

Oyster culture on the Amazon mangrove coast: asymmetries and advances in an emerging sector

Dioniso de Souza Sampaio, Claudia Helena Tagliaro, Horacio Schneider and Colin Robert Beasley 

Institute of Coastal Studies, Bragança Campus, Federal University of Pará, Bragança, Pará, Brazil

Correspondence

Colin Robert Beasley, Instituto de Estudos Costeiros, Campus de Bragança, Universidade Federal do Pará, Alameda Leandro Ribeiro s/n, Bairro Aldeia, CEP 68.600-000 Bragança, Pará, Brazil. Email: beasley@ufpa.br

Received 16 June 2017; accepted 27 October 2017.

Abstract

Oyster culture activity along the eastern Amazon mangrove coast in Pará state, Brazil, was evaluated using socio-economic data to support its management and future development. Between 2013 and 2014, surveys were carried out in the region's seven oyster culture associations through interviews with the president of each association as well as with 56 members (72% of the total). Further data up to 2016 were obtained from annual reports of the *Serviço Brasileiro de Apoio às Micro e Pequenas Empresas* in Pará and the *Instituto Brasileiro de Geografia e Estatística*. Two associations stand out from the rest due to their larger on-growing areas and total production in 2013. However, smaller associations are more efficient with higher production per unit area. Currently, oyster culture in Pará provides an alternative source of income for 80 families, where total production has increased from 8.25 tons in 2013 to 41.8 tons in 2016. Although associations have grown in number since 2006, along with increased capacity and production due to government assistance, in comparison with other regions of Brazil, they need to be better organized internally, including regular monitoring of growth, production and environmental variables, development of depuration facilities and improved distribution and presentation of products. Diversification of seed supply among different locations is desirable. There should also be less dependence on public funding and more partnerships with private enterprise, as well as active coparticipation in the development of legislation and public policies regulating both oyster culture and protection of natural oyster beds.

Key words: *Crassostrea gasar*, Estuary, Mariculture, coastal resources, Brazil.

Oyster culture worldwide and in Brazil

Oyster culture is a traditional activity with a long history, especially in South-East Asia (Lam & Morton 2003). Globally, oyster culture is an important sector (Forrest *et al.* 2009; Campbell & Pauly 2013) representing over 32% of all molluscan aquaculture in 2015 (Subasinghe 2017). *Crassostrea gigas* (Thunberg 1793) is the most widely cultivated oyster species, produced in thirty countries and that with the highest production: a total of 583 464 tons were produced in 2015 (FAO 2017) mostly from China (Barbieri *et al.* 2014; Pauly & Zeller 2015). Up to eight species of *Crassostrea* are cultivated worldwide. For example, in 2015, production of *Crassostrea virginica* (Gmelin, 1791) in the Americas was 98 263 tons in 2015 and that of *Crassostrea gasar* (Adanson, 1757) was 419 tons from Gambia and Senegal, West Africa (FAO 2017).

Two native mangrove oyster species, *Crassostrea rhizophorae* (Guilding, 1828) and *Crassostrea gasar* (Adanson, 1757), synonymous with *Crassostrea brasiliiana* (Lamarck, 1819), as well as the introduced *C. gigas* (Thunberg, 1793), are cultivated in Brazil. Originally, from the Pacific, *C. gigas* is cultivated in the cooler waters of the southern states of Brazil, where growth is better (Ostrensky *et al.* 2008; Barbieri *et al.* 2014). In 2010, Brazil produced only 1500 tons of *C. gigas* and 400 tons of the native *C. rhizophorae* (Campbell & Pauly 2013). Santa Catarina state is the largest producer of *C. gigas* in Brazil, employing 5000 people and with 2932 tons in 2013, 3670 tons in 2014 and 3030 tons in 2015 (EPAGRI 2016, 2015; Suplicy *et al.* 2015). Brazil produced 20 828 tons of molluscs (oysters, scallops and mussels) in 2016 (IBGE 2016) with Santa Catarina leading with 20 392 tons (97.907% of the total), followed by São Paulo (113 tons, 0.543%), Rio

de Janeiro (79 tons, 0.379%), Paraná (69 tons, 0.330%) in the South and South East, and Bahia (64 tons, 0.307%), Pará (42 tons, 0.202%), Alagoas (41 tons, 0.197%), Maranhão (27 tons, 0.130%) and Sergipe (1 ton, 0.005%) in the North and North East. The south-eastern and eastern states produce oysters, mussels and scallops, whereas the northern and north-eastern states produce only native oysters. In 2014, Pará produced only 8 tons (0.04%) of *C. gasar* (IBGE 2014). With recent investments, Pará is now rapidly increasing production of oysters, and with its relatively well-conserved mangrove coast and low-level impact of urban and industrial development, in comparison with the rest of Brazil (Tenório *et al.* 2014; Ferreira & Lacerda 2016), it has potential to expand production even further. However, there is still a major asymmetry in the oyster culture sector in Brazil. There are little or no species-specific production data available, and assuming roughly 15% of all mollusc aquaculture in southern and south-eastern Brazil is *C. gigas*, we estimate that native oysters account for only around 5.7% of all Brazilian oyster production.

In contrast to *C. gigas* culture, most native Brazilian oyster culture systems are rudimentary, with low, diffuse levels of investment and little use of technology, often merely complementing other forms of income, such as farming (Tureck *et al.* 2014). Oyster culture units are generally run by associations from small communities or are family-based (Hoshino 2009; Mendonça & Machado 2010; Macedo *et al.* 2016). However, such small-scale units, largely aided by government incentives, have greatly contributed to the dissemination of native mangrove oyster culture along the Brazilian coast (Pereira & Rocha 2012). *Crassostrea gasar* has been cultivated on a small-scale in south-eastern and southern Brazil for some time now (Muniz *et al.* 1986; Absher *et al.* 2000; Christo & Absher 2006), and there has been a recent surge in research on its culture, especially in Santa Catarina and Paraná (Silveira *et al.* 2011; Lopes *et al.* 2013; Ramos *et al.* 2013, 2014; Gomes *et al.* 2014; Tureck *et al.* 2014; Castilho-Westphal *et al.* 2015; Silva *et al.* 2015). Yet, overall production of the mangrove oyster *C. gasar* remains low, perpetuating the asymmetry in Brazilian oyster production.

Molluscan seed production (in thousands) in Brazil in 2016 (IBGE 2016) was similarly asymmetric with 60 584 (90.8%) concentrated in the municipality of Florianópolis (Santa Catarina), 3850 (5.8%) in the municipality of Angra dos Reis (Rio de Janeiro) and, significantly, 2268 (3.4%) in the municipality of Curuçá (Pará). The latter is the only supplier of *Crassostrea gasar* seed harvested from the wild, whereas both the former supply laboratory-raised seed, mostly *C. gigas* (IBGE 2016). However, *C. gasar* seed production trials have been carried out in Santa Catarina (Silveira *et al.* 2011; Tureck *et al.* 2014).

Despite growth in Brazilian oyster culture, mentioned above, there are a number of weaknesses in the sector, which is in need of strategic planning, with a view to avoiding possible conflicts and/or the elimination of small-scale units should operations on a larger, more industrial scale come into effect (Ostrensky *et al.* 2008). Environmental degradation of mangroves and coastal pollution is of considerable concern along the Brazilian coast (Souza 2009; Rovai *et al.* 2012). Losses of South American oyster beds have been inferior to 50% but, despite a relatively better status in relation to other continents, there is little or no regular monitoring (Carranza *et al.* 2009; Beck *et al.* 2011). The São Paulo and Paraná coasts are the only locations in Brazil where, since 1987, legislation has been in place to protect natural oyster beds (Mendonça & Machado 2010). In 2003, as an aid to the planning and development of mariculture in Brazil, the Federal Government adopted the *Plano Local de Desenvolvimento de Maricultura* (PLDM, Local Mariculture Development Plan), which is elaborated in conjunction with local partnerships with the aim of evaluating the potential for mariculture and the delimitation of culture units in each state (Novaes *et al.* 2011; Vianna *et al.* 2012; Suplicy *et al.* 2015). Such plans have been carried out in some Brazilian states, but Santa Catarina is at the forefront of this process and, since 2007, has fully implemented a PLDM, along with other coastal management schemes (Vianna *et al.* 2012), and should be in a position to lead the sector into ecologically and socio-economically sustainable growth (Suplicy *et al.* 2015).

