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Implementation of aquaculture parks in Federal Government waters in Brazil

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Abstract

The Brazilian Government has been promoting studies on the zoning and demarcation of aquaculture parks dedicated to the production of fish in net-cages in the large public reservoirs of the country. The methodology employed for the zoning of these aquaculture parks consists of the execution in three consecutive stages of multidisciplinary evaluations for their social, environmental and economical characterization (global, regional and local). The purpose of the studies involves the generation of thematic maps and scenarios of environmental models that facilitate the process of understanding the regional peculiarities and taking the decisions to identify the most appropriate areas for the installation of the aquaculture parks. The application of this instrument for zoning the reservoirs will assist a more effective planning of investments and efforts, both by the government and by private initiative, in the aquaculture activity. With the implantation of aquaculture parks along the lines of an ecosystemic aquaculture, Brazil has the potential to become one of the largest producers of fish in net-cages in the world.

Key words: aquaculture, aquaculture parks, aquaculture zoning, public waters.

Introduction

World aquaculture output has increased substantially, from <1 million tonnes of annual production in 1950 to the 55.7 million tonnes reported for 2009, increasing at three times the rate of world meat production (2.7% from poultry and livestock together) in the same period. In contrast to world capture fisheries production, which has almost stopped growing since the mid-1980s (current catches are at, or close to, their maximum sustainable productions, with no room for further expansion), the aquaculture sector maintained an average annual growth rate of 8.3% worldwide between 1970 and 2008 (FAO 2011).

Therefore, aquaculture is a zootechnical activity in unmistakable and continual expansion. The forecast is that by 2030, the international demand for fish will increase by more than 100 million tonnes per year (FAO 2011).

In this context, Brazil with approximately 12% of the available freshwater on the planet (Tundisi & Tundisi 2008), 5.5 million hectares of waters impounded in lakes and reservoirs (ANEEL 2011) and a coastline extending more than 8000 km, is one of the few countries in conditions of attending the increasing world demand for fish from aquaculture.

One of the principal modalities of aquaculture being developed in Brazil is the rearing of freshwater fish, especially the Nile tilapia (*Oreochromis niloticus*) and, more recently the rearing of the tambaqui (*Colossoma macropomum*) and pintado (*Pseudoplatystoma* sp.) in net-cages systems installed in large reservoirs.

The utilization of the reservoirs for multiple uses in Brazil, aquaculture among them, was established by the National Policy of Hydric Resources in 1997 with the law n. 9.433. This legal framework was complemented by Decree No. 4.895, of 2003 and the Interministerial Normative Instruction No.6, of 2004, which regulate the use of Brazilian waters and public spaces, that is, the ‘Federal waters’, for the practice of aquaculture. In addition to this, the Interministerial Normative Instruction No.7, of 2005, specifies that up to 1% of the surface area of the federal waters are available for aquaculture purposes, which correspond to at least 55 000 hectares (ANEEL 2011).

Based on this regulatory framework, the Federal Government provided an incentive for the installation of fish-farming projects in reservoirs of hydroelectric power plants, as a means to increase food production and promote social development.

However, for the occupation of these areas to take place in an orderly manner and respecting the environmental peculiarities of each reservoir, the Brazilian Government is fostering the realization of technical studies for the implantation of parks and aquatic areas in the main Brazilian reservoirs. The aquatic areas are individual spaces dedicated to aquaculture, ceded by physical persons or legal entities. The aquaculture parks are groupings of diverse aquatic areas within a context of economy or production in ordered agglomeration.

The location of each aquaculture park is decided on the basis of a set of multidisciplinary studies that identify the best areas, estimate the maximum production attainable in these parks without compromising the local environmental stability and avoiding conflicts with other users of aquatic resources and environments. After their approval and processing in the respective government instances (Navy, National Agency of Waters, Secretariat of Patrimony of the Union, environmental organs (federal and state) and the Ministry of Fisheries and Aquaculture itself), the results of these studies are utilized for the environmental licensing of the aquaculture parks. The following step is to subdivide and allot the aquaculture areas of each park to the final public (entrepreneurs, fish farmers, fishing communities). The areas are ceded for a period of 20 years, renewable. The allotments take place in the social modality, which is free of charge, or else in the business modality which is onerous, that is, for a cost.

In this manner, the promotion of this activity in Brazil is being realized on the basis of technical, scientific and legal criteria that encompass the social, environmental and economic questions, enabling the ordering and subsequent management of these spaces dedicated to fish production. The zoning carried out in this fashion contributes towards a more effective planning system, in which the investments and the efforts, both by the government and by private initiative, are applied in accordance with the peculiarities of the zones, which are then dealt with as planning units. This methodology concurs with the concepts defended by Butsic *et al.* (2010), whereby the ordering and zoning tools should be directed towards evaluating and programming the use of the area, in accordance with its potential characteristics and aptitudes, taking into account the natural resources, the economic and social activities and the distribution of the population, within the framework of a policy of conservation and protection of the ecological systems.

