor people are stuck in a poverty-environment trap. In their report ‘Our Common Future’ (1987, p.27) the commission states that poor people in developing countries are left with little choice but to overexploit the available natural resources in order to survive. The subsequent natural resource degradation further impoverishes them, making them even more reliant on the available natural resources. In reality the relationship between poverty and the environment appears to be more complex.

For instance, Dasgupta (1995) conjectures that the degradation of natural resources lowers the reservation wage for activities that do not rely on the natural resource. If this assertion is correct, a degradation of the fishing stock would give rise to an increased income diversification in non-fishing activities. Barbier (2010) argues that access to factor and product markets (e.g. for labour, credit, goods and services) is crucial for Dasgupta's hypothesis to hold. This is rarely the case for poor people in developing countries. First, local labour markets are often underdeveloped and provide only limited options – especially for unskilled workers. Second, the absence of rural credit markets often prevents poor people from engaging in certain economic activities. Third, poor households living in remote locations are less likely to engage in non-farm employment as they face higher transaction and transportation costs. The livelihoods of low educated, asset-less and credit-constrained poor people living in rural communities may therefore critically depend on the available environmental resources, in line with the poverty-environment trap hypothesis and the concern raised in the 'Our Common Future'-report.

In sum: when attractive outside options are within reach and markets function well, resource degradation will induce individuals to reallocate labour away from resource dependent activities. If these conditions are not fulfilled, poor people who rely on degrading natural resources may fall into a poverty-environment trap (Barbier, 2010).

4. Data and descriptive statistics

We study the relationship between natural resource degradation and income diversification for 18 fishing communities in southern Benin. Specifically, we examine how a number of individual-, household-, and community-level covariates influence the level of income diversification. In this section we describe the data used and offer some descriptive statistics on income diversification and natural resource degradation in our sample. In the next section we lay out the empirical strategy.

4.1. Survey design

The data was obtained from a survey among 540 households, implemented in the period March-July 2009, by the authors of this paper and a team of 30 enumerators and 4 supervisors. The survey sample was randomly selected from the 2006 fishery census of Benin, and stratified geographically across 18 villages belonging to three communes located at the three main southern lakes. The location of the communes (Kpomasse, So-Ava and Aguesgues) and the three lakes (Ahémé, Nokoué and Porto Novo lagoon) is illustrated in Figure 1.

The three communes differ in a number of relevant aspects. So-Ava is located at the largest lake, lake Nokoué. Despite being closest to the main city (Cotonou) So-Ava is the most remote commune in our sample as many of its fishing villages are built on the water surface and therefore difficult to reach. Kpomasse, although located furthest from the large urban centres, can easily be reached across land and is located at Lake Ahémé, which is a relatively small lake. Aguesgues is the least remote commune, easily reachable from the capital city (Porto Novo) which is much smaller and less industrialized than Cotonou.

In order to collect accurate information on income and consumption, the households were visited every two weeks. During each of these visits, income and consumption data was recorded. In addition, a standard household module was implemented, treating different topics at each visit, e.g. social capital, credit, annual income and economic activities, shocks and coping strategies, health and education. The full survey sample includes 2,141 individuals aged 15 years or older.

4.2. Natural resource degradation

We employ two measures of natural resource degradation: i) a self-reported degradation measure; and ii) a degradation index based on physicochemical parameters of water quality.

(a) Self-reported measure of degradation

During our first visit to the fishermen, we asked their opinion on the evolution of the fishery stock: *"In your opinion how did the fishery stock evolve in the past 10 years?"*. The answer categories included (1) increased, (2) decreased, (3) unchanged, (4) don't know. The results, shown in Table 1, indicate that the large majority of our respondents (66%) report a decrease in the fishing stock over the past ten years. We observe notable differences across the three lakes: self-reported degradation was higher at lake Ahémé (93%) compared to Porto Novo lagoon (70%) and lake Nokoué (47%).

For each village, we use the share of respondents who report a decreasing fishing stock as a proxy for village-level natural resource degradation (see Table 2). We are confident that it is a reasonable proxy. First, the variation of responses across lakes makes sense as the effects of degradation are more apparent in smaller lakes, which start off with less abundant natural resources and are more prone to silting. Second, other studies in the sample area report similar numbers with respect to self-reported degradation of the fishing stock. Roche International (2000) interviewed 1,800 people living around Porto Novo lagoon, lake Ahémé and lake Nokoué. The large majority (75%) of fishermen reported that catch sizes in terms of weight had declined and nearly all of them (90%) reported that fish sizes had reduced. Similar numbers are found by Atti-Mama (1998), who interviewed 270 people living in 17 villages around lake Nokoué. Another study reports data from Benin's directorate of fisheries on the evolution of fishing productivity, measured in tons of fish caught on a yearly base, from 1990 to 2000 (Cledjo, 2006). In line with our data, the reported decrease in fishing productivity is strongest at lake Ahémé, smaller at Porto Novo lagoon and smallest at lake Nokoué. Finally, the level of self-reported degradation also varies across districts and villages, which is in line with different fishing communities having different fishing locations.

(b) Degradation index based on water quality

As a second measure for natural resource degradation, we construct a degradation index based on physicochemical parameters of water quality. To map the relationship between pollution and aquatic fauna, Gnohossou (2006) collected data from 33 measuring stations at lake Nokoué. Every measuring station recorded the following parameters: temperature, depth, salinity, transparency, pH values, oxygen levels (concentration and saturation) and the concentration of ammonium ions. To take into account seasonal variations, measurements took place both during the rainy season (September 2004 & September 2005) – when the rivers grow and fill the lakes with fresh water – and during the dry season (February 2005 & February 2006) – when the rivers dry up and seawater enters the lakes.

Gnohossou (2006) used this information to construct a bio index which assigns a score to each measuring station – ranging from 1 (very polluted water) to 5 (water of high quality) [7]. Using Gnohossou's bio index and the GPS locations of the measuring stations, we calculated a degradation index for the six villages in our sample which are located at lake Nokoué. More

[7] See Gnohossou (2006) for a detailed description of the methodology used to construct the bio index. We recoded the bio index such that a higher score relates to higher levels of degradation.

precisely, in ArcGIS, we created a 4 km. buffer around each village and calculated the average bio index score for the measuring stations that lay within it.

4.3. Income diversification

To measure income diversification, we use two standard measures: (1) the number of income sources [8], and (2) the Herfindahl index of diversification which takes into account the number of income sources and the income share derived from each source (Barrett & Reardon, 2000). Among the existing specifications of the Herfindahl index, we use the complementary proportion (1-proportion) such that a higher Herfindahl index indicates stronger income diversification:

$$H = 1 - \sum_{i=1}^{N} (S_i)^2 \qquad (1)$$

where S_i is the income share of activity i. The index ranges from zero, indicating that all income is generated by a single income source, to $1 - \left(\frac{1}{N}\right)$, indicating that all N income sources equally contribute to total income. For instance, if two income activities each contribute 50% to total revenue, the Herfindahl index takes the value 0.5. Income is more diversified if ten different income activities each provide 10% of total revenue, yielding an index of 0.9.

We construct these indices on the basis of two survey modules. First, we use information from the module on economic activities which was implemented once for all individuals aged 15 or more and consists of recall questions with respect to the year 2008 (the year preceding the survey implementation). Second, we use information from the bi-weekly module on income which includes information on activities and earnings for the two weeks prior to the interview and was implemented seven times for all individuals aged 15 or more (in the period March-July 2009).

Table 3 shows that approximately one third of the sample was not economically active during the year 2008. This percentage is significantly higher at Porto Novo lagoon compared to the other lakes. Data from the bi-weekly income module confirms this pattern of income sources

[8] As only 4% of our sample relies on a single income source which is not related to the fishing sector, this is essentially the same as looking at the number of income sources outside the fishing sector. Our results remain valid when we use the number of income sources outside the fishing sector as a measure of income diversification.

and inactivity across the lakes. Among the reasons for not working, school attendance was mentioned most often [9]. Approximately 80% of the economically active individuals relied on a single income source throughout the year 2008, about 20% had two income sources and only 3% had more than two income sources. Dependence on one income source is strongest at Porto Novo lagoon while people at lake Ahémé report the largest number of income sources (see Figure 4).

Economic activities can be classified in five income sectors: fishing, agriculture and livestock-keeping, petty trade, other self-employment in the non-farm sector (e.g. barbers, tailors, etc.) and wage employment (e.g. government officials or people employed by an NGO or a private company). The fishing sector is by far the most important sector, both in terms of employment and in terms of contribution to annual income. Table 4 shows that the large majority of the economically active sample is at least partly employed in the fishing sector. Fishing is also the most profitable activity, yielding an average annual income of 1,023,341 FCA [10]. Petty trade and self-employment in the non-farm sector are the second and third most profitable sectors with an average annual income of 801,974 and 694,561.