A short history of the development of oyster culture in Pará state

The *Secretaria de Estado de Ciência, Tecnologia e Meio Ambiente* (SECTAM, Executive Secretary for Science, Technology and the Environment), a state body, now restructured and responsible for supporting sustainable scientific development, financed equipment and initial pilot studies of oyster culture in Pará, from April 2001, in the municipalities of Augusto Corrêa and Magalhães Barata (Alcântara Neto 2003). The *Serviço Brasileiro de Apoio às Micro e Pequenas Empresas* (SEBRAE, Brazilian Support Service to Micro and Small Enterprises) is an autonomous body that supports local businesses. In November 2005, together with municipal authorities, the Federal University of Pará (UFPA), the agri-aquaculture association AGRONOL, now AGROMAR, and the Pará branch of SEBRAE (SEBRAE/PA) brought members of several communities from Pará on a fact-finding technical visit to oyster culture facilities in Bahia state, on the east coast of Brazil (Sampaio & Boulhosa 2007). In 2006, SEBRAE/PA began formal support for groups interested in oyster culture and, in 2009, provided the incentive for the creation of a network called *Rede*

Nossa Pérola (RNP, Our Pearl Network), bringing together oyster growers from Augusto Corrêa, Maracanã, Curuçá and São Caetano de Odivelas. Institutes of higher education and research (IHERs) involved in aquaculture in Pará state through teaching, research, outreach and funding also participated. RNP meets every 2 months in different municipalities. In the years following its establishment, the main difficulties discussed by RNP included legalization of culture units, environmental licensing, funding and credit, difficulty in harvesting seed, effects of low salinity on on-growing, as well as problems in acquiring materials and equipment, which often have to be imported (Sampaio & Boulhosa 2007; Hoshino 2009).

Hoshino (2009) evaluated the progress of three community oyster culture projects from Augusto Corrêa, Maracanã and Curuçá that had been in operation for over 2 years. The oyster growers were mostly small farmers and artisanal fishermen, supplementing their family diet and income through oyster culture. Many oyster growers stated that as soon as they could increase production, they would dedicate themselves exclusively to this activity (Hoshino 2009). The project at Curuçá is noteworthy as the largest number of natural oyster beds is found in this region, which is the origin of all seed for on-growing in Pará, as well as a smaller proportion exported to other states (França *et al.* 2011; Lopes *et al.* 2013).

As interest in oysters and their potential for culture increased in Pará, research projects began to evaluate oyster genetics, settlement and reproduction. Molecular genetics has revealed there are two native species of oyster in northern and north-eastern Brazil, *Crassostrea gasar* (Adanson, 1757), *syn. Crassostrea brasiliiana* (Lamarck, 1819) and *Crassostrea rhizophorae* (Guilding, 1828), the former predominant and the latter uncommon along the Pará coast (Varela *et al.* 2007; de Melo *et al.* 2010; Melo *et al.* 2013). However, additionally, an exotic species of *Crassostrea* was detected in the municipality of Bragança, Pará (Varela *et al.* 2007; Gardunho *et al.* 2012). In terms of oyster recruitment, Marques-Silva *et al.* (2006) found that settlement of *Crassostrea* was greater in the dry season and on the undersides of wooden substrates placed closest to the bottom of mangrove tidal creeks in Bragança, Pará. In the same area, between 2000 and 2005, peaks in settlement of *Crassostrea* occurred between September and December, the driest time of the year when salinity was highest, but numbers settling tended to decrease over the 6 year period (Beasley *et al.* 2010). Paixão *et al.* (2013) noted that seasonal changes in rainfall and salinity accompanied gonadal maturation in *C. gasar* from Nova Olinda, Augusto Corrêa, Pará, and that the best time for harvesting seed from the water column was during the dry and dry to wet periods of the year. In contrast, seed of an exotic *Crassostrea* settling on a mangrove island, Ilha Canela,

Bragança, Pará, was abundant and regular in these waters, which have a relatively constant higher salinity (>20) throughout the whole year (Gardunho *et al.* 2012), in comparison with locations on the coast, which vary between 0 and 40 (Cohen *et al.* 1999; Funo *et al.* 2015; Monteiro *et al.* 2016; Moura & Nunes 2016) and in some places up to 50 (Lead author, pers. obs.).

In Pará state, planning for mariculture, via the PLDM, was carried out between 2008 and 2012, through an agreement between the now extinct *Ministério da Pesca e Aquicultura* (MPA, Ministry of Fisheries and Aquaculture) and the *Fundação de Apoio a Pesquisa, Extensão e Educação na Ciência Agrícola* (FUNPEA, Foundation for Support to Research, Outreach and Education in Agricultural Science), in partnership with the Amazon Rural Federal University (UFRA). According to an unpublished MPA report, 16 oyster culture parks were proposed in a total of 171 ha of coast among the municipalities of Curuçá, Salinópolis, São João da Ponta and São João de Pirabas, identified as favourable for the activity. However, the PLDM in Pará state was not developed in a fully participatory or integrated manner with local stakeholders. Traditional coastal communities that were active in the sector since 2006 did not take part in the elaboration of the PLDM, nor were their culture units included in the aquaculture parks delimited along the Pará coast. Furthermore, although a preliminary proposal was presented to the public in Bragança, the final result was not.

Currently, there are seven oyster culture associations in five municipalities, all of which except for one, in Salinópolis, are located in a marine *Reserva Extrativista* (RESEX), which are areas designated for management by users of resources living within the reserve (Senado Federal 2008). However, there are problems related to the environmental and economic sustainability of oyster culture in Pará state, such as unregulated exploitation and lack of environmental legislation governing the use of natural oyster beds, as well as conflicts between those that harvest oysters from natural beds and the oyster growers. There are also problems with regulatory aspects of the sector, the lack of full-time oyster growers and a lack of investment of private capital, which may be hampering development. As an example to be followed, France, the largest oyster producer in Europe (Bihan *et al.* 2013), with a long tradition in the sector, is dominated by relatively small family-run businesses where investment of private capital was essential to driving the industry forward (Buestel *et al.* 2009). Considering the relatively recent development of oyster culture in Pará state and the challenges facing the sector there, the objective of this study was to evaluate oyster culture activity in the region, provide information for management and suggest priorities for its future development.

Study area, survey and analysis

The study covers the north-eastern coast of Pará state, representing 6.7% (83 182.6 km²) of the total area of Pará, which has a population of 1.942 million inhabitants, or 23.2% of the state population. Surveys were carried out in each of the seven oyster culture associations in five municipalities in the region (Table 1, Fig. 1). Fieldwork took place between September 2013 and April 2014, during which two visits were made to each oyster culture association. The president of each association was interviewed separately to obtain primary data by means of semi-structured questionnaires (Viertler 2002) with the aim of describing the sector with respect to social organization, infrastructure, production and commercialization, relationships with other organizations, adherence to current legislation and perspectives for the future. During visits, additional interviews were carried out with 56 oyster growers (see Table 1 for breakdown among associations).