The application of these concepts will permit in Brazil the development of an ecosystemic aquaculture, which should always be focused on three different levels: the local, comprising the aquaculture farm; the regional, represented by the body of water and by its hydrographical basin; and the global, in relation to the scale of the market. According to various authors, the ecosystemic aquaculture should respect three fundamental principles: (i) that activity should be developed in the context of the functions and services of the ecosystems, without degrading them beyond their capacity of resilience; (ii) that aquaculture should promote the well-being of humankind and be developed in equity with intervening activities; and (iii) that aquaculture must be developed in an integrated form with other socio-economic sectors (Soto *et al.* 2008; Halide *et al.* 2009; Aguilar-Manjarrez *et al.* 2010).

In this context, the objective of the present article is to approach the principal factors involved in the aquaculture zoning methodology that is being applied for the demarcation of aquaculture parks in Brazilian reservoirs.

Methodology for zoning aquaculture parks in Brazilian reservoirs

The principal objective of the studies sponsored by the Brazilian Government, in addition to zoning the reservoirs for the installation of aquaculture parks, is to stablish tools that permit the integrated management of the physical space in environmental, social and economic terms, as well as generating the information on the territory required to plan the sustainable occupation and use of the natural resources.

The methodology utilized for zoning the aquaculture parks in Brazilian reservoirs involves three consecutive stages of multidisciplinary evaluations for the social, environmental and economic characterization:

First stage

This commences with a macro analysis of the reservoir and surrounding region, with a view to the indication of the zones of preliminary priority for aquaculture, the exclusion of areas that present disadvantages for the installation of cultures or legal restrictions and, also, the orientation and panorama of the site for planning the execution of the next stages.

Second stage

The second stage involves a densification of the studies in the areas already indicated in the previous stage, by means of environmental models, the realization of support capacity scenarios, the development of mathematical models for evaluation of the dispersal of wastes and the exclusion of areas that confirm the presence of factors conflicting with the practice of aquaculture, to generate the demarcation of initial polygons of the parks with the conclusion of this stage.

Third stage

The third stage contemplates the last phase of the studies and defines the aptitude of the selected areas, considering the level of favourability of the allocation of small or large aquaculture ventures, the social profile of the local community and disposition towards the activity, as well as, the survey of the information required for the regularization and environmental licensing of the parks.

There follows a better specification of each of the stages of the environmental zoning process for purposes of aquaculture.

Stage 1 – global

The general objective of this stage is to indicate the areas that are not apt, as well as, those previously apt, in addition to orienting the sites and the features best deserving evaluations in the field during the subsequent phases.

To this effect, a survey is made of the information necessary for a preliminary selection of the technically adequate areas for aquaculture, by means of collections of data and secondary information, scientific research, official documents and those obtained from environmental regularization processes. In the case of the data not being available or being insufficient, primary information will have to be surveyed to subsidize the initial preparation of the maps of Obligatory Exclusion, Conditional Exclusion and of Conflicts and Facilities.

Map of obligatory exclusion

This consists of the geographical representation of the areas excluded due to physical or legal factors impeding the practice of aquaculture. Table 1 presents the elements comprising this map.

Table 1 Definition of criteria excluding areas for aquaculture

Maps of exclusion	
Exclusionary criteria	Specifications
Depletion zone*	Elevation Q95*
Depth†	≤4 m
Conservation units	Integral Protection Group
Small branches and compartments*	Areas ≤10 hectares

*Q95 – historical minimum elevation of the reservoir 95% of the time considered.
†These items of information must overlap each other.

The map shall represent the first cut-out made in the environment and, therefore, its elaboration must be concluded in the first stage of the studies in order for the subsequent evaluations and the collection of primary data to be directed towards a restricted area, thus optimizing the time and resources needed for zoning the aquaculture parks.

Depletion zone
This is defined as the difference between the maximum reservoir elevation and its operating elevation at level Q95, that is, it is the minimum elevation operated by the power plant during 95% of the energy-generating period. It must be stressed that the choice of the minimum elevation can vary, and in some cases, the historical minimum elevation may be chosen to guarantee the viability of the areas to be marked out for aquaculture.

The choice of this criterion may be due to the fact that in these zones, there can be – especially in the accumulation reservoirs – a very great variation in the depth, including completely drying out, thus making aquaculture unviable.