We find that fishing activities are relatively more important at lake Ahémé and lake Nokoué compared to Porto Novo. Petty trade and self-employment on the other hand prevail at Porto Novo lagoon. Agriculture and livestock keeping are mostly practiced at lake Ahémé, where people have more access to agricultural land. At every lake, the fishing sector accounts for about 80% of annual income. Despite the obvious degradation of the fishing stock, the fishing communities in southern Benin clearly remain extremely dependent on their fishing activities.

Table 5 confirms that income diversification is rather limited in the sample area. People on average derive their income from 1.24 sources and have a Herfindahl index of 0.05 – with the index ranging from 0 to 0.5. In a bivariate analysis we find that three factors correlate significantly with the level of income diversification. First, income diversification is more wide-spread at lake Ahémé compared to the other lakes. Second, the level of income diversification is significantly higher for individuals who report a degradation of the fishing stock compared to

[9] A T-test revealed that the economically inactive population in 2008 was on average significantly younger (21 compared to 36 years old) and had enjoyed significantly more years of schooling (4.7 compared to 1.2 years) compared to the economically active population.

[10] There is however a strong variability in fishing incomes, as can be seen from the standard deviation (see Table 4) and the kernel density plot of annual fishing income (see Figure 5).

those who did not. Third, our descriptive statistics suggest that education matters. We find that literate individuals have a higher number of income sources and a higher Herfindahl index compared to illiterate individuals. Similar results were found using the years of schooling as a proxy for educational attainment (not reported).

4.4. Self-reported reasons for entering non-fishing activities

In light of the strong dependence on the fishing sector, we are interested in the motives of individuals who diversify their income towards non-fishing activities. In this section we explore self-reported reasons for entering the non-fishing sector and assess the role of natural resource degradation.

Table 6 indicates that the large majority of individuals who abandoned their economic activity between 2002 and 2009 were fishermen. At the same time, Table 7 indicates an increased participation in non-fishing sectors. We find a strong proportional growth in non-fishing sectors, especially in petty trade, at all three lakes and especially at lake Ahémé (Panel A). Moreover, the data show a positive and highly significant correlation between the share of individuals who entered the non-fishing sector and the level of self-reported degradation (Panel B). Respondents reported taking up non-fishing activities mainly because of their higher return (26% of cases), because of the ban on shrimp exports to the EU [11] (15% of cases), because of the degradation of the fishery stock (11% of cases) or because of reasons related to their life cycle or human capital (e.g. attending school, taking care of children, doing HH chores – 27% of cases) (Panel C).

In Table 8 we look at the relationship between declining fishing revenues and the degradation of the fishing stock. The large majority of our respondents reported decreasing fishing revenues between 2002 and 2009 (Panel A). Moreover, we find that respondents living in villages with a higher level of degradation report a stronger decline in fishing revenues (Panel B) and a lower level of fishing revenues in 2009 (Panel C). Finally, the majority of our respondents attribute the decrease in fishing revenues to a degradation of the fishing stock (panel D).

In sum, our descriptive evidence is in line with the assertion of Barbier's model. The dramatic degradation of the fishing stock is reported as the main reason for the decreasing

[11] In 2003 a ban on shrimp exports to the EU was imposed due to a lack of compliance with the newest food standards (see Houssa & Verpoorten, mimeo).

fishing revenues, which in its turn is reported as the main reason for switching to the non-fishing sector; i.e. the degradation of the fishing stock seems to lower the reservation wage for activities in the non-fishing sector and stimulate income diversification. Moreover, the share of people who are entering the non-fishing sector is higher in areas where the degradation stronger. In the following section, we try to empirically identify the impact of natural resource degradation on income diversification.

5. Empirical strategy

5.1. Baseline econometric framework

Formally, the empirical model can be written as follows:

$$ID_{ihv} = \alpha_0 + \alpha_1\, degradation_v + X'_{ihv}\,\Omega + W'_{hv}\Delta + \alpha_2\, pop_v + \alpha_3\, Nokoué_v + \alpha_4\, Porto\ Novo_v + \varepsilon_{ihv} \quad (2)$$

where i indexes individuals, h households and v villages. ID_{ihv} denotes income diversification at the individual level; α_0 is a constant; $degradation_v$ denotes natural resource degradation at the village-level; X_{ihv} and W_{hv} are vectors containing individual and household level covariates; pop_v denotes the log of total village population; $Nokoué_v$ and $Porto\ Novo_v$ represent lake dummies with lake Ahémé as the base category, and ε_{ihv} is the standardized error term [12].

The measures of income diversification serve as our dependent variables. Depending on the measure, we face the choice between different estimation methods. The determinants of the number of income sources can be estimated by a Poisson model for count data or, if we consider a natural upper bound to the number of sources from which a person can derive income, an ordered probit model. We use the latter approach in the baseline results and report the former as a robustness check. The determinants of the Herfindahl index can be estimated using OLS or, given the limited range of the index, by a tobit model. Again, we use the latter approach in our baseline results and report the former as a robustness check.

As we are specifically interested in the relationship between income diversification and resource degradation, α_1 is the main coefficient of interest. Our hypothesis follows the conjectures of DasGupta (1995) and Barbier (2010). **Hypothesis:** *A degradation of the fishing*

[12] As we attempt to measure the effect of several household level variables on individual income diversification, we allow for within-household dependence in estimating the standard errors of treatment effects by estimating cluster-robust standard errors through the use of the Huber-White variance estimator (see Moulton 1990 for a defense of the use of corrected standard errors).

stock decreases the labour productivity of fishing and hence lowers the reservation wage for outside activities – inducing fishers to reallocate labour away from the fishing sector. $\alpha_1 > 0$.

(a) Individual level controls

In our empirical specification we control for a number of individual level covariates which may be related to the level of income diversification. *Gender* is an important determinant in the choice of economic activities – either because of social norms or because of comparative advantage, e.g. related to physical strength. Several studies have demonstrated that the gender division of labour may affect income diversification, with men in rural Africa being more likely than women to diversify their income (Barrett et al., 2001; Ellis, 1999; Lanjouw et al., 2001; Smith et al., 2001). In Benin's coastal fisheries, fishing is reserved for men (with the exception of setting traps for crabs and looking for oysters) while women function as small or intermediate traders and take up the reproductive roles.

Age may also play a role in the choice of economic activities. Using the medokpokonou for instance, requires physical strength which reduces with age. Age is also related to social capital as it takes time to develop a social network which may enhance a person's opportunities for outside employment. Older men, on the other hand, may have been able to acquire acadjas on a first come first serve basis, leaving younger men empty-handed until they inherit an acadja. *Education* may increase productivity both in fishing and non-fishing activities, and can improve access to non-fishing activities. We measure educational attainment by the number of years an individual attended school – to account for decreasing returns to schooling we use the natural logarithm. Finally, we control for *ethnicity* as some societies are traditionally more involved in fishing activities than others due to their different times and patterns of settlement around and on the lakes (Pliya, 1980). We include dummy variables for the three most prevalent ethnicities (i.e. Goun, Houedah and Tofin) which jointly account for 91% of the sample. The remaining eleven smaller ethnicities form the base category.

(b) Household level controls

Although budgets are separately managed by husband and wife (wives), the size and structure of a family may still influence the activity portfolio of its members. We therefore include the *size* and the *dependency ratio* of the household as possible determinants of income diversification.

The dependency ratio is calculated as the ratio of the number of inactive individuals to the number of active individuals in the household [13]. We also include a dummy variable which indicates if the household owns damaging fishing gear (i.e. acadja or medokpokonou) because these instruments determine to a large extent the productivity of the fishing activity.

(c) Community level controls

Finally, community level covariates may be important as well. The *population size of a village* may influence the opportunities of engaging in outside employment and affect the potential gains from both fishing and non-fishing activities through the availability of markets. Additionally, larger villages may be more likely to suffer from degradation of natural resources due to overfishing and pollution. *Lake dummies* are included to control for the location of the villages.

5.2. Addressing endogeneity

(a) Potential sources of endogeneity

Our measures for natural resource degradation may suffer from endogeneity. The self-reported degradation measure is subjective and may thus depend on individual characteristics which could also be related to income diversification. For instance, as full-time fishers are better informed about the evolution of the fishing stock they may report higher levels of degradation leading to a negative relationship between income diversification and natural resource degradation. On the other hand, individuals who do not fish may base their assessment on information received from others – this may be 'worst news' information, leading to a positive relationship between income diversification and natural resource degradation. Besides these potential biases, self-reported degradation may also be contaminated with measurement errors or 'noise' which could attenuate our results.