Data on production, commercialization and infrastructure at each association between 2011 and 2013 were provided on request by SEBRAE/PA (2014), which included the number of oyster seed in stock (in thousands), the number of adult oysters sold (in dozens), the most commonly commercialized size of oyster (Baby 60–79 mm, Medium 80–99 mm and Master >100 mm), market diversity (number of markets, i.e. number of municipalities or communities, not individual clients) and the number of lantern nets and bags used for on-growing. Mean number of days spent in maintenance and whether or not the association receives government technical assistance were obtained from interviews. The on-growing area (m²) was calculated from coordinates obtained with a portable geographic positioning system at each association. Variables related to social organization were obtained for each association as follows: number of members actively engaged in oyster culture, mean age of oyster growers, the coefficient of the proportion of men and women, the percentage of members in the following age classes: 20–40 years,

40–60 years and >60 years, year association was established, year oyster culture began and the percentage of members with access to government financial assistance. Additional information on oyster production (in tons) and seed (in thousands) for municipalities in Pará was obtained from the *Instituto Brasileiro de Geografia e Estatística* (IBGE, Brazilian Institute of Geography and Statistics) (IBGE 2013, 2014, 2015, 2016). Monetary values are expressed as the Brazilian Real R\$ with reference to the date in the text.

All nominal and ordinal variables were numerically coded to quantify the response. The data from each association, as well as that publicly available during the study period (Data S1), were used to generate a dissimilarity matrix based on Euclidean distance in order to quantify the relationships among associations. Variation among associations in terms of the data for 2013 to 2014 was evaluated with an ordination by nonmetric multidimensional scaling using the package *vegan* (Oksanen *et al.* 2017) in GNU-R (R Core Team 2017) and the Euclidean dissimilarity distance matrix as input.

Results

Legal status and social organization

As of 2013, all seven oyster culture associations have been registered with the *Cadastro Nacional de Pessoa Jurídica* (CNPJ, Brazilian National Register of Legal Entities). The first register was in 1999 and the most recent in 2012. From 2006, four oyster culture associations were registered with the CNPJ. As members of registered associations, oyster growers may go about their activities producing oysters, but associations are not allowed to legally commercialize their produce; in Brazil, only cooperatives and registered businesses are allowed to do this. The transition from an association to a commercial entity may be a difficult one, as in all seven associations, each oyster grower is responsible for their own production and commercialization. This is an unusual situation in mariculture, where labour is generally carried out collectively by members of the community

Table 1 Name, municipality, abbreviation and year of establishment of each of the seven oyster (*Crassostrea gasar*) culture associations in Pará state, as well as the total number of active members and the number of interviewees in each association during the present study

Association, Municipality	Abbreviation	Year established	Total active members, number interviewed
Associação de Mulheres na Pesca e Agricultura de Pererú, São Caetano de Odivelas	AMPAP	2007	13, 8
Associação dos Produtores de Ostras de Pererú de Fátima, São Caetano de Odivelas	ASSOPEF	2006	11, 11
Associação de Aquicultores da Vila de Lauro Sodré, Curuça	AQUAVILA	2006	10, 6
Associação Agropesqueira de Nazaré de Mocajuba, Curuça	AGRONAM	2012	13, 7
Associação dos Aquicultores, Produtores Rurais e Pescadores de Nazaré do Seco, Maracanã	AAPPNS	2006	10, 6
Associação dos Agricultores e Aquicultores de Santo Antônio de Urindeua, Salinópolis	ASAPAQ	2009	9, 5
Associação dos Agricultores e Aquicultores de Nova Olinda†, Augusto Corrêa	AGROMAR	2006	13, 13

†Formerly known as Associação Agropesqueira de Nova Olinda (AGRONOL).

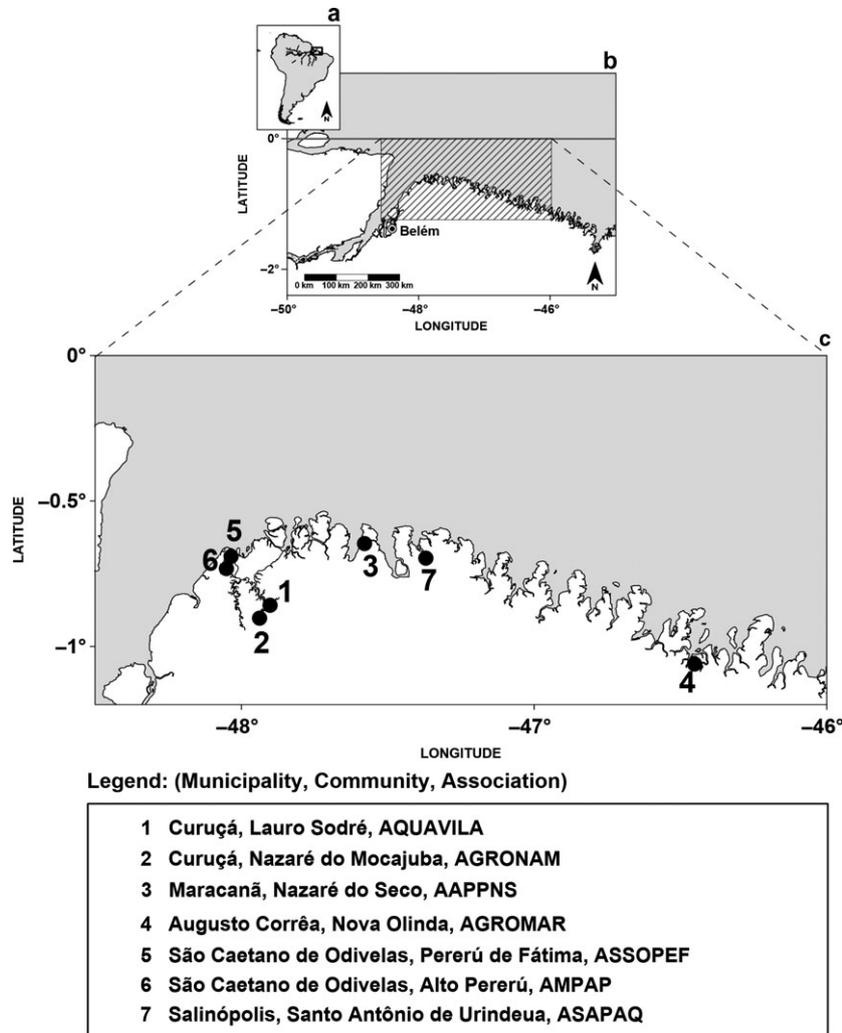


Figure 1 Location on the northern coast of South America (a), of the study area, along the north-eastern coast of Pará state (b) and the seven oyster (*Crassostrea gasar*) culture associations (c, 1-7).

(Singer 2000), thus facilitating the transition to a cooperative.

At present, there are a total of 184 members among all seven associations, which are involved in agriculture and/or oyster culture. Of this total, 43% (79 members) participate predominantly in oyster culture. During the study, 72% of the 56 interviewees indicated that although oyster culture was their main economic activity, they have other business interests or activities, the most important of which is family-based agriculture. Among coastal communities near mangrove areas, small-scale farming is the principal activity in the region, which is a permanent, year-long activity for the whole family (Glaser 2003; Blandtt & Sousa 2005). Family-based plantations of beans, manioc and rice, among others, are the main sources of income in all seven oyster culture associations in Pará. The complementary nature of

shellfish culture is common in Brazil. For example, Fagundes *et al.* (2004) observed that the main activity of mussel growers in São Paulo state was fishing. As an example in Pará, the association AGROMAR from the community of Nova Olinda, Augusto Corrêa, had 15 members in 2015, among which oyster culture was a full-time activity for six and a secondary one for the remainder. Only two members had a monthly income of over 1 minimum salary (R\$788 in December 2015), both of whom were full-time oyster growers.

Among the oyster growers interviewed, 71% are men and 29% women, and the latter corresponds to the 28% reported for participation of women in the labour force among coastal communities in Latin America (Abramo 2007) but is greater than the 19% global involvement of women in fisheries and aquaculture in 2014 (FAO 2016). In

other regions of Brazil, participation of women in oyster culture is lower than that recorded in Pará, for example 21.4% in Cananéia, São Paulo (Mendonça & Machado 2010), and only 9.1% in Baía de Ilha Grande, Angra dos Reis, Rio de Janeiro (Moschen 2007). Among the seven associations in Pará, there is no division of labour among men and women oyster growers, and only a single association, ASSOPEF, in the municipality of São Caetano de Odivelas did not have women members.