Depth
The minimum depth was defined considering the Brazilian legislation, specifically in accordance with the Interministerial Normative Instruction No. 07, of 2005, which establishes under Item 1 of its 1st article 'the depth of the area selected for implantation of cultures that require feeding shall consider the submerged height of the cultural structure plus a minimum distance of 1.50 m between the lower part of the structure and the alveoli of the body of water or the ratio of 1:1.75 m between the submerged part of the cultural structure and the clearance under the same, prevailing whichever is greatest'. In this manner, considering a net-tank of small size with a height of 2 m, at least 4 m of useful depth will be required to comply with the abovementioned legislation.

Conservation units of the integral protection group
The Conservation Units (CUs) are territorial spaces, created and instituted by the National System of Conservation Units, Law No. 9.985 of 2000, whose objective is the conservation of the natural resources. To this effect, the CUs are divided into two groups, integral protection and sustainable use. In this case, the CUs of the integral protection group do not permit compatibility between productive activities and, therefore, their limit is considered as an unfit area for demarcation of aquaculture parks.

Small branches and compartments
The Brazilian legislation, by means of the INI 06 of 2004, suggests that the entire area marked out for cultivation in net-tanks possess a ratio of dilution between 1:5 and 1:8 for

the allotment of the culture structures. For the delimitation of aquaculture parks, the Brazilian Government has utilized a dilution ratio of at least 1:10, as a measure to minimize the possible impacts generated during the operation of these enterprises.

In this sense, compartments of up to 10 hectares possess a useful area of one hectare, enclosing a maximum of 10 free-of-charge (social) areas or merely one area of the onerous (business modality). In this manner, the Ministry of Fishery and Aquaculture/MPA as a result of the costs and efforts spent in evaluating these areas failed to justify their potential for productive inclusion and chose to disregard them. It should be stressed that this criterion is easier to apply in more boxed-in reservoirs, in which the branches are well defined, and whose application requires cross-checking the information on depth and depletion zone.

Map of conditional exclusion

This map comprises all the elements restricting aquaculture, and which lack the proof of primary data concerning its presence and area of influence.

The preparation of this map commences in the first stage and can be finalized at the end of the studies. However, it is suggested that it be concluded at the very beginning of the studies, with the purpose of orienting the environmental models by disregarding all the unfit areas.

The elements that compose the conditional exclusion map can vary in function of the specific environmental characteristics of each reservoir and also in function of the level of knowledge regarding a particular locality. Table 2 presents the minimum criteria to be considered in preparing the map. It is emphasized that other elements can and should be incorporated, conditioned by the possibility of verifying the area of influence.

In the case of any information provided in the map of conditional exclusion not having its existence or area of influence verified, these items should be included in the map of conflicts and facilities which shall be dealt with below.

Map of conflicts and facilities

This map consists of a compilation of all the information that might conflict with aquaculture operations, although they might not be measurable, or might impede the activity. It also fulfils the function of adding information on logistics, local infrastructure, productive chain and others that might facilitate the use and support for the operation of aquaculture parks. Therefore, this tool has the objective of assisting the planning of the operation of the parks, managing conflicts, as well as, supporting decisions on the public investments necessary to make viable and implement the ventures.

The construction of this tool should commence during the secondary data compilation stage and only conclude at the end of Stage 3, which shall subsidize the decision regarding the social or entrepreneurial aptitude of the parks.

Table 3 lists some elements that might be utilized in the preparation of this map. However, as in the case of the conditional exclusion, its composition can vary as a function of the specifications of each environment.

Table 2 Indicators for preparation of the map with restrictions or conditional exclusion

Maps of restriction or conditional exclusion	
Exclusive restrictive criteria	Conditional elements
Emission of effluents	Verify data on area of influence against primary data
Water intake for human consumption	Evaluate safe distance from catchments of water for human, animal or crops against primary data (agriculture professional)
Water traffic	Only legally established routes or proven by documents
Safety areas	On condition that there is an approved Director Plan and verify related legislation
Underwater vegetation	Verify occurrence and influence on cultures
Mineral rights	Only legally leased areas considered and verify area of influence against primary data
Sustainable use CUs	Shall be restrictive when affected by contrary decision taken by their management council
Marinas	Only legitimate marinas are to be considered. It is necessary to consider their area of influence upon the cultures considering their dimensions
Leisure, tourism and scenery	Only areas used by legalized establishments are to be considered, requiring documentation proving legal compliance of the enterprise and demonstrating a position contrary to the activity
Indigenous lands	Only areas legally instituted by the FUNAI (National Indigenous Foundation). Require documents proving a position contrary to aquaculture
Use of the surroundings	Shall only consider impacts proven by primary data
Damping zone of CUs	Conform to the Resolution CONAMA (National Council for the Environment) no. 428 of 2010
Protected áreas	Areas recognized as historical, cultural and environmental patrimony