The degradation-index is an objective measure but may also suffer from endogeneity issues. An omitted variable bias may arise if the use of high-yielding fishing gear correlates both with income diversification and degradation. For instance, the use of acadja and medokpokonou accelerates degradation but also provides its users with a high income which may allow them to invest in activities outside the fishery sector. Alternatively, non-fishery activities may generate

[13] We also tried a different specification of this variable, using age categories, which did not substantially change the results.

the income needed to invest in high-yielding damaging fishing gear. Both of these scenarios (let's call them scenario 2 and 3) would yield a positive relationship between natural resource degradation and income diversification, although through a different channel than the one outlined by Barbier's model (scenario 1). Figure 5 gives an overview of the possible scenarios: scenario 1 is represented by steps A, B, C and D; scenario 2 is represented by steps E and F while steps F, G and H represent scenario 3.

We deal with these endogeneity issues in two ways. First, we assess the likelihood of an omitted variable bias. Second, we use an Instrumental Variables (IV) approach in order to control for any remaining endogeneity.

(b) Omitted variable bias

We estimate two model specifications – one in which we include ownership of acadja or medokpokonou and one in which we don't – and compare the outcomes. If our estimation method suffers from omitted variable bias (as described in scenario 2 and 3), we expect to see that individuals who have access to the revenues of acadja or medokpokonou are more likely to diversify their income. Moreover, we would expect the coefficient on natural resource degradation to differ between both specifications. A largely unchanged coefficient, on the other hand, would indicate that our results do not suffer from omitted variable bias.

(c) Instrumental Variables approach

We use an IV approach relying on the distance between each village and the sea channel as an instrument for our degradation measures. The instrument is relevant as it is highly correlated with degradation. Several factors underlie this correlation: First, the further from the sea channel, the more shallow the lake is – which makes it more prone to silting, low oxygen levels, poor water circulation and higher levels of salinity (Gnohossou, 2006). Second, acadja can only be placed in areas where the lake is shallow (see Figure 7), adding to the positive correlation between the distance to the channel and degradation. Finally, large fishing nets such as medokpokonou are usually placed close to the channel, thereby leaving few resources for fishermen further downstream – which again creates a positive relationship between distance to the channel and the level of degradation.

Distance to the sea channel is a valid instrument if it only affects income diversification through its effect on degradation. If it affects income diversification in another way, the exclusion restriction is violated. To safeguard the exclusion restriction, we add lake fixed effects and control for the ownership of acadja and medokpokonou, as they may also affect income diversification through income effects apart from their effect on degradation.

Lake Nokoué and Porto Novo lagoon form one large water basin which is connected to the ocean by Cotonou channel. Lake Ahémé connects to the ocean through Ahô channel. To take into account the heterogeneous effect of the distance measures across lakes, we also include the interaction term between $Ahémé_v$ and the distance measure as an instrument [14].

In a first step we estimate village-level degradation by regressing it on the set of included instruments and the set of excluded instruments, denoted by Z_v. In a second step we estimate individual-level income diversification by regressing ID_{ihv} on $\widehat{degradation}_v$, estimated in the first step, and the other explanatory variables. The IV procedure is given by the following equations:

$$degradation_v = \beta_0 + \beta_1 Z_v + X_{ihv}{'}\Omega' + W_{hv}{'}\Delta' + \beta_2\, pop_v + \beta_3\, Ahémé_v + \mu_{ihv} \quad (3)$$

$$ID_{ihv} = \alpha'_0 + \alpha'_1\, \widehat{degradation}_v + X_{ihv}{'}\Omega'' + W_{hv}{'}\Delta'' + \alpha'_2\, pop_v + \alpha'_3\, Ahémé_v + \varepsilon_{ihv} \quad (4)$$

$$\text{with } \widehat{degradation}_v = \hat{\beta}_0 + \hat{\beta}_1 Z_v + X_{ihv}{'}\hat{\Omega}' + W_{hv}{'}\hat{\Delta}' + \hat{\beta}_2\, pop_v + \hat{\beta}_3\, Ahémé_v + \mu_{ihv} \quad (5)$$

The first stage findings, reported in Table 9, indicate that the instruments are relevant. The coefficient of the interaction term is significant, indicating that the distance to the channel has a different effect on self-reported degradation at lake Ahémé compared to the other lakes. The logarithm of distance to the channel ($log\ channel_v$) is positively and significantly related to both self-reported degradation and the degradation index. As we control for the ownership of acadja and medokpokonou, this indicates that our instrument influences degradation beyond its effect on the use of damaging fishing gear. Self-reported degradation is higher at lake Ahémé compared to the other lakes.

[14] When instrumenting for the degradation index, which was calculated for the six villages located at lake Nokoué, we only use the distance measure as an instrument.

6. Results

6.1 Baseline results

Tables 10 to 15 show the estimation results of equations (2) and (4), using the measures of income diversification as dependent variables. For each measure we estimated two models, using either self-reported degradation or the degradation index as the main variable of interest.

Our results are consistent with the conjecture of Dasgupta (1995) and Barbier (2010): the degradation of the fishing stock correlates positively and significantly with income diversification. This result is robust across both measures of income diversification and both measures of natural resource degradation. The coefficient related to natural resource degradation does not change substantially when we control for the ownership of damaging fishing instruments, reducing concerns about possible omitted variable bias. Moreover, ownership of acadja or medokpokonou is negatively related to the level of income diversification (see Tables 10 to 14), providing further evidence against scenarios 2 and 3. The data reported in Table 11 indicate that a 10% increase in the average of village-level self-reported degradation decreases a villager's likelihood of having one income source by 17 percentage points while it increases his likelihood of having 2 income sources with 13 percentage points. We obtain similar results when using the degradation index instead of the self-reported degradation measure (see Table 13).

Tables 10, 12, 14 and 15 show the second stage results of the IV procedure. The positive and significant effect of natural resource degradation on income diversification remains. In fact, the coefficient on the degradation variable becomes substantially larger after instrumentation suggesting that the IV procedure takes care of attenuation bias stemming from noise in our measures for natural resource degradation.

In the literature review of section 3 we mentioned a number of factors which may influence the accessibility of attractive outside options and confound or enhance the relation between degradation and income diversification. First, our results confirm that education is important. The number of income sources is positively and significantly influenced by the number of years an individual attended school, suggesting that there are educational constraints to entering certain types of outside activities (see Tables 10, 11 and 13). Alternatively, it could be argued that education leads to an increased awareness of the impact that overexploitation has on the fishery stock and an increased awareness of the need for sustainable fishing management (Feeny et al., 1996).

Second, Tables 12 and 13 indicate that women are less likely than men to have more than one income source. Women also seem to have a lower Herfindahl index (see Table 15).

Third, in all model specifications age is positively and significantly related to the level of income diversification. This could be explained by the loss of physical strength as one gets older, which makes it more difficult to operate some of the high yielding fishing techniques such as the medokpokonou. People also tend to expand their social network as they grow older which might enhance opportunities for outside employment.

Fourth, the structure of a household does not have a strong influence on individual income diversification. Although, in some model specifications, household size is associated negatively with individual-level number of income sources and the Herfindahl index – while the opposite is true for the dependency ratio (see Tables 10 and 11). A certain degree of income pooling or risk sharing at the household level could explain why individuals living in larger households are less likely to diversify their income. In contrast, in households with a high dependency ratio, the economically active household members may be required to take up several income sources in order to provide for their family.

Finally, with respect to ethnicity we notice that people belonging to the three main ethnicities of the area – Goun, Houedah and Tofin – have lower levels of income diversification compared to the base category of smaller ethnicities. Due to their different times and patterns of settlement around and on the lakes, people from the three main ethnic groups are traditionally strongly involved in fishing activities.

6.2 Robustness checks

We perform a number of robustness checks in order to assess the validity of our results. The results can be consulted in the appendix. First, we check if our results still hold when using different estimation methods. We find that the estimation outcomes using a Poisson model for the number of income sources and an OLS model for the Herfindahl index are largely in line with the baseline results reported in Tables 10 to 15.

Second, as our results only are based on those individuals who engage in at least one economic activity, we use a Heckman selection model to evaluate whether our specification suffers from selection bias stemming from selection into being economically active. The *atanrho* variable is statistically insignificant in both Heckman selection models, indicating that there is no significant correlation between the error terms of the selection and outcome equations; i.e. our baseline results are not influenced by selection bias.

Third, we use a different definition of educational attainment. The number of years of schooling may not be the best indicator of human capital, as – descriptive statistics showed that a substantial fraction of individuals who attended school for several years still report to be illiterate. As a robustness check we therefore used literacy as a proxy for educational attainment. Our baseline results were again confirmed: we find that literate people are significantly more likely to have several income sources and have a significantly higher Herfindahl index compared to illiterate people (results not reported).