Among interviewees from all seven oyster culture associations in Pará, age ranged between 27 and 68 years for women and 23 and 71 years for men, with mean ages (\pm SE) of 48.3 (\pm 12) and 40.9 (\pm 12) years, respectively. Although Amorim (2007) did not present data on the age of men, the age of women participants in mariculture in Santa Catarina state, most of whom were aged between 41 and 50 years, is similar to the mean age of women involved in the sector in Pará. Among associations, the lowest mean age, 38 years, was recorded for AQUAVILA in Curuçá and the largest mean age, 52 years, for ASAPAQ in Salinópolis.

In the present study, 55% (31) of the interviewed oyster growers did not complete primary education, most of whom were distributed among the associations AGROMAR (9), AQUAVILA and ASSOPEF (six in each), and AMPAP (4). A further six oyster growers completed primary education and four had an incomplete secondary education. Only a single oyster grower, from AGROMAR, did not receive any formal education, self-declaring illiterate. All of the communities with oyster culture associations have access to municipal schools with primary education. However, in communities in Pará that are dependent on the mangrove ecosystem, it is common for school-goers to abandon their studies early to begin work in order to supplement their families' incomes (Blandtt & Sousa 2005). However, 12 association members (21%) completed secondary school and two members (4%), one each from AGROMAR and ASSOPEF, completed a third level course, both being schoolteachers. The community of Nova Olinda in Augusto Corrêa, where AGROMAR is located, is the only one with access to secondary education through a state school.

In relation to government assistance, 43 of the 79 oyster growers in Pará have access to programmes run by the federal government, such as *Bolsa Família*, a social welfare project that provides a guaranteed minimum income for families, which varies with the number of children and the family income. Such programmes are focused on the poorest sectors of Brazilian society and demand only that the family maintains their children in school, are not involved in illegal underage work and are up-to-date with vaccinations and medical examinations (Castro *et al.* 2009; *Bolsa Família* 2017), thus contributing not only to bringing families involved in oyster culture in Pará above the poverty

line, but also to improving their education and health. For example, the son of an oyster farmer at AGROMAR recently graduated with a bachelor's degree in Fisheries Engineering from UFPA, Bragança, and sales of oysters sustained him during his studies (Lead author pers. obs.).

In terms of experience in the sector, 46% of the interviewees have been involved for 4–6 years, 27% for 2–4 years and 27% for up to 2 years. As oyster culture in Pará is a relatively recent activity, it is relevant that almost half of those interviewed have at least 4 years of experience in the sector. By comparison, 62% of those involved in mussel culture along the São Paulo coast, which is long established there, have 5 years of experience (Fagundes *et al.* 2004).

Exploitation of oyster beds and conflicts with oyster growers

Social instability in coastal communities in Pará state with poor social support is indicated by increased poverty, migration and violence (Grasso 2005). Increasing population growth and, as a consequence, greater competition for natural resources have increased conflict within and among coastal communities in Pará (Glaser 2003). The exploitation of oyster beds is an important example. From colonial times, lime from the shells of marine bivalves had been used in mortar and plaster for building in Brazil. However, since the 1950s, the Brazilian cement industry emerged, and the old lime factories (*caieiras*) began to disappear (Kanan 2008). Oyster growers from all seven associations in Pará reveal that lime was extracted from oyster shells up to around 20 years ago.

However, harvesting of oyster from beds for consumption or sale as food still occurs, and in Augusto Corrêa, Curuçá and Magalhães Barata, the disappearance or degradation of natural beds of oysters has been noted by locals (Lead author, pers. obs.). Of these municipalities, Magalhães Barata is the only one not to have an oyster culture association, but exploitation of oyster beds occurs there, and over the past 20 to 30 years, coastal communities from Maracanã and Magalhães Barata have been commercializing oysters from natural beds for the restaurant industry in the state capital, Belém. In Vila de Lauro Sodré, Curuçá, there are, on the one hand, harvesters, locals who exploit natural oyster beds for over 20 years and, on the other hand, members of AQUAVILA who have been carrying out oyster culture since 2006 (see Table 1) and exploitation of oyster beds before that. However, it should be noted that only four members of AQUAVILA are involved in oyster bed exploitation (Reis 2015). In recent years, several conflicts and disagreements have arisen among harvesters and oyster growers in Vila de Lauro Sodré, Curuçá, specifically in the RESEX Mãe Grande de Curuçá. The oyster growers accuse the harvesters of

removing large quantities of oysters, thus damaging natural beds, as well as seed production. Up to 2015, AQUAVILA was the only association in Pará to commercialize seed both inside and outside the state (IBGE 2014). Reis (2015), in her study of the social organization of the production and sale of oysters from Curuçá, noted that the association AQUAVILA probably entered the conflict due to concerns over potential reductions in seed production as a result of harvesting oysters from natural beds. This is of course highly relevant due to the absolute dependence of all other oyster culture associations on the supply of seed from AQUAVILA, which, if interrupted, would abruptly terminate oyster culture in Pará.

The harvesters from Lauro Sodré argue that they only remove small quantities of oysters, as a complement to their income from agriculture (Reis 2015). The inhabitants of the reserve, who see themselves as farmers that exploit oysters to sell at weekends, reinforce this idea: ‘... I don’t depend on the oyster to live; I guarantee the sustenance of my family through agriculture the whole week, the sale of oysters is a complement to pay an installment and other things we may need’ (Reis 2015). In interviews in the present study, around 30 harvesters in Lauro Sodré, Curuçá, sustain their families with income solely from the sale of exploited oysters. Furthermore, Reis (2015) recorded that the harvesters accuse members of AQUAVILA of removing large quantities of oysters every week and of impacting oyster beds in the region. Reis (2015) notes that while harvesters of natural oyster beds are invariably labelled villains by both AQUAVILA oyster growers and consultants from SEBRAE/PA, some AQUAVILA members also harvest oysters from natural beds. The conflict in Curuçá continues to persist, and unless an objective mediator steps in, it is unlikely to be solved in the near future.

Interviews during the present study have shown that over the past 10 years, AQUAVILA was the only association that managed to expand its market for oysters as far as the municipality of Marabá (around 600 km to the south). This market penetration has probably been possible via the inclusion for sale of oysters that are harvested from natural beds (Lead author, pers. obs.). One of the reasons for this is that the AQUAVILA on-growing area is far from the seed-harvesting site, limiting adult oyster production. Facilities are, however, now being built to allow oyster growers to stay over at the on-growing site, which may increase the output of cultivated oysters from AQUAVILA in the near future, thus reducing pressure on natural beds.

Fortunately, the conflict between harvesters and oyster growers in Lauro Sodré has not been seen in other municipalities with oyster culture, despite the presence of harvesters in São Caetano de Odivelas, Maracanã, Salinópolis and Augusto Corrêa (Lead author, pers. obs.). Little is known of the impact of harvesting on oyster beds in the

region. In fact, harvesting of oysters is not legally prohibited in Brazil as, up to now (2017), there is no legislation nor any agreement linked to the environmental agencies *Instituto Chico Mendes de Conservação da Biodiversidade* (ICMBIO, Chico Mendes Institute for the Conservation of Biodiversity) and the *Instituto Brasileiro do Meio Ambiente e de Recursos Naturais* (IBAMA, Brazilian Institute for the Environment and Natural Resources) relating to protection of natural oyster beds. The only existing Brazilian legislation dates from the 1980s and protects natural beds of oysters along the Cananéia (São Paulo state) and Paranaguá (Paraná state) coasts (Mendonça & Machado 2010). The manager of the marine RESEX Mandira in Cananéia, Marco Aurélio dos Santos, in an interview during the present study in 2013, indicated that the above legislation is, in fact, quite effective for protecting oyster beds. Subsequently, this information was passed on by the lead author to oyster growing associations, SEBRAE and ICMBIO in Pará, and, after several meetings since then, a decision was made to develop similar legislation for the Pará coast. In March 2016, an initial meeting on developing protective legislation for oyster beds was hosted by ICMBIO in Belém, Pará. An outreach project, involving the Federal University of Pará and the seven oyster culture associations approved for funding in March 2016 and coordinated by the lead author of the present study, aims to increase support for the protection of natural oyster beds in areas where oysters are cultivated.