Table 3 Indicators for preparing the map of conflicts and facilities

Maps of conflicts and facilities	
Identification of conflicts and opportunities	Detailing
Access	Existence or not and characterization of same (vehicles capable of using it, type of soil, proximity to the highway network, etc.)
Urban zone	Proximity to urban centres, means of access, resorts, industries, etc.
Structures of support and promotion of aquaculture	Identify warehouses, ice factories, ration suppliers, net-tanks, moorings, cords; freezer packing houses, fish nursery, etc.
Highway network	Characterization of the network with regard to distances from centres of consumption of the product
Use of the surroundings	Characterize all forms of use and occupation of the areas evaluated
Elements of restitution	All the elements that cannot be verified in accordance with the specifications contained in the frame of restriction maps as elements of conflict

Stage 2 – regional

The general objective of this stage is to evaluate the areas previously suitable for the insertion of aquaculture parks, with the verification of the aptitude and the modelling of the capacity of the environment to support the activity.

To the effect, environmental models are developed that employ as inputs hydrodynamics information, bathometry, water quality, fetch of the wind, flow in the reservoir, zootechnical data on the species cultured and simulations of nutrient and solids dispersal.

The proposed environmental models intend, by means of the construction of scenarios, to simulate limit situations of nutritional enrichment of the environment resulting from aquaculture activities. This is attained by the utilization of the species best adapted to the environment being studied. Then, evaluations are made of the theoretical effects of increased contributions of nutrients upon the growth of the phytoplanktonic biomass in the simulated environment. The results are then employed to estimate the local production potential of fish by means of aquaculture.

Finally, the rates of nutrient dispersal and of particulate material generated in the aquaculture park must be tested by simulations. The results obtained can be used to reduce the aquaculture areas or reallocate them within the aquaculture park, depending on the pollution potential and the location of nutrient accumulation and particulate material zones. Table 4 presents the detailing of these models and their prerequisites.

Stage 3 – local

The objective of this stage is to define the fitness of the aquaculture parks in relation to the destination they will be given, that is, social ventures (free of charge) or business ventures (onerous), propose the delimitation by polygons of the areas of culture, compile the information required for their regularization and terminate the map of conflicts and facilities. The characteristics involved in the preparation of the map of favourability are variable, due to the peculiarities of each environment, of the available cultivation technologies and of the socio-economic profile of the surrounding communities. A process of hierarchical analysis (AHP) is used to define the fitness of the parks, which takes into consideration the environmental and zootechnical characteristics that directly influence the choice of the structures for the culture. As the technology is constantly changing and being perfected, this stage entails a socio-economic and environmental analysis with the intention of defining the characteristics that limit the use of different

Table 4 Factors presented in the map with the possible scenarios for the practice of aquaculture

Scenario		
Environmental modelling	Detailing	Prerequisites
Hydrodynamic modelling	Hydrodynamic modelling in the area of influence of the parks	Detailed bathometry; wind fetch; maximum and minimum flows
Culture species	Evaluate zootechnical and environmental indexes of the species indicated	Food conversion; culture cycle; provision of nutrients; tolerance to environmental factors
Feeds	Evaluate the nutrient contribution to the environment	Level of phosphorous nitrogen and organic matter; digestibility; time to disintegrate and rate of sedimentation
Water quality modelling	Model algae growth (eutrophication) with the enrichment of nutrients in the area studied, in order to establish the limits of nutrient input from aquaculture	Water quality and eutrophication level; ratio between nutrient input and algae growth
Dispersal modelling	Evaluate areas of nutrient accumulation resulting from the proposed activity	Compilation of all data generated for the realization of the remaining modelling

types of culture structures, together with the purchasing potential of the local communities, in the case of implanting social ventures. Merely as simplified examples, Table 5 presents the characteristics that can be utilized to differentiate a particular social aquaculture park from a business park.

For the proposed delimitation of the polygons relative to the aquaculture parks, the Ministry of Fisheries and Aquaculture/MPA suggests that the social areas (free of charge) should possess the minimum adequate dimension for providing an income of at least two minimum wages per month (at present equivalent to close to US$ 600.00). To this effect, the studies carried out in this last stage should compile the available zootechnical information on the species indicated for the culture and perform an economic feasibility analysis, considering the morphological characteristics of the region, beyond the analysis of the existence or not of legal restrictions on the cultivation of the species in the watershed.