As a final robustness check, we use information from the 2006 Benin fishery census to expand our analysis to all 109 villages and 11,421 individuals located in the five communes [15] which border lake Nokoué. The census includes rather crude information on income diversification, but has the advantage of a large coverage. As a dependent variable, we construct dummy that takes the value of zero if an individual is a full-time fisher, while it takes the value of 1 if this is not the case. We used Gnohossou's (2006) bio-index to create a commune-level degradation index in ArcGIS. Specifically, we identified the 10 closest measuring stations with respect to the border between the lake and each commune, and assigned their average bio-index score to the commune. We estimate an IV probit model, using distance to the channel as an instrument for the degradation index. The first and second stage estimation results again confirm our baseline findings.

7. Discussion and conclusion

Fishing still is by far the most important income source for the fishing communities in southern Benin, although severe resource degradation has led to a marked decline of the fishery stock. In order to curb this declining trend, fishing communities need to alleviate the pressure on the

[15] Abomey-Calavi, So-Ava, Cotonou, Aguegues and Sèmè-Podji

lakes' resources. One way to do so is to diversify income and develop activities outside the fishing sector.

As shown by Barbier, such a move becomes more attractive as degradation becomes more severe, lowering the fishermen's reservation wage for outside employment. In this paper, we have examined this hypothesis by studying the nexus between degradation and income diversification for individuals belonging to 18 different fishing villages in southern Benin.

We find that the level of income diversification is higher in areas where natural resource degradation is more severe, a result that remains throughout a number of robustness checks and when controlling for a large number of individual-, household- and village-level covariates. The result also remains when (i) using a bio-index to measure degradation rather than self-reported degradation, (ii) when instrumenting degradation using distance to the sea channel, and (iii) when using a larger sample of households from the 2006 census.

Despite the positive link between degradation and diversification, the fishing communities in southern Benin remain extremely dependent on the fishing stock, with fishing activities accounting for 80% of annual income, on average. It is unlikely that this low level of income diversification is sufficient to relieve the stress on the lakes. Therefore, without attractive outside options, there may be a real danger that these fishing communities fall into a poverty-environmental trap.

In terms of policy implications, our result suggests that policymakers should try to stimulate the creation of economic activities outside the fishing sector e.g. by offering microfinance support for the development of microenterprises. In fact, policymakers in Benin have already initiated such a program but without much success, suggesting that there may be bottlenecks in the form of important complementary factors that are not well developed, such as transportation networks and education levels. Our analysis confirms the importance of education for diversification, showing that higher educational attainment leads to higher levels of income diversification. At the same time, however, schooling levels in our sample are on average very low, with 70% of our respondents being illiterate, probably keeping their potential earnings outside the fishery sector relatively low. The Sustainable Fisheries Livelihood Program also stressed that education and literacy are crucial for fisheries management, environmental conservation and livelihoods diversification. The program recommends a focus on 'functional' schooling (instead of formal schooling) with an applied orientation (FAO, 2001). For example, formations may help fishermen to understand and access microfinance, digital technologies such as satellite navigation, mobile phones and the internet, and the ecotourism market

The promotion of ecotourism could be an interesting option for the coastal lakes and lagoons of Benin. This kind of tourism provides incentives to limit pollution and mangrove destruction while creating outside employment opportunities at the same time. Ecotourism would also allow fishing communities to preserve their culture and to keep living according to their traditional lifestyle. Tourism in general is not a well-developed sector in Benin, although there is one village on lake Nokoué that succeeds in attracting tourists. Ganvié is a relatively large pile village which mainly consists of wooden stilt houses; in 1996 Ganvié was added to the UNESCO World Heritage tentative list. It could be interesting to investigate the nature of the tourism at Ganvié and to explore the possibilities for expansion to other fishing communities in southern Benin.

Another reason why income diversification may be low, is because fishermen who face degradation intensify their fishing effort in an attempt to keep their fishing income, and thus reservation wage stable. The intensification of the fishing activity mainly implies the use of very powerful, but damaging, fishing gear, i.e. the acadja and the medokpokonou. This suggests that any policy to stimulate diversification should be combined with a policy that regulates the use of these damaging gears. Currently, a variety of institutions attempt to regulate the fishing activities, but without much success (see Briones et al., mimeo).

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Figure 1: Location of the sampling area and the three main lakes of southern Benin