Availability of infrastructure, production and commercialization

Since 2006, oyster culture associations in Pará state were only able to acquire material for on-growing either through research projects or agreements with federal, state or municipal bodies and/or IHERs. The most recent agreement (039/2009) was signed in 2009 and involves the now extinct MPA, *Secretaria de Pesca e Aquicultura do Estado do Pará* (SEPAQ, Secretary for Fisheries and Aquaculture of the State of Pará) and SEBRAE/PA, whereby material for on-growing would be provided on condition that the oyster growers return production data every 2 months. The MPA and SEPAQ have since been incorporated into the *Ministério da Agricultura, Abastecimento e Pecuária* (MAPA, Ministry for Agriculture, Supply and Livestock), and the *Secretaria Estadual de Desenvolvimento Agropecuário e de Pesca* (SEDAP, State Secretary of Agricultural and Fisheries Development), respectively.

Two on-growing systems are used in oyster culture in Pará state. The fixed table is a static system with bags used in areas with wide tidal variation (BMLP 2006) and used by all associations in Pará. The longline is a buoyed suspended system in the water column with lantern nets and/or bags

used in deeper waters and currently used only by AGROMAR (Fig. 2). Data from SEBRAE/PA (2014) show that in 2011, oyster culture associations in Pará possessed a total of 927 bags for on-growing. From 2013 onwards, after receiving the bags and lantern nets for on-growing via the above agreement, oyster on-growing capacity in Pará grew by 700% over 2 years to 7526 (Table 2). In the light of this, SEBRAE/PA correctly predicted that oyster production in Pará would be around 40 tons in 2014 (see Table 3). Although on-growing capacity has increased significantly, recent production data (IBGE 2013, 2014, 2015, 2016) vary among municipalities (and presumably among associations) and may be related to management practices and dedication to the activity, where low levels of maintenance and engagement in other activities result in lower production. The association with the least number of on-growing bags is AGRONAM, which was the last one to join RNP. Only AGROMAR and AQUAVILA have relatively more advanced management, including regular cleaning of equipment, planning ahead using data from past production records, as well as more members with greater dedication to oyster growing (SEBRAE/PA, pers. comm.).

During the study period, AQUAVILA from Lauro Sodré, Curuçá, was the only association that, besides being involved in on-growing, also carried out harvesting of seed (up to 29 mm) from the wild. AQUAVILA had approximately 3000 artificial seed collectors made from PET bottles (Fig. 3) in 2013–2014, and the goal of increasing this to 5000 collectors in 2016, according to association member Sr. José da Silva Galvão, was actually met earlier, in 2015. In 2013, IBGE (2014) officially reported that AQUAVILA sold 900 000 seed, whereas an extra-official figure of



Figure 2 Oyster (*Crassostrea gasar*) farming in the community of Nova Olinda, municipality of Augusto Corrêa, Pará, Brazil, showing use of both on-growing systems (fixed and longline). Photograph by lead author.

Table 2 Numbers of on-growing bags among the seven oyster (*Crassostrea gasar*) culture associations in Pará state between 2011 and 2013 (SEBRAE/PA 2014)

Association	Year		
	2011	2012	2013
AMPAP	72	84	1182
ASSOPEF	118	70	887
AQUAVILA	279	236	1382
AGRONAM	0	100	476
AAPPNS	102	107	903
ASAPAQ	80	90	921
AGROMAR	276	222	1775
Total	927	909	7526

596 000 seed was divulged through RNP (SEBRAE/PA 2014). Considering only the data from SEBRAE/PA (2014), the oyster seed harvest increased by 360% between 2011 and 2013. All oyster culture associations, except AAPPNS, increased their stock of seed, purchased exclusively from AQUAVILA, which increased its harvest over the same period (Fig. 4a).

Although there are natural oyster beds close to all culture units in Pará, oyster growers consider these to be, in their words, ‘weak’ and the seed of ‘low quality’. As a result, over the past 8 years, most associations have focused on the on-growing of oysters, whereas AQUAVILA focused on supplying seed and was the only supplier in the region until recently. AGRONAM from Nazaré do Mocajuba, Curuçá, as well as a new association from the municipality of São João de Pirábas, has recently begun supplying seed for on-growing. Low salinity during the rainy season around the communities of Nazaré do Mocajuba and Lauro Sodré in Curuçá, means seed harvesting is more profitable than on-growing adult oysters. The potential for seed harvesting in this municipality is very high as demonstrated by França *et al.* (2011). Several communities from the neighbouring municipality of São João da Ponta, around 20 km from Nazaré do Mocajuba and Lauro Sodré, are also interested in seed harvesting, according to an analyst at ICMBIO (Waldemar Londres Vergara Filho, pers. comm.). However, because these communities are so close, there is potential for competition for harvesting sites. Moreover, an overdependence on seed from a single location in Pará is undesirable as disease, environmental variability, human impact and exotic species could potentially reduce seed supply from this location, bringing the sector to a halt.

With regard to sales of seed and juveniles, the value of the *milheiro* (defined as 1000 seed, up to 29 mm, or juveniles, 30–59 mm) was established by means of an agreement between technical staff at SEBRAE/PA and associations at an RNP meeting. By the end of the 2nd quarter of 2015, a *milheiro* of seed was worth R\$30, and a

Table 3 Production of *Crassostrea gasar* (tons) between 2013 and 2016 in the municipalities of São Caetano de Odivelas, Curuça, Salinópolis and Augusto Corrêa, Pará state, Brazil. All data are from IBGE (2013, 2014, 2015, 2016)

Year	Municipality and Association(s)				Total
	São Caetano de Odivelas AMPAP ASSOPEF	Curuça AQUAVILA AGRONAM	Salinópolis ASAPAQ	Augusto Corrêa AGROMAR	
2013	3.45	4.80	0.0	0.0	8.25
2014	4.10	4.50	16.0	18.0	42.6
2015	5.40	5.64	8.7	18.5	38.24
2016	3.80	4.80	20.0	13.2	41.8
Total	16.75	19.74	44.7	49.7	130.89

**Figure 3** Oyster (*Crassostrea gasar*) seed collectors, made using PET plastic from bottles, deployed at the Aquavila Association of Lauro Sodré, municipality of Curuça, Pará, Brazil. Photograph by lead author.

milheiro of juveniles was worth R\$60 in Pará state. From 2013 to 2015, seed production at Curuça increased from 900 through 1000 to 2480 *milheiros*, and São João de Pirabas began producing seed in 2015 and sold 70 *milheiros* (IBGE 2013, 2014, 2015). In 2016, 2198 *milheiros* of seed were sold in Curuça, and São João de Pirabas again sold 70 *milheiros*, generating incomes of R\$242 000 and R\$3000, respectively. AGROMAR now only buys juveniles, which are larger and more expensive than seed but reach minimum market size in about 3–4 months from the date of purchase. Most restaurant owners prefer to purchase these smaller sized oysters (Baby), since a dozen easily fit on a plate. However, private consumers prefer medium-sized oysters (Medium).