Finally, a compilation is made of the remaining information required for compliance with the INI 06 from 2004, with a view to the regularization of the proposed areas and the final maps are prepared containing the proposed areas offered, in accordance with the summary of Table 5.

Aquaculture in public areas in the world

As the beginning of modern civilization, human beings have been altering and transforming wetlands, lakes, lagoons, rapids and rivers, in order to adapt them to their own needs. Surveys carried out in the Middle East and in Asia indicate that the reservoirs are engineering jobs that are being built for at least 5000 years (Petts 1984). The objective of these works has generally been the discharge of residual waters, navigation, fishing (Su *et al.* 2010), but principally flood control, irrigation and domestic water supply (Petts 1984). In recent centuries, the interventions of aquatic environments have been particularly dramatic, especially those caused by population increase, by industrialization (Barton & Fløysand 2010) and by the need to generate hydroelectric energy (Agostinho *et al.* 2007). At present, the rate of construction of reservoirs is close to one per day with close to 50 000 large dams built around the world, that, together, impound more than 6500 km^3 of water occupying an area equivalent to the territory of France (Nilsson 2009).

Table 5 Favourability Map Indicators

Maps of favourability	
Aquaculture favourability	Detailing
Water quality	Consider ranges of environmental comfort and zootechnical performance of the species indicated for the culture
Hydrodynamics*	$\leq$0.3 m s^{-1} small-size ventures $\geq$0.3 m s^{-1} large-size ventures
Bathometry*	Up to 20 m small-size ventures Over de 20 m large-size ventures

*Will vary according to resevoir characterists.

Table 6 Zoning map of the aquaculture parks

Zoning map of aquaculture parks	
Elements composing the maps	Detailing
Type of areas	A proposal of areas shall be made in accordance with the social or business fitness of the Parks
Size	Definition of the minimum sizes for the social areas and maximum sizes for the business areas
Spacing	Proposal of minimum spaces between the culture areas
Polygons	Final definition of the polygons of the Aquaculture Parks

According to Cowx *et al.* (1998), the production of fish in reservoirs has the potential to contribute significantly to the worldwide offer of fish, especially in Asia (De Silva 2002) and in South America (Petrere 1996).

Aquaculture is considered to be a viable source of cheap and high-quality protein, principally in developing countries suffering a shortage of protein (El-Gayar & Leung 2000). For this reason, the flooded areas of artificial lakes and lagoons are increasingly being employed for aquaculture (Ayer & Tyedmers 2009; Barton & Fløysand 2010). In addition to food production, the expansion of this activity in reservoirs generates benefits for the regional economies in the form of jobs and income throughout the entire aquaculture production chain (Ross *et al.* 2011), constituting an important productive alternative for the populations affected by dams, for example (Abery *et al.* 2005).

The cultures in public waters and spaces, using net-tanks, pens or cages, are already the principal means of production of aquatic organisms in Asia, especially in rivers and reservoirs (Beveridge 2004), with emphasis on China, Thailand, Cambodia and Vietnam (Phouthavongs 2006). Merely in 2005, 704 254 tonnes of aquatic organisms were produced in lakes, rivers and reservoirs in China (Chen *et al.* 2007). The principal species cultivated in these systems on the continent are Chinese carp (*Cyprinus carpio carpio*), Pangas catfish (*Pangasius pangasius*), catfish (*Ictalurus punctatus*), snakehead species (*Channa* spp.) and, more recently, the tilapia (*Oreochromis niloticus*) (De Silva & Phillips 2007). An example of the large growth of aquaculture development in public waters in Asia occurred in Laguna Bay, the largest reservoir in the Philippines. The area occupied by the fish culture structures leapt from barely 38 hectares in 1970 to more than 30 000 hectares in 1983 (Nepomuceno 2004), coming to occupy one-third of the entire surface of the lake (Hambrey *et al.* 2008).

According to Rojas and Wadsworth (2007) in South America and in the Caribbean, the ventures carried out in net-tanks and cages mainly involve marine environments, principally dedicated to the culture of salmons (*Salmo salar*), notably in Chile. Nevertheless, there is great regional potential for the production of tilapia – the principal freshwater species cultivated in South America and the Caribbean – in public waters. Fitzsimmons (2000) estimated that over an interval of 10 years, tilapia production in net-tanks and cages would leap from 10% to 30% of the total produced by tilapia culture in the region. The greatest potential, in this case, is that of Brazil, which possesses more than 32 500 km^2 of areas flooded by reservoirs (Agostinho *et al.* 2007). In general, there is a great lack of statistical information relating to fish production and to the values generated in public waters around the world, a situation repeated in North America. According to Masser and Bridger (2007), what is known is that the production in rivers and lakes of the United States is insignificant and that few states permit the practice of aquaculture in public waters. In this respect, Canada advances in the development of a legal framework and technologies that permit the sustainable development of the activity. In 2003, close to 80% of the 4550 tonnes of rainbow trout produced in Ontario, Canada, were cultivated in net-cages (Brister & Kapuscinski 2000). However, the cultures in net-tanks and cages in North America are practically limited to the rainbow trout (*Oncorhynchus mykiss*) and the channel catfish (*Ictalurus punctatus*).