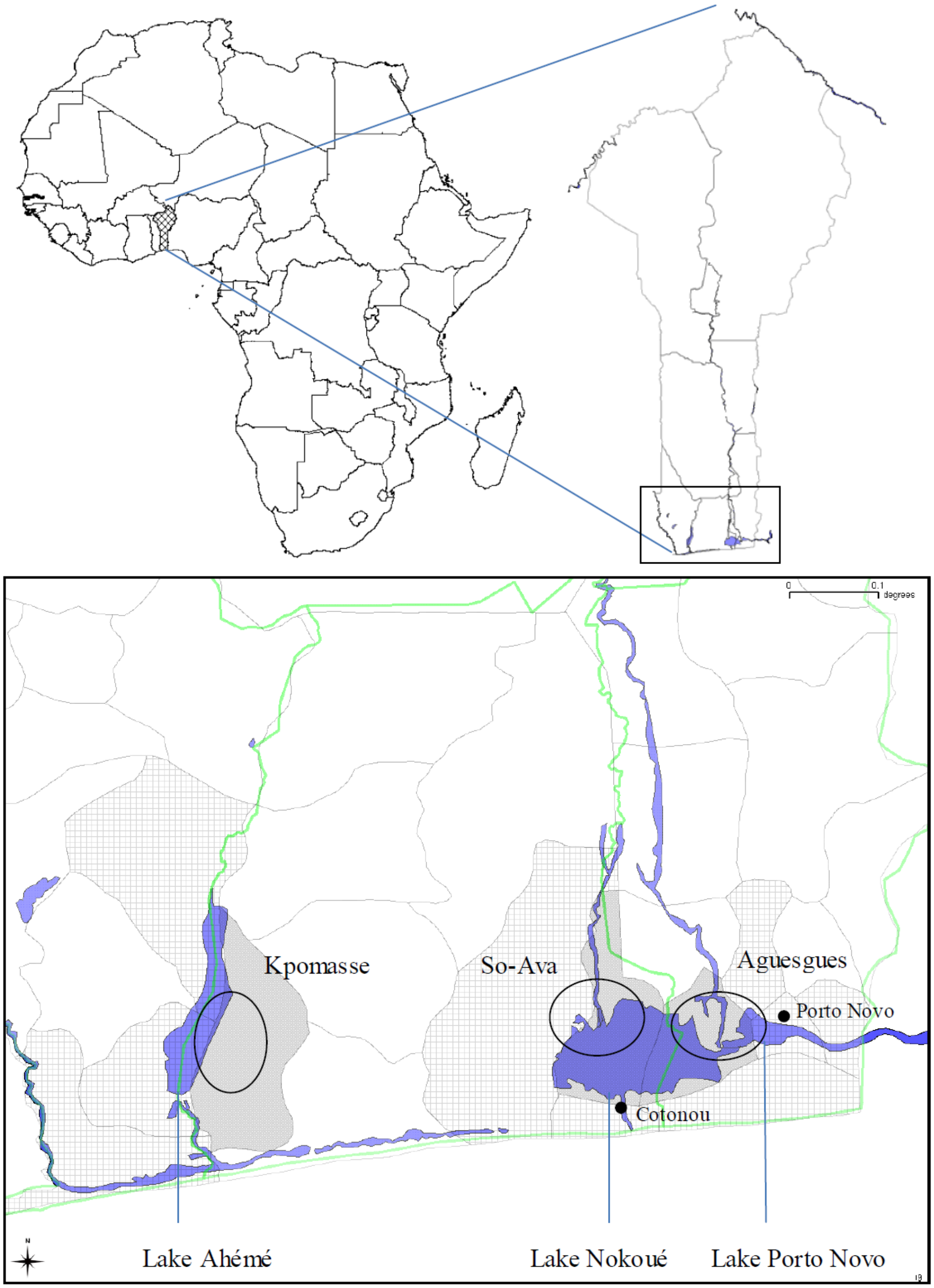

Figure 2: Acadja

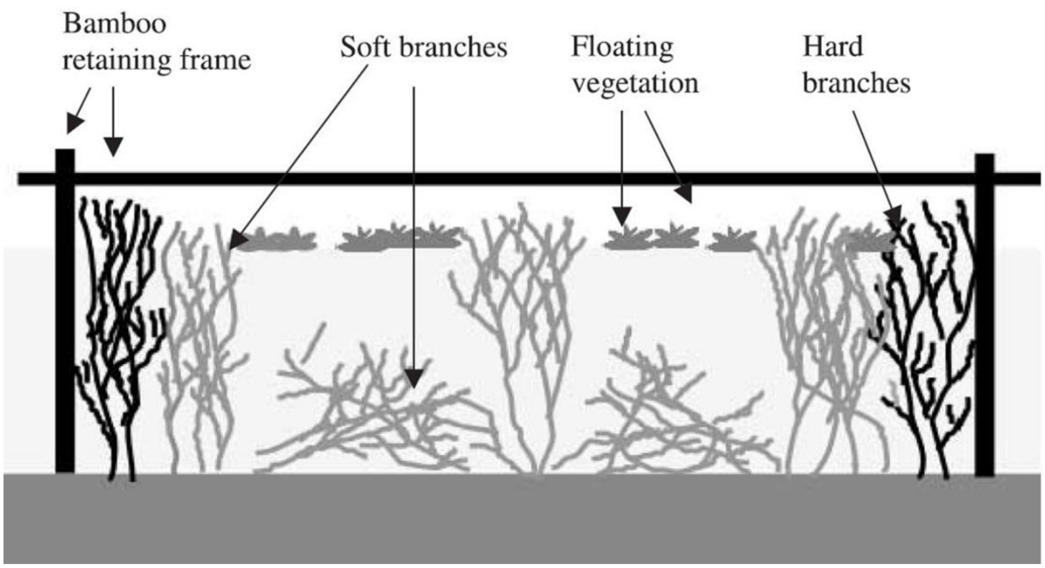

Figure 3: Medokpokonou

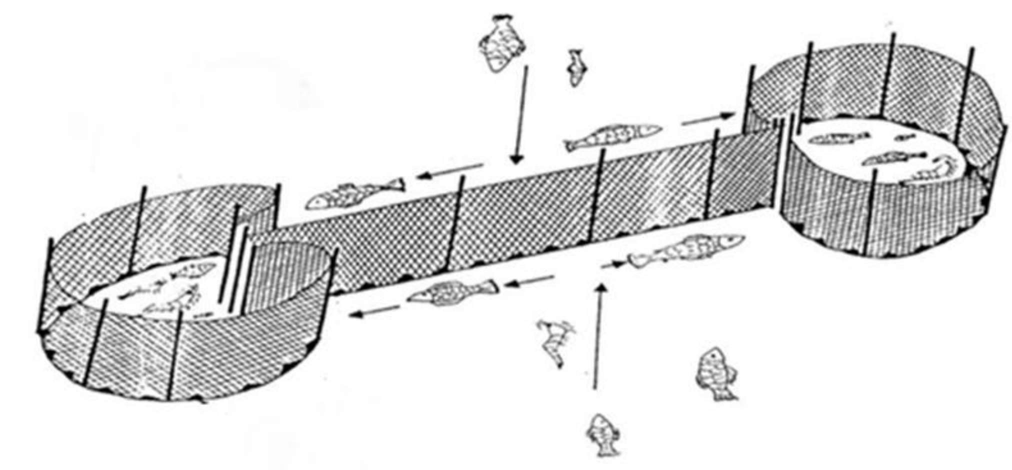

Figure 4: Number of income sources in 2008, by lake

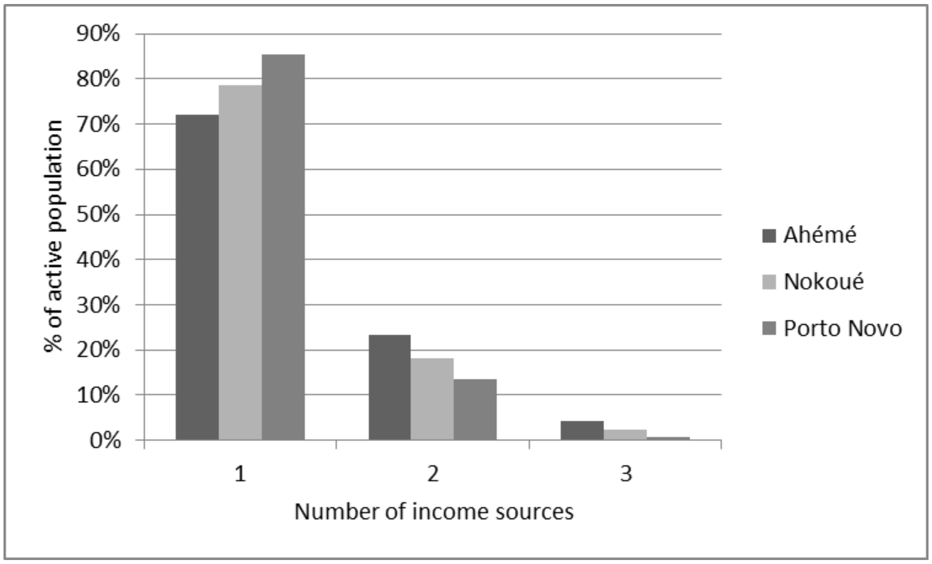

Figure 5: Kernel density of annual fishing income

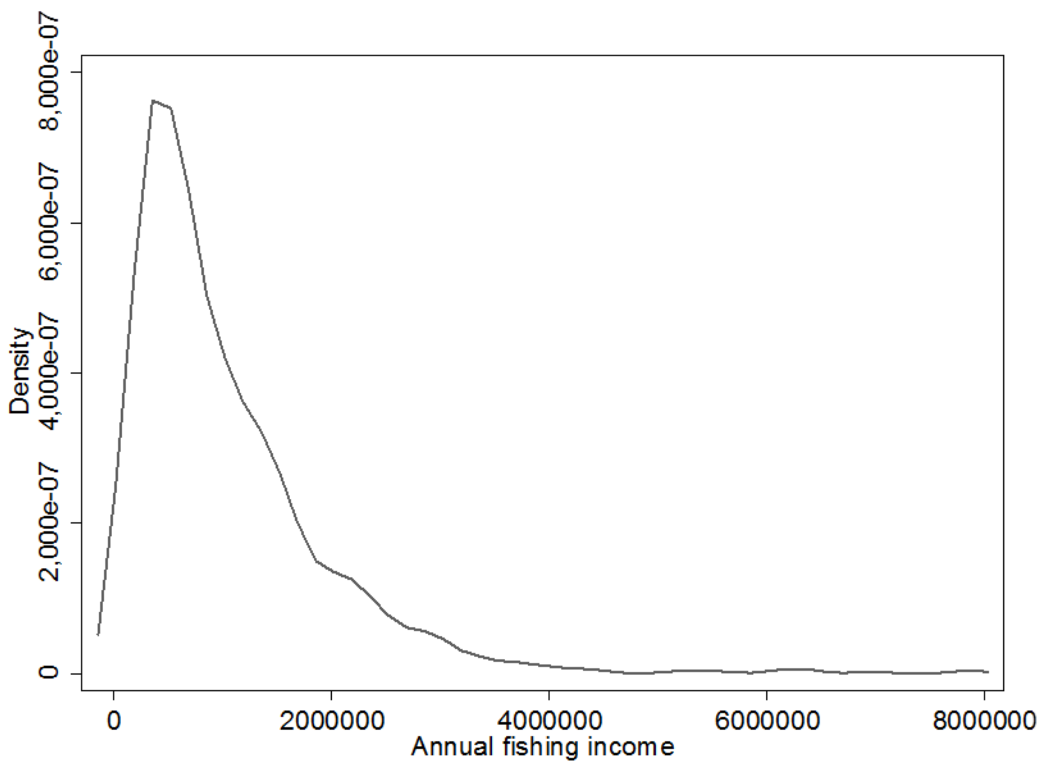

Figure 6: Potential sources of endogeneity

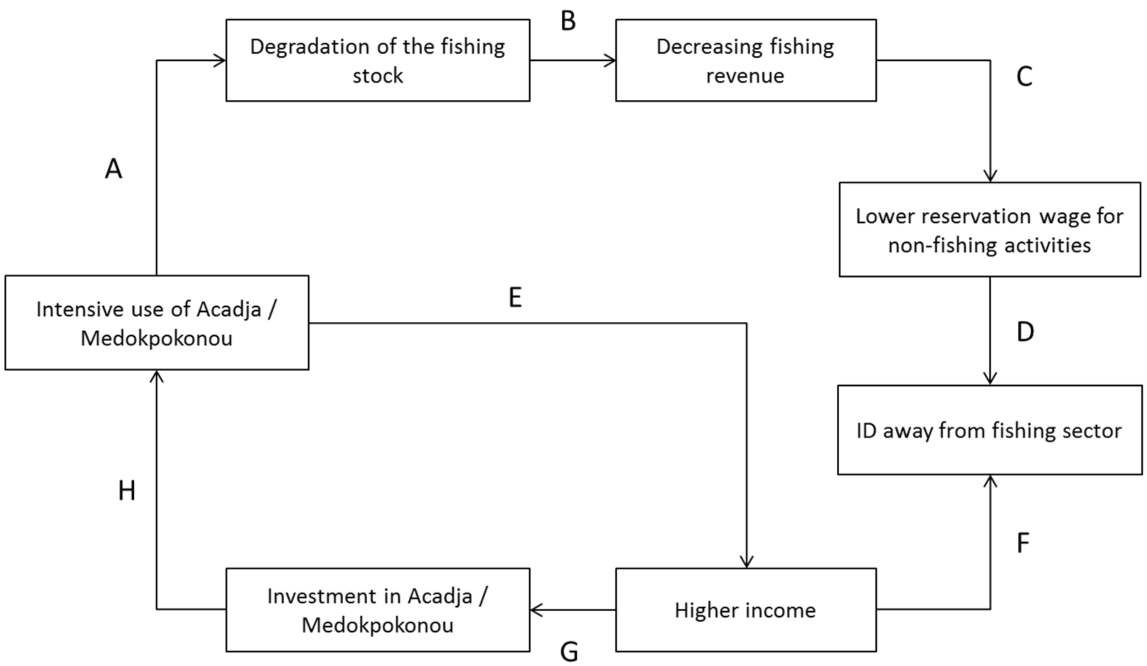

Figure 7: Acadja coverage of lake Nokoué in 2003 (source: Cledjo, 2006)

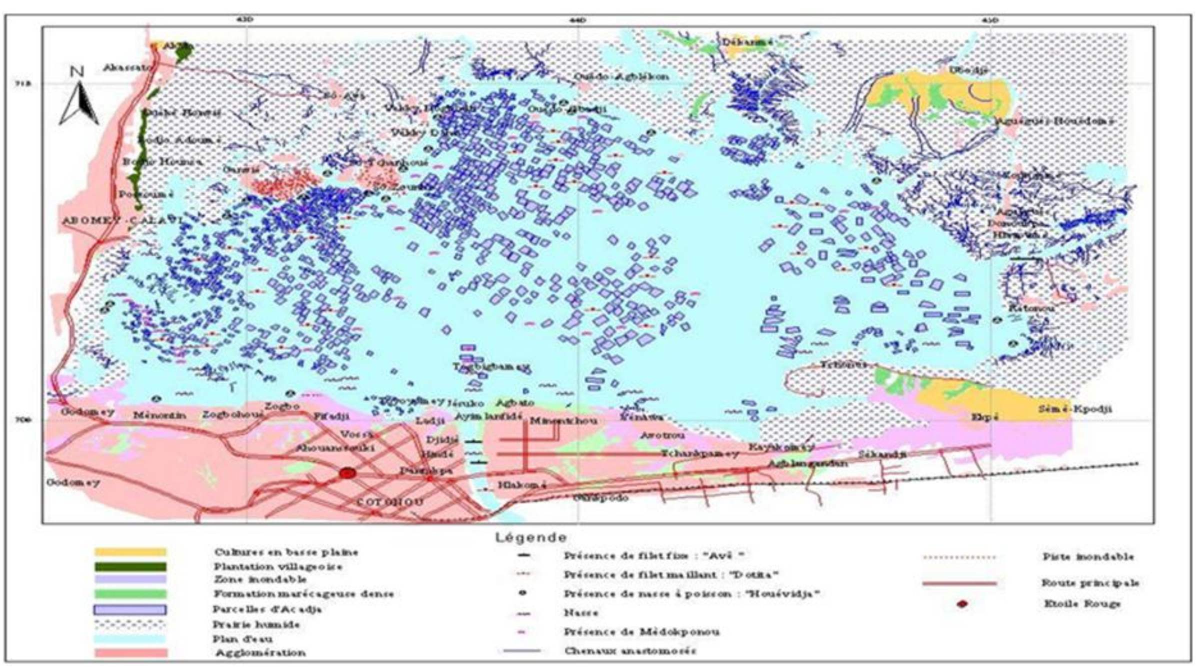

Table 1: "In your opinion, how did the fishing stock evolve in the past 10 years?"

	Total		By lake (%)		
	frequency	%	Ahémé	Nokoué	Porto Novo
Increased	105	5	0.4	3	9
Decreased	1,409	66	93	47	70
Unchanged	434	20	2	35	14
Don't know	193	9	5	14	7

Table 2: % of ind. indicating a decline of the fish stock by village and lake

Lake Ahémé		**Lake Nokoué**		**Lagune de Porto Novo**	
Adja Tokpa I	82	Agoundankomey	68	Aholoukome	37
Segbohoue I	100	Sokomey	42	Akpoloukome	73
Segbohoue II	97	Tohokomey	19	Dogodo	98
Gbetozo	91	Gbetigao	44	Djigbekome	32
Lokogbo I	100	Todo	60	Houndekome	95
Tokpa-Dome II	95	Vekky Daho	29	Kindji	91
total lake	**93**	total lake	**47**	total lake	**70**

Table 3: Number of income sources in 2008

	Total		By lake (%)		
nr.	freq.	%	Ahémé	Nokoué	Porto Novo
0	635	30	21	23	41
1	1,176	55	57	61	50
2	269	13	18	14	8
3	35	2	3	2	1
4	6	0.3	0.2	0.6	0.1

Table 4: Income sectors in the sample area

Panel A: *Employment and mean annual income (CFA)*

	nr. of ind.	mean annual income	st.dev.
Fishing	1,287	1,023,341	904,376
Petty trade	123	801,974	935,063
Agriculture & livestock keeping	109	261,416	281,017
Other self employment in non-farm sector	152	694,561	664,541
Wage employment	4	369,850	347,824

Panel B: *Average share of total annual income (%)*

	Ahémé	Nokoué	Porto Novo
Fishing	84.7	82.3	77.9
Petty trade	4.5	5.1	10.4
Agriculture & livestock keeping	8.1	0.7	1.5
Other self employment in non-farm sector	2.5	8.9	10.0
Wage employment	0.2	0.0	0.3

Table 5: Mean income diversification

Anova-test by:		nr. of income soucres	Herfindahl index
Lake			
	Ahémé	1.33	0.09
	Nokoué	1.26 ***	0.03 ***
	Porto Novo	1.16 ***	0.04 ***
Degradation			
	No degradation	1.17	0.03
	Degradation	1.29 ***	0.07 ***