An introduced *Crassostrea* sp. is sometimes found on seed collectors in Pará. Gardunho *et al.* (2012) describe the events leading to the detection of this unidentified *Crassostrea* sp. which appears to be exotic, at a mangrove island in Bragança, Pará, but is also found in southern China (Liu *et al.* 2011). Oyster growers report that *Crassostrea* sp. is found in all culture units in Pará, and 68% of oyster growers say they are able to distinguish between the exotic seed

and that of the native *C. gasar*. Those unable to distinguish between the two species say it is due to their lack of experience having been engaged in the activity for only a short length of time. In the past, the lack of ability to identify the exotic *Crassostrea* sp. led to a lack of productivity. Today, when in doubt, the oyster grower waits for a few days for the seed to develop to evaluate its size, as the exotic seed does not grow as fast as the native one. However, no study has been carried out so far to determine whether oyster growers are indeed able to correctly distinguish between the two species. For the moment, it appears that there is no cause for concern regarding *Crassostrea* sp., as most oyster growers are able to weed it out quickly (Lead author pers. obs.). Furthermore, *Crassostrea* sp. appears only to be most abundant where salinity is always above 20 (Gardunho *et al.* 2012). Along most of the coast, there is large variation in salinity (0–50, Lead author pers. obs.), which does not allow *Crassostrea* sp. to permanently establish. However, there is a need for more vigilance on the part of port authorities to guard against further invasions of exotic species, as well as resistance on the part of oyster growers to accept seed or adults from other regions of Brazil, or other exotic species for culture. In south-east Australia, decreases in the production of the native *Saccostrea glomerata* have been attributed to a number of causes, including the introduction of *Crassostrea gigas* (Schroback *et al.* 2014). A code of conduct for marine introductions and transfers for aquaculture has been recommended by the International Council for the Exploration of the Sea (ICES 2005).

Much of the discussion above relates to risks and requires that oyster growers adopt risk perception and management strategies to safeguard their activity, which is necessary even in countries such as France (Bihan *et al.* 2013), where there is a much longer tradition of oyster culture. At present, the oyster culture sector in Pará is extremely vulnerable to disturbance and needs to be aware of and plan for potential risks. The asymmetry in relation to oyster seed supply in Pará, where AQUAVILA dominates, is a weakness in the sector, and the participation of more associations (such as AGRONAM and suppliers from São João de Pirabas) in seed harvesting and supply will help

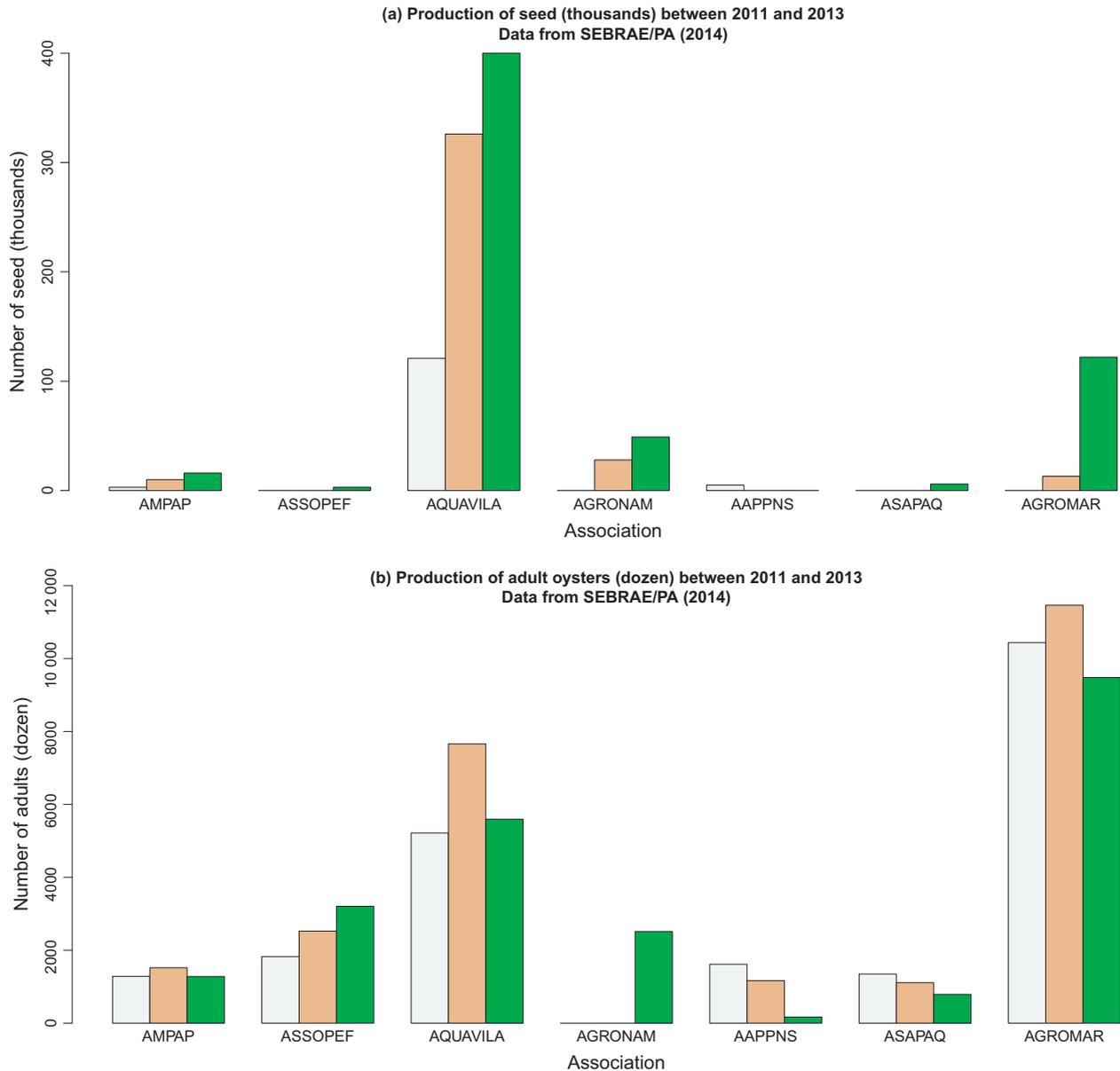


Figure 4 (a) Number of *Crassostrea gasar* seed (in thousands, or *milheiro*) acquired by oyster culture associations in Pará between 2011 and 2013. Up to recently, AQUAVILA was the only producer of seed, which is harvested from the wild and sold to the other associations. (b) Total production of adult oysters (in numbers of dozens) sold by oyster culture associations in Pará between 2011 and 2013. All data are from SEBRAE/PA (2014). □ 2011; ■ 2012; ■ 2013.

strengthen the sector, especially when these are from different locations along the Pará coast.

The associations in São Caetano de Odivelas, ASSOPEF and AMPAP are nearest to the state capital, Belém, approximately 100 km, whereas the most distant is AGROMAR in Augusto Corrêa, approximately 270 km from Belém. Difficulties with transport infrastructure and the logistics of the supply of live oysters to the market are another weakness in the sector, as many of the associations lack vehicles and/or are located in areas with poor road access. Both of these

problems are unlikely to be fully resolved in the near future.

The production of adult oysters (in numbers of dozens) in Pará increased by 17% between 2011 and 2012 but fell by 10% from 2012 to 2013. The reason for the fall in production was not released by RNP, but the decrease occurred in five associations (Fig. 4b). Only ASSOPEF and AGRONAM increased production over the period, with AGRONAM being a newcomer to the sector in 2013 (Fig. 4b). According to SEBRAE/PA (2014), the association with the

greatest total production was AGROMAR with 9480 dozen oysters in an area of approximately 8725 m², and the association with the lowest production was AAPPNS in Maracanã with 167 dozen in an area of approximately 370 m². The effect of the increase in on-growing capacity from 2013 has been seen in municipal data from 2014 onwards (Table 3, IBGE 2013, 2014, 2015, 2016), but since then, no data from *individual* associations have been released by SEBRAE/PA. From 2013 onwards, however, IBGE began to publish these data annually per municipality (in tons). The absence of association-specific data may be another significant weakness in the sector. Currently, there is no official publication of fisheries and aquaculture statistics obtained by SEBRAE/PA or by state authorities (SEDAP), and regular publication of such a document would greatly facilitate diffusion of information and help speed up decision-making and investments in relation to the sector and potential partners. Over the past 10 years, strategic information on oyster culture in Santa Catarina and São Paulo has been made available via state agencies (EPAGRI 2016; IPSP 2017), respectively.