In Europe, the use of net-tanks and cages also prevails in marine environments. In freshwaters, the fish culture in cages is only practised on a small scale, generating insignificant volumes and principally involving the production of rainbow trout in countries like Italy, Turkey, Cyprus (Cardia & Lovatelli 2007) and Norway (Grøttum & Beveridge 2007).

According to Brummett *et al.* (2008), in Africa, despite 40 years of research and development and hundreds of millions of dollars spent, aquaculture as a whole is far from realizing its high environmental potential. The activity is still seriously hampered by ineffective institutional arrangements, although there are some successful large-scale commercial fish production experiences in public waters, notably in Tanzania, Uganda and Zimbabwe (tilapia produced in cages and principally directed to exportation) and in Zambia, Kenya and Ghana (also produced in cages but addressing the local markets).

In Oceania, the net-tank and cage ventures present large competitive disadvantages in comparison with other regions, principally with regard to Asia. The costs of labour in Australia and New Zealand are quite high, the same as for the majority of the items that comprise the production costs of aquaculture products (Tacon & Halwart 2007).

Risks of aquaculture in public areas

The development and promotion of aquaculture need to give the more planned and orderly manner. In Brazil, one of the aquaculture sectors that have shown an incremental growth is the shrimp aquaculture, which has increased by about 20% per year during the last decade along the NE coast of Brazil due to the optimal climate and environmental setting (Lacerda 2006), despite all the very restrictive legislation, in both federal and state wise. As already documented in the literature, the rapid expansion of shrimp aquaculture ponds may induce potentially detrimental changes in extent and health of coastal habitats utilized by migratory shorebirds (Zitello 2007). Although this same author reported in his work, aimed to describe the landscape changes that occurred between 1990 and 2006 in coastal Northeast Brazil as a result of increased shrimp pond development, pointed out that contrary to the literature, the expansive tidal salt flats in the study area, not mangrove forests, are experiencing the greatest destruction as a result of shrimp aquaculture. Similar conclusion was also drawn from Guimarães *et al.* (2010) where they conducted a study using remote sensing methods and a geographical information system with the aim of quantifying the participation of this activity in the reduction in the mangrove areas along the northern coast of the State of Pernambuco (northeast, Brazil), and concluded that the real contribution of shrimp farming to this reduction was just 9.6% (197 ha) of the total area (2052 ha of mangrove). Other anthropogenic activities, such as agriculture, urban expansion and tourism, contributed greatly to the reduction in the mangrove areas in this state. In that way, Brazilian legislation has recently implented significant change with the new forest code, law no. 12 727 from 17 October 2012, in which defines the areas (land) that can be used for agriculture production, and more specifically separates and classifies mangrove and saltmarshes (tidal salt flats) determining in what way it can be used by the farms adjacent to it. The occupation of public areas for aquaculture purposes can not commit possible errors observed when the expansion of shrimp farming in the country. In this context, zoning aquaculture is an important tool for public management of the activity.

In terms of fish, Brazil has more than 40 native species that can be grown in their reservoirs and lakes (Godinho, 2007). And those currently among the top five commercial species grown in terms of production volume are tambaqui (*Colossoma macropomum*) in third place with 11.3% of the total aquaculture production, followed by their hybrid (tambaqui x pacu) and pacu (*Piaractus mesopotamicus*); however, if we consider the volume of production for tambaqui and its hybrids as a category 'round natives fish' it would be in second place with 21.3% of total national aquaculture production in 2010 (MPA 2010). However, the most studied species, and produced in the country, is still the Nile tilapia (*Oreochromis niloticus*), which is not native, but an exotic species of African origin and had their lineage developed in Japan and improved in the Royal Chitralada Palace in Thailand, being introduced in Brazil in 1996, from fingerlings donated by the Asian Institute of Technology (AIT).