Literacy			
	Illiterate	1.23	0.05
	Literate	1.35 ***	0.08 ***
Total		1.24	0.05

*** p<0.01, ** p<0.05, * p<0.1

Table 6: "Which activities did you abandon between 2002 - 2009?"

	Ahémé	Nokoué	Porto Novo
Fishing	92%	73%	52%
Agriculture & livestock keeping	0%	0%	10%
Petty trade	2%	20%	27%
Wage-employment	0%	2%	2%
Other self-employment outside fishing sector	6%	5%	8%

Table 7: Resource degradation and the growth of the non-fishing sector

Panel A *: Share of individuals who entered the non-fishing sector between 2002-2009*

	Ahémé	Nokoué	Porto Novo
Petty trade	56%	42%	29%
Agriculture & livestock keeping	8%	0%	32%
Other self-employment outside fishing sector	33%	19%	24%
Wage-employment	100%	0%	0%

Panel B: *correlation between self-reported degradation and the share of individuals who entered the non-fishing sector between 2002 - 2009*

Petty trade	21%	***
Agriculture & livestock keeping	39%	***
Other self-employment outside fishing sector	28%	***
Wage-employment	39%	***

Panel C: *Reasons given for entering the non-fishing sector*

	Ahémé	Nokoué	Porto Novo
These activities are more profitable	33%	39%	5%
Life cycle, human capital	27%	10%	43%
Ban on shrimp exports to EU	13%	13%	19%
High entry costs	7%	19%	11%
Degradation of the fish stock	13%	10%	11%
No particular reason	7%	10%	11%

*** p<0.01, ** p<0.05, * p<0.1

Table 8: Resource degradation and declining fishing revenue

***Panel A**: % of individuals indicating a declining fishing revenue between 2002-2009*

	Ahémé	Nokoué	Porto Novo
Fishing	80%	42%	77%
Commerce & services in fish sector	75%	54%	80%

***Panel B:** Correlation between self-reported degradation and the % of ind. indicating a declining fishing revenue between 2002-2009*

Fishing	36%	***
Commerce & services in fish sector	28%	***

***Panel C**: Correlation between self-reported degradation and daily fishing revenue in 2009*

Ahémé	-0.26	***
Nokoué	-0.11	**
Porto Novo	-0.13	***

***Panel D:** Self-reported reasons for the decreasing fishing revenue between 2002-2009*

	Ahémé	Nokoué	Porto Novo
Degradation of the fish stock	68%	42%	28%
Ban on shrimp exports to EU	27%	18%	32%
Life cycle, human capital	1%	11%	4%
High entry costs	2%	19%	25%
Other activities are more profitable	0%	8%	9%
No particular reason	1%	2%	1%