Examining production in 2013 relative to on-growing area, the most efficient units by far are AGRONAM and ASAPAQ, which produce 8.1 and 12.7 dozen oysters per m² (Fig. 5). On the other hand, associations such as AQUAVILA and AGROMAR, which have the largest on-growing areas, could potentially be much more efficient. Besides having the largest number of partnerships with other institutes, social, economic, commercial and institutional data from each association show that AQUAVILA and AGROMAR are distinct in terms of on-growing area and total production in 2013 (Fig. 6). However, in contrast,

AGRONAM and ASAPAQ are characterized by much higher per unit area production. With greater efficiency, associations should consider becoming cooperatives if the members are interested in market expansion, as under Brazilian law, associations are not-for-profit organizations, whereas cooperatives are commercial entities (Frantz 2012).

Currently, oyster culture in Pará provides an alternative source of income for 80 families, where total production has been increasing more recently, from 8250 tons in 2013 to 41 802 tons in 2016 (Table 3). The greatest increases have occurred in Salinópolis (ASAPAQ) and Augusto Corrêa (AGROMAR). Despite similar investment in capacity in 2013 (Table 2), other associations have not significantly increased their production of adult oysters. Total income has increased from R\$50 000 in 2013 through R\$421 000 in 2014 to R\$217 000 in 2015. In 2016, income from the production of adult oysters in Pará state varied from R\$30 000 (São Caetano de Odivelas) to R\$180 000 (Salinópolis) with a total income of R\$322 000.

Regarding commercialization and marketing, SEBRAE/PA created the brand *Nossa Pérola (Ostra da Amazônia)* or Our Pearl (Amazon Oysters), and proposed strengthening commercialization and sales of oysters cultivated by RNP members. In 2010, SEBRAE/PA elaborated three commercialization strategies: a) capacitate oyster growers to better showcase their products, b) provide supporting materials for use by associations in divulging the brand *Nossa Pérola (Ostra da Amazônia)* and c) develop other strategic marketing actions. The latter includes organizing oyster festivals, for example the II *Circuito da Ostra (Oyster Circuit)* in Salinópolis in 2017 and degustation events throughout the

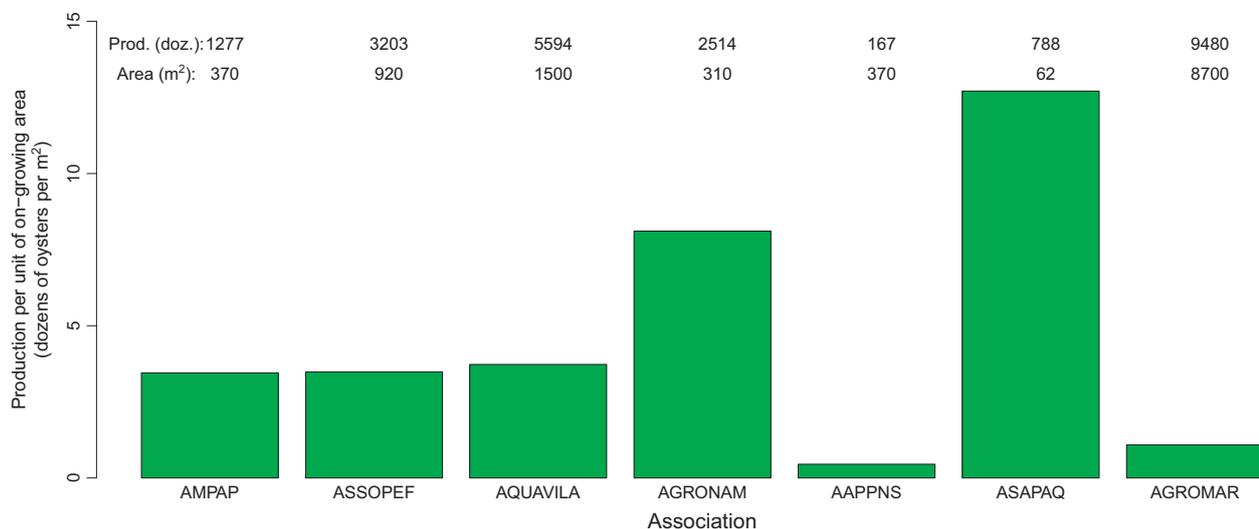


Figure 5 Total oyster (*Crassostrea gasar*) production (data from SEBRAE/PA 2014) per unit of on-growing area (dozen per m²) at each of the seven oyster culture associations in Pará in 2013. Total production of oysters (dozen) and area (m²) are given above each bar.

Ordination of associations based on socio-economic characteristics in 2013–2014

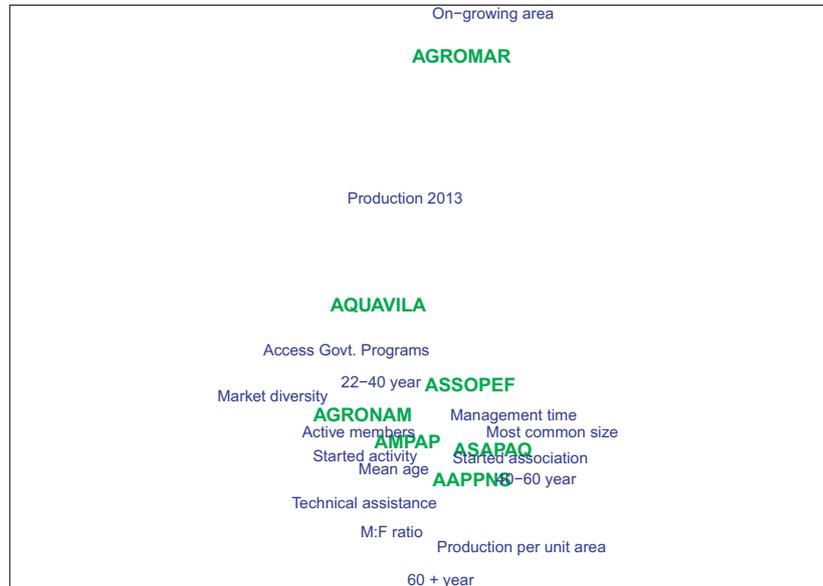


Figure 6 Nonmetric multidimensional scaling of the seven oyster (*Crassostrea gasar*) culture associations using a Euclidean distance matrix based on socio-economic characteristics of each association.

year organized via SEBRAE/PA and the *Associação Brasileira de Bares e Restaurantes* (Abrasel, Brazilian Association of Bars and Restaurants). Although the brand *Nossa Pérola* (*Ostra da Amazônia*) has not been officially registered at the *Instituto Nacional de Propriedade Intelectual* (INPI, National Institute for Intellectual Property), a restaurant owner in Belém has noted that use of the brand *Nossa Pérola* (*Ostra da Amazônia*) via placement of the logo on marketing materials increased sales of oysters by over 200%. Each association carries out its marketing independently, but use of a flyer is the most common form of marketing. The associations could negotiate the use of the flyer directly on restaurant tables or in markets. On the downside, oysters are not yet commercialized in standardized packaging and are sold either by the unit, dozen, hundred or thousand, according to the client's needs.