Tilapia production in the Brazil increased 105% in just 7 years and is currently around 155 000 tons per year, which represents 32.4% of the production of farmed fish in the country (MPA 2010). Due to the significant increase in production of this exotic species introduced in South, Southeast, Midwest and Northeast regions of Brazil, there are increased concernes with the ecological risk that this may have for other native species for reasons of competition, predation and sanity. Simberloff (2011) suggests that the impacts caused by invasive species relate both to changes in ecosystem processes, such as in communities and in their structure. According to Pelicice *et al.* (2013), the increase in the installation of aquaculture crops may create opportunities for the occurrence and spread of invasive species across the country, with the risk of damaging the biodiversity of native species, ecosystem functioning and the condition of the environment on a continental scale. Britton and Orsi (2012) claim that the establishment of populations of invasive species impacts the diversity of native fish species. On the same line, salmon aquaculture worldwide has been the focus on of the causes for the loss of biodiversity on the natural stocks, but in a recent study from Jackson *et al.* (2013) on the impacts of aquaculture and freshwater habitat, they found no correlation between the presence of aquaculture and the performance of adjacent wild salmon stocks, pointing that freshwater habitat quality was found to have a highly significant correlation with stock status. The nature of these impacts is specific to each species, as it differs according to the ecological characteristics.

In this context, the Brazilian Institute of the Environment, IBAMA published the 145N Ordinance in 15 October 1998, laying down strict rules for the introduction, reintroduction and transfer of fish, crustaceans, molluscs and aquatic macrophytes for aquaculture in national territory delimited watersheds. This ordinance defines and limits the growing of tilapia in certain regions of Brazil and consequently in reservoirs and lakes where the species is not established, for example, banning the cultivation of this species in the Amazon Basin.

Despite their evident economic and social benefits, the ventures directed to fish culture in public waters, unless they are developed under strict planning, ordering and monitoring can entail risks to the environment (Costa-Pierce & Bridger 2002). The major impacts relating to aquaculture in rivers, lakes and reservoirs are linked to the increase in the inflow of particulate and dissolved nutrients into the environment (Guo 2003; Sugiura *et al.* 2006; Azevedo *et al.* 2011; Gondwe *et al.* 2011) the occurrence of fish mortalities and losses of biodiversity (Sang 2006); contamination by chemical compounds (through the use of antifouling, antibiotics, parasiticides, anaesthetics and disinfectants) (Burridge *et al.* 2010); localized reductions in the concentrations of dissolved oxygen (Hamblin & Gale 2002); occurrence of toxic algae blooms (Sowles 2009); in the increase in concentrations of organic matter and metals in the sediment (Chou *et al.* 2004); alterations in physiochemical properties and biodiversity of the microflora of benthonic sediments (Buschmann *et al.* 2009); introduction of exotic species (Arthur *et al.* 2010); dissemination of illnesses that can affect wild stocks (Israel 2007) and, in some cases, cause direct conflicts with other users of hydric resources and other adverse social impacts (Béné & Obirih-Opareh 2009).

An analysis of experiences worldwide shows that aquaculture in public waters today faces some large challenges before consolidation in a sustainable manner, such as, for example: to create bases for sustainable economic development; promote an adequate environmental management and the equitable distribution of the benefits; clearly define the roles of the public and private sectors in the process; create mechanisms for coexistence between large and small ventures; maintain coherence with other policies and strategies, such as those relating to reduction in poverty or industrial development; guarantee respect for the rights of the traditional populations; dedicate research on scientific bases, on the support capacity of the aquatic environments (Philminaq 2008; Sowles 2009). To this effect, the execution of governmental-planning programmes dealing with the occupation of physical spaces and the use of the aquatic resources plays a key role in the future of aquaculture in public waters.

What is observed, however, is that in a general manner, there is a certain institutional incapacity of the countries in fostering aquaculture on adequate lines. Either the environmental laws are so strict that they impede the development of aquaculture in lakes, rivers and reservoirs, or else they are so mild and their application is so uncontrolled, that they impede avoidance of the already mentioned and unacceptable adverse effects upon the environmental goods and services and ecosystems. In addition to this, due to their complexities, the planning of aquaculture development in public waters can be difficult without the assistance of modern decision-taking technologies, although, on the other hand, the utilization of such tools in aquaculture is still incipient (El-Gayar & Leung 2000). One of the exceptions is Ontario, in Canada, where these systems have been incorporated into the process of ceding public waters and the aquaculture has developed in a compatible manner with other multiple uses and interests (OMNR 2009).

In Africa, in a general manner, both the policies of promoting aquaculture, and those of environmental conservation, are still scarce (Brummett *et al.* 2008; The WorldFish Center 2010).

In Asia, the promotional policies are generally superimposed over those that could guarantee environmental stability (Islam 2005), especially in the cases in which the ventures prove lucrative. Under those conditions, the governments have encountered difficulties in regulating the activity (Philminaq 2008).