*** p<0.01, ** p<0.05, * p<0.1

Table 9: Instrumental Variables, first stage

Dependent variable:	self-reported degradation	degradation index
Instruments:	log distance to channel (km)	log distance to channel (km)
	log distance to channel (km)*Ahémé	
	(1)	(2)
log distance to channel (km)	0.595***	8.145***
	(0.082)	(0.423)
log distance to channel (km) * Ahémé	-0.557***	
	(0.093)	
Ahémé	5.701***	
	(0.870)	
log age	-0.029**	0.034
	(0.013)	(0.046)
female	0.009	0.108**
	(0.011)	(0.045)
log schooling	0.010	0.001
	(0.008)	(0.034)
log village population	0.109***	-0.599***
	(0.012)	(0.029)
Goun	0.075***	
	(0.024)	
Houedah	0.021	
	(0.025)	
Tofin	0.109***	
	(0.030)	
household size	-0.016***	-0.020**
	(0.002)	(0.009)
dependency ratio	0.051***	0.007
	(0.009)	(0.042)
ownership acadja / konou	0.013	0.346***
	(0.017)	(0.048)
Constant	yes	yes
Observations	1,314	413

Notes: *** p<0.01, ** p<0.05, * p<0.1; Robust standard errors in parentheses. The second column only includes the six villages at lake Nokoué for which we have calculated the degradation index; as 99% of respondents living at lake Nokoué is Tofin, ethnicity dummies are excluded in column 2.

Table 10: Determinants of the number of income sources

Degradation measure:	Self-reported degradation		
Estimation method:	ordered probit	ordered probit	IV ordered probit (2nd stage)
	(1)	(2)	(3)
log age	0.628***	0.651***	0.654***
	(0.102)	(0.106)	(0.113)
female	-0.128	-0.088	-0.085
	(0.078)	(0.079)	(0.080)
log schooling	0.171***	0.179***	0.127**
	(0.062)	(0.063)	(0.058)
degradation	0.699***	0.665***	2.406**
	(0.241)	(0.250)	(0.939)
Ahémé			-0.484
			(0.478)
Nokoué	0.437	0.505	
	(0.308)	(0.329)	
Porto Novo	-0.542**	-0.452*	
	(0.224)	(0.268)	
log village population	-0.533***	-0.547***	-0.750***
	(0.105)	(0.118)	(0.111)
Goun	-0.191	-0.174	-0.372**
	(0.180)	(0.183)	(0.181)
Houedah	-0.638***	-0.636***	-0.548***
	(0.186)	(0.187)	(0.158)
Tofin	-0.521**	-0.485**	0.266
	(0.243)	(0.244)	(0.172)
household size	-0.047*	-0.044*	-0.003
	(0.025)	(0.026)	(0.027)
dependency ratio	0.242***	0.243***	0.1
	(0.063)	(0.064)	(0.096)
ownership acadja / konou		-0.136	-0.253**
		(0.160)	(0.116)
Constant	yes	yes	yes
Observations	1,293	1,221	1,221

Notes: *** p<0.01, ** p<0.05, * p<0.1; the robust standard errors are adjusted for clustering by household and are reported in parentheses. The IV estimations use 'log distance to channel (km)' and 'log distance to channel (km) * Ahémé' as instruments for self-reported degradation; the first stage results are reported in Table 9.

Table 11: Determinants of the nr. of income sources, marginal effects

Degradation measure:	Self-reported degradation			
Number of income soures:	(1)	(2)	(3)	(4)
log age	-0.167***	0.129***	0.029***	0.007***
	(0.019)	(0.015)	(0.006)	(0.002)
female	0.022	-0.017	-0.004	-0.001
	(0.015)	(0.012)	(0.002)	(0.001)
log schooling	-0.046***	0.035***	0.008***	0.002**
	(0.013)	(0.010)	(0.003)	(0.001)
degradation	-0.171***	0.132***	0.030***	0.007**
	(0.050)	(0.039)	(0.010)	(0.003)
Nokoué	-0.138*	0.102*	0.027	0.007
	(0.080)	(0.054)	(0.019)	(0.006)
Porto Novo	0.115***	-0.090**	-0.019***	-0.004***
	(0.044)	(0.037)	(0.007)	(0.002)
log village population	0.140***	-0.108***	-0.025***	-0.006***
	(0.023)	(0.017)	(0.006)	(0.002)
Goun	0.044	-0.034	-0.007	-0.002
	(0.033)	(0.027)	(0.005)	(0.001)
Houedah	0.141***	-0.108***	-0.025***	-0.006***
	(0.025)	(0.022)	(0.004)	(0.002)
Tofin	0.116***	-0.089***	-0.020***	-0.005***
	(0.037)	(0.031)	(0.006)	(0.002)
household size	0.011**	-0.009**	-0.002**	-0.000*
	(0.005)	(0.004)	(0.001)	0.000
dependency ratio	-0.062***	0.048***	0.011***	0.003***
	(0.013)	(0.010)	(0.003)	(0.001)
ownership acadja / konou	0.035	-0.027	-0.006	-0.002
	(0.032)	(0.024)	(0.006)	(0.001)
Observations	1,221	1,221	1,221	1,221

Notes: *** p<0.01, ** p<0.05, * p<0.1; Columns represent the nr. of income sources; marginal effects were calculated from the model represented in column 2 of table 10.

Table 12: Determinants of the number of income sources

Degradation measure:	Degradation index		
Estimation method	ordered probit	ordered probit	IV ordered probit (2nd stage)
	(1)	(2)	(3)
log age	0.597***	0.666***	0.504***
	(0.176)	(0.180)	(0.193)
female	-0.381**	-0.301*	-0.365**
	(0.151)	(0.155)	(0.152)
log schooling	0.104	0.13	0.097
	(0.106)	(0.106)	(0.112)
degradation	0.358***	0.302**	0.929***
	(0.102)	(0.138)	(0.230)
log village population	-0.106	-0.119	0.271*
	(0.119)	(0.134)	(0.157)
household size	-0.003	0.003	0.037
	(0.043)	(0.044)	(0.033)
dependency ratio	-0.035	-0.059	-0.12
	(0.136)	(0.144)	(0.139)
ownership acadja / konou		-0.164	-0.374**
		(0.227)	(0.179)
Constant	yes	yes	yes
Observations	411	358	358

Notes: *** p<0.01, ** p<0.05, * p<0.1; the robust standard errors are adjusted for clustering by household and are reported in parentheses. The IV estimations use 'log distance to channel (km)' as an instrument for the degradation index; the first stage results are reported in Table 9.

Table 13: Determinants of the nr. of income sources, marginal effects

Degradation measure:	Degradation index			
Number of income soures:	(1)	(2)	(3)	(4)
log age	-0.177***	0.127***	0.031***	0.013***
	(0.010)	(0.007)	(0.003)	(0.002)
female	0.071***	-0.053***	-0.011***	-0.005***
	(0.007)	(0.006)	(0.001)	(0.001)
log schooling	-0.035***	0.025***	0.006***	0.003***
	(0.006)	(0.005)	(0.001)	(0.001)
degradation index	-0.080***	0.058***	0.014***	0.006***
	(0.008)	(0.006)	(0.002)	(0.001)
log village population	0.031***	-0.023***	-0.006***	-0.002***
	(0.008)	(0.005)	(0.001)	(0.001)
household size	-0.001	0.000	0.000	0.000
	(0.003)	(0.002)	(0.000)	(0.000)
dependency ratio	0.016*	-0.011*	-0.003*	-0.001*
	(0.008)	(0.006)	(0.001)	(0.001)
ownership acadja / konou	0.043***	-0.031***	-0.008***	-0.003***
	(0.013)	(0.010)	(0.002)	(0.001)
Observations	358	358	358	358

Notes: *** p<0.01, ** p<0.05, * p<0.1; Columns represent the nr. of income sources; marginal effects were calculated from the model represented in column 2 of table 12.