Another problem for the oyster culture sector in Pará is in relation to public health and involves the need to establish reliable depuration facilities so that oyster growers can bring their products for sanitation before marketing. Although nonobligatory under Brazilian law, São Paulo and Santa Catarina states have again lead the way in terms of the safety of cultivated oysters by monitoring algae and pollution (Souza *et al.* 2009) and providing depuration facilities, financed by the World Bank in São Paulo (Lead author, pers. obs.). Although raw *Crassostrea gasar* may be microbiologically safe for consumption for up to 8 days after harvesting (Maziero & Neto 2015), Ristori *et al.*

(2007) reported that microbial pathogens were less prevalent in depurated oysters than in nondepurated ones. Gamma irradiation has been used to inactivate *Salmonella* and *Vibrio* microbes in *C. gasar*, without affecting odour, flavour or appearance of the oyster (Jakobi *et al.* 2003). As oyster culture expands along the northern and north-eastern coasts of Brazil, so too have records of pathogens and diseases, associated with *Crassostrea gasar*, some of which require notification, such as *Perkinsus* spp., and include the estuarine region of the São Francisco in Bahia (Silva *et al.* 2014, 2015), the Mamanguapé in Paraíba (Queiroga *et al.* 2015), Cananéia in São Paulo (Ristori *et al.* 2007) and the coast of Pará state (Azevedo *et al.* 2005). Access to depuration facilities will not only be beneficial for public health, but along with certification will also increase the value and acceptability of oysters on the market. The installation of a depuration facility in Coruripe, Alagoas state, through a partnership between the State Government and the Spanish Agency for International Cooperation for Development has shown that the investment is paying off through an increased volume of sales, and greater income for oyster growers, as well as more interest and confidence in the consumption of oysters (Panorama da Aquicultura, 2014). In interviews during the present study, members of the cooperative Cooperostra in Cananéia, São Paulo, report that some stall owners, who sell oysters at beaches, deliberately purchase nondepurated oysters, because these taste better, according to their clients.

Finally, calcium carbonate from cultivated oyster shells, which are otherwise discarded, could provide raw material for a diverse range of products for construction, cosmetics and other industries (Chierighini *et al.* 2011). Nonorganic residues (mainly plastic debris) may pose a problem in coastal areas where oyster culture is intensive (Liu *et al.* 2015). In Pará, the use of natural materials from the mangrove means residues from oyster culture is mostly biodegradable, but, of course, the use of materials from the mangrove has a potentially negative impact on the habitat, which needs to be mitigated by sustainable management.

Relationships and identification with other institutes and external entities

Association presidents report a total of 13 institutions that are partners with the oyster culture sector in Pará, of which both SEBRAE/PA and SEPAQ supported all associations. Additionally, the *Empresa de Assistência Técnica e Extensão Rural do Estado do Pará* (EMATER, Enterprise for Technical Assistance and Rural Outreach of the State of Pará) supported ASSOPEF, AQUAVILA and AGRONAM, and the now extinct MPA supported AGRONAM and ASAPAQ. IHERs, such as UFPA supported ASSOPEF, AGRONAM and AGROMAR, and the Federal Institute of Pará supported AGRONAM and ASAPAQ. Local municipal authorities supported AQUAVILA, AGROMAR and ASAPAQ, and local fishing and rural workers' unions supported AQUAVILA. The associations with the greatest number of partnerships, besides SEBRAE/PA and SEPAQ, were AQUAVILA and AGRONAM (four each), followed by ASAPAQ (3), ASSOPEF and AGROMAR (2 each). It should be noted that mostly all institutes are public, either Federal, State or Municipal, and there are very few partnerships with businesses and nongovernmental organizations.

Since 2009, SEBRAE/PA, through RNP, has stimulated regular discussion of oyster culture activities in Pará, which have been very helpful for the sector's development and growth. IHERs regularly took part in these discussions at the start, but the RNP statutes were changed in 2010 such that IHERs would only be invited to take part in the network on an *ad hoc* basis. The contribution from scientific research to supporting aquaculture in Brazil is sometimes neglected by the sector (Valenti & Moraes-Valenti 2010). de Andrade (2016) highlights the vital role of research and outreach over the three decades of development of the Santa Catarina bivalve culture industry. Thus, IHERs in Pará will need to systematically engage the sector more aggressively, securing partnerships with as many associations as possible and by demonstrating a continued and ample participation in the network, try to win back support for their regular inclusion in RNP.

One of the advantages of aquaculture in relation to fishing and seafood harvesting is a much stronger linkage to services and industry as well as a wider socio-economic effect associated with aquaculture (Byron *et al.* 2014). For example, in France, interaction between oyster culture, heritage and tourism may have potential, once tourist preferences are known (Dachary-Bernard & Rivaud 2013). In Brazil, there is a strong relationship between oyster culture and tourism and general culture, for example, the *Festa Nacional da Ostra e da Cultura Açoriana* or National Oyster and Azorean Culture Festival, which has taken place annually in Florianópolis, Santa Catarina, for the past 15 years (Corrêa & Müller 2016). Over the past 2 years, the oyster culture associations AGROMAR and AQUAVILA have received occasional visits from small groups where visitors tour the culture unit, sample the oysters and optionally spend a night there. Although oyster culture has a lower revenue than other industries, this is offset by greater ecological and social sustainability (lower rates of unemployment) (Chen *et al.* 2013), Oyster culture has been seen as a means of reducing poverty and unemployment in coastal communities (Olivier *et al.* 2013), and even where the sector has been recently established, such as in South Australia where oyster growing began at the end of the 1980s, there have been positive benefits for the local community (Pierce & Robinson 2013). Closer interaction between authorities and the oyster culture sector in New South Wales, Australia, has created benefits in relation to sustainability and the protection of estuarine habitats (O'Connor & Dove 2009). On the one hand, the Australian authorities have been proactive in regard to protecting estuaries where oyster culture is carried out, whereas, on the other hand, the oyster culture industry has moved to rely on laboratory-raised seed, as well as develop environmentally based research in aquaculture. Thus, there are sound social, economic and environmental reasons for the involvement of industry, services and government authorities, as well as the public in general, in supporting oyster culture. This is a situation which will certainly need strengthening in Pará state.

Licensing and environmental legislation

Environmental licensing from public authorities is designed to verify adherence to technical and legal obligations associated with certain activities in order to harmonize economic development with the protection of natural resources (Vianna *et al.* 2012). Currently, none of the oyster culture associations active in Pará state have been included in the areas designated as aquatic parks through the PLDM. According to SEBRAE/PA, five associations are exempt from licensing as each of their cultivable areas is less than two hectares (AQUAVILA and AGRONAM in Curuça,

AMPAP and ASSOPEF in São Caetano de Odivelas and AGROMAR in Augusto Corrêa). Oyster growers are now applying for registration with the Federal Government as aquaculturists. Up to now, none of the associations possesses a concession for use of water resources that is granted by the *Agência Nacional de Águas* (ANA, National Waters Agency).

Conclusions and future perspectives

Since the start of activities in 2006, oyster culture in Pará state has been assisted by government-funded projects. The sector has clearly grown in terms of on-growing capacity, production, number of producers and number of associations. Weaknesses in the sector that have emerged in recent years need to be tackled and include the need for transition to cooperatives, reducing the asymmetry in seed supply, the introduction of legislation for the protection of natural oyster beds, access to secure depuration facilities before sale, solutions to problems of the logistics of transport and packaging, diversification of marketing efforts, adoption of risk perception and management strategies, as well as increasing investments and partnerships with private enterprise and institutes of higher education.

Acknowledgements

We thank the oyster culture associations of Pará state for their cooperation and hospitality during the study, the *Serviço Brasileiro de Apoio a Micro e Pequenas Empresas* (SEBRAE/PA), for kindly providing data on the production and commercialization of oysters in Pará from 2011 to 2013, and Osmar Guedes da Silva Júnior (Universidade Federal do Pará) for calculating the on-growing area of each association. This study was funded by the *Conselho Nacional de Desenvolvimento Tecnológico e Científico* and the *Ministério de Pesca e Aquicultura* via Grant Number 406533/2012-1 and was carried out under Licence Number 28304-1 from the *Instituto Chico Mendes de Conservação da Biodiversidade*. We thank Vando José Costa Gomes, Me., for producing the map in Fig. 1.

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Data S1 Supplementary Material