Table 14: Determinants of the Herfindahl index

Degradation measure:	Self-reported degradation		
Estimation method	tobit	tobit	IV tobit (2nd stage)
	(1)	(2)	(3)
log age	0.300***	0.295***	0.273***
	(0.061)	(0.063)	(0.071)
female	-0.047	-0.031	-0.039
	(0.048)	(0.048)	(0.051)
log schooling	0.058	0.059	0.039
	(0.036)	(0.036)	(0.032)
degradation	0.569***	0.528***	1.118**
	(0.146)	(0.150)	(0.465)
Ahémé			-0.193
			(0.222)
Nokoué	0.200	0.184	
	(0.195)	(0.209)	
Porto Novo	-0.058	-0.073	
	(0.138)	(0.168)	
log village population	-0.457***	-0.434***	-0.484***
	(0.073)	(0.078)	(0.092)
Goun	-0.114	-0.105	-0.154
	(0.109)	(0.109)	(0.112)
Houedah	-0.212**	-0.213**	-0.152*
	(0.108)	(0.108)	(0.092)
Tofin	-0.267*	-0.259*	-0.041
	(0.150)	(0.149)	(0.106)
household size	-0.024	-0.024	-0.008
	(0.015)	(0.015)	(0.014)
dependency ratio	0.141***	0.141***	0.091**
	(0.035)	(0.035)	(0.041)
ownership acadja / konou		-0.004	-0.023
		(0.104)	(0.078)
Constant	yes	yes	yes
Observations	1,293	1,221	1,221

Notes: *** p<0.01, ** p<0.05, * p<0.1; the robust standard errors are adjusted for clustering by household and are reported in parentheses. The IV estimations use 'log distance to channel (km)' and 'log distance to channel (km) * Ahémé' as instruments for self-reported degradation; the first stage results are reported in Table 9.

Table 15: Determinants of the Herfindahl index

Degradation measure:	Degradation index		
Estimation method	tobit	tobit	IV tobit (2nd stage)
	(1)	(2)	(3)
log age	0.380***	0.389***	0.373**
	(0.117)	(0.118)	(0.156)
female	-0.252**	-0.226*	-0.265**
	(0.116)	(0.118)	(0.127)
log schooling	-0.036	-0.037	-0.048
	(0.080)	(0.078)	(0.089)
degradation	0.229***	0.139	0.370*
	(0.088)	(0.098)	(0.213)
log village population	-0.204**	-0.202**	-0.085
	(0.085)	(0.088)	(0.121)
household size	0.034	0.034	0.034
	(0.030)	(0.029)	(0.026)
dependency ratio	-0.236	-0.273	-0.287*
	(0.145)	(0.177)	(0.165)
ownership acadja / konou		0.220	0.127
		(0.179)	(0.158)
Constant	yes	yes	yes
Observations	411	358	358

Notes: *** p<0.01, ** p<0.05, * p<0.1; the robust standard errors are adjusted for clustering by household and are reported in parentheses. The IV estimations use 'log distance to channel (km)' as an instrument for the degradation index; the first stage results are reported in Table 9.

Appendix corresponding to section 6.2 Robustness checks

1. Using different estimation methods to repeat the analysis presented in Tables 10 to 15

Dependent variable: Degradation measure: Estimation method:	Nr. of income sources self-reported Poisson	Herfindahl index self-reported OLS	Nr. of income sources degradation index Poisson	Herfindahl index degradation index OLS
log age	0.160***	0.039***	0.163***	0.029**
	(0.027)	(0.009)	(0.051)	(0.014)
female	-0.037*	-0.006	-0.091**	-0.026**
	(0.020)	(0.008)	(0.044)	(0.013)
log schooling	0.046**	0.012	0.033	-0.004
	(0.019)	(0.007)	(0.038)	(0.012)
degradation	0.150**	0.074***	0.067***	0.014**
	(0.059)	(0.022)	(0.022)	(0.006)
Nokoué	0.033	0.005		
	(0.076)	(0.033)		
Porto Novo	-0.183***	-0.035		
	(0.063)	(0.028)		
log village population	-0.155***	-0.059***	-0.068	-0.031***
	(0.031)	(0.010)	(0.048)	(0.011)
Goun	-0.049	-0.021		
	(0.045)	(0.020)		
Houedah	-0.198***	-0.045		
	(0.063)	(0.029)		
Tofin	-0.095*	-0.034		
	(0.055)	(0.023)		
household size	-0.009	-0.003	-0.002	0.003
	(0.007)	(0.002)	(0.016)	(0.004)
dependency ratio	0.060***	0.021**	-0.020	-0.018**
	(0.019)	(0.008)	(0.037)	(0.009)
Constant	0.863***	0.346***	-1.300*	-0.140
	(0.226)	(0.073)	(0.739)	(0.180)
Observations	1,293	1,293	411	411

Notes: *** p<0.01, ** p<0.05, * p<0.1; the robust standard errors are adjusted for clustering by household and are reported in parentheses.

2. Heckman selection model

a. Using the self-reported degradation measure

Degradation measure:	self-reported degradation		
Dependent variable:	economically active	nr. of income sources	Herfindahl index
Equation:	selection	outcome	outcome
log age	1.163***	0.699***	0.346***
	(0.083)	(0.121)	(0.077)
female	-0.289***	-0.137*	-0.054
	(0.097)	(0.083)	(0.050)
log schooling	-0.455***	0.129**	0.035
	(0.042)	(0.063)	(0.036)
degradation	0.395*	0.739***	0.594***
	(0.202)	(0.228)	(0.141)
Nokoué	-0.597**	0.418	0.191
	(0.301)	(0.316)	(0.187)
Porto Novo	-0.35	-0.546***	-0.062
	(0.219)	(0.211)	(0.124)
log village population	-0.172*	-0.535***	-0.460***
	(0.090)	(0.082)	(0.063)
Goun	0.002	-0.183	-0.111
	(0.151)	(0.183)	(0.104)
Houedah	-0.341	-0.653***	-0.223**
	(0.207)	(0.154)	(0.090)
Tofin	0.313	-0.502*	-0.261*
	(0.243)	(0.259)	(0.148)
household size	0.01	-0.045**	-0.022*
	(0.016)	(0.020)	(0.012)
dependency ratio	-0.846***	0.138	0.081
	(0.048)	(0.106)	(0.059)
tofin*female	0.273		
	(0.168)		
Constant	yes	yes	yes
Observations	1,988	1,988	1,989
atanrho		0.316	0.339
		(0.295)	(0.304)

Notes: *** p<0.01, ** p<0.05, * p<0.1; The selection equation measures the determinants of being economically active, while the outcome equations measure the determinants of income diversification.

b. Using the degradation index

Degradation measure:	degradation index		
Dependent variable:	economically active	nr. of income sources	Herfindahl index
Equation:	selection	outcome	outcome
log age	0.834***	0.626***	0.406**
	(0.134)	(0.222)	(0.167)
female	-0.596	-0.378**	-0.251**
	(0.565)	(0.149)	(0.120)
log schooling	-0.417***	0.083	-0.056
	(0.079)	(0.149)	(0.101)
degradation index	-0.067	0.355***	0.228**
	(0.111)	(0.116)	(0.109)
log village population	-0.148	-0.109	-0.207**
	(0.154)	(0.107)	(0.091)
household size	0.004	-0.002	0.034
	(0.026)	(0.033)	(0.026)
dependency ratio	-0.905***	-0.089	-0.277
	(0.093)	(0.283)	(0.176)
tofin*female	0.651		
	(0.564)		
Constant	yes	yes	yes
Observations	612	612	612
atanrho		0.152	0.268
		(0.735)	(0.831)

Notes: *** p<0.01, ** p<0.05, * p<0.1; The selection equation measures the determinants of being economically active, while the outcome equations measure the determinants of income diversification.

3. Expansion of the analysis to all villages located in the five communes which border lake Nokoué

IV probit: Dependent variable:	first stage degradation	2nd stage ID
log distance to channel (km)	0.182***	
	(0.008)	
log age	0.071***	0.108*
	(0.007)	(0.061)
female	-0.009	-0.235
	(0.039)	(0.380)
log schooling	0.019***	0.142***
	(0.002)	(0.017)
degradation		2.605***
		(0.268)
log village population	0.030***	-0.096***
	(0.003)	(0.019)
Goun	-0.438***	0.334**
	(0.012)	(0.144)
Tofin	-0.337***	-0.238*
	(0.011)	(0.141)
Houédah	-0.177***	(0.460)
	(0.039)	(0.335)
Aïzo	-0.042***	0.419***
	(0.012)	(0.082)
Wémè	-0.586***	1.771***
	(0.013)	(0.145)
Xwla	(0.003)	-0.485***
	(0.011)	(0.078)
number of children	-0.024***	-0.038
	(0.004)	(0.034)
ownership acadja / konou	0.014***	-0.231***
	(0.004)	(0.030)
Constant	-0.416***	-4.225***
	(0.088)	(0.427)
Observations	11,421	11,421

Notes: *** p<0.01, ** p<0.05, * p<0.1; the first stage estimates the determinants of the commune-level degradation index, using 'log distance to channel (km)' as an instrument; the second stage looks at the determinants of fishing full time. ID is a dummy variable which takes the value 0 if an individual is a full-time fisher and 1 otherwise.