In China, there are more than 100 public policies, laws and environmental regulations (Liu & Diamond 2005). The laws forbid, for example, the installation of any enterprise that might pollute aquatic environments. What happens is that the laws are simply disobeyed and, in this manner, have little effect in braking the rhythm of degradation of the aquatic resources (Su *et al.* 2010). According to Liu and Diamond (2005), China will need a real 'environmental miracle' throughout the next decades to complement the 'economic miracle' experienced in the country in the most recent decades.

Even so, the worldwide trend is for, in addition to the emission of authorizations, licences and collection of taxes, the national governments to be increasingly compelled to concern themselves with the protection of the environment and the sustainable management of the aquatic resources.

In Chile, aquaculture ventures must obtain the consent of the National Water Commission. There are regulations on exotic species, medicines, residual waters, the use and application of hormones and antibiotics, rations and strict rules for the occupation of public waters (D'Andrea 2005; Rojas & Wadsworth 2007). Even so, the government does not issue new authorizations for the use of lakes for aquaculture (OCDE, CEPAL 2005). In Denmark, which until the 1980s decade did not even demand environmental licensing for aquaculture projects, today there is rigorous legislation controlling the inputs of nitrogen and phosphorus to the aquatic environments, which even limits the characteristics of the feeds and is severely audited (Skonhoft 2005; Su *et al.* 2010).

In Oceania, the limited availability of sites for culture and rigorous legislation related to environmental licensing limits the development of continental aquaculture in public waters (Tacon & Halwart 2007).

However, beyond the eminently legal or environmental questions, there are problems with the competence of institutional attributes and conflicts between competences that have limited the development of aquaculture in the world. In many countries, the ceding of areas for purposes of continental aquaculture in public waters is managed on the state or municipal levels (Productivity Commission 2004; WorldFish Center, PRIMEX Inc 2007), which hinders the realization of efficient zoning, the delimitation of the total number of ventures in a particular lake or reservoir, or even the number of cages, the stocking densities employed and the management practices adopted (Mercene-Mutia 2001). In the United States, on the other hand, the majority of the states possess environmental agencies that regulate access to public waters and these agencies, in addition to failing to motivate, often prohibit the use of reservoirs and lakes for purposes of aquaculture (King 2006; Masser & Bridger 2007).

Due to this, at present, there is a tendency for the zoning for utilization of rivers, lakes and reservoirs for purposes of aquaculture to be executed at the federal level, however, it also entails the involvement of state institutions, as already happens in Brazil and in Mexico (Ross *et al.* 2011). This model permits adequately dealing with central questions relating to aquaculture zoning, such as: carrying out a strategic environmental analysis for the aquaculture; the definition of water quality standards to be respected; forecasting the load of nutrients and solid wastes and of possible conflicts and the development and application of support capacity models; the development of effluent dispersal models for different types of aquaculture; the compatibility between the multiple uses of the resources and physical spaces, minimizing conflicts; the development of integrated and geo-referenced data banks; the execution of environmental impact studies; the establishment of environmental monitoring programmes; and, principally, the establishment of means to ensure the legislation is effectively obeyed (Abery *et al.* 2005; Israel 2007; WorldFish Center, PRIMEX Inc 2007; Philminaq 2008; Sowles 2009).

According to Philminaq (2008), some trends commence to be observed in relation to aquaculture throughout the world. In parallel with the zoning process, the governments have fostered the adoption of systems improving the quality of processes relating to aquaculture and supported the implementation of programmes like Risk Analysis and Critical Control Points (HACCP), Good Management Practices, capacity building and training programmes, of certification ISO 9000 (quality) and ISO 14000 (environment), in addition to defining rules and regulations applicable to the productive chain. In the same manner, there is ever more frequent involvement of companies and producer associations in the establishment of rules and regulations or of specific codes of conduct that are applicable to their own productive processes, which is very important, because whatever degradation observed in the aquatic system, where they are installed and producing, will affect their aquaculture production. Systems are also beginning to be created and applied to tracking in fishing and aquaculture. In this context, the Brazilian programme for aquaculture in park can make an important contribution to the more orderly development of the activity.

Final considerations

Further analysis of the model adopted by Brazil for aquaculture zoning can only made from the operation of the parks currently being installed. But there is no doubt that the country is heading in a right direction.

One of the main points that still need to be investigated is the development and even the operation of analytical methods to estimate the carrying capacity in Brazilian reservoirs and even worldwide.

The importance of estimating the reservoirs carrying capacity as in means of ensuring the sustainability of aquaculture in cages, especially considering that the vast majority of the freshwater reservoirs have multiple users with interests quite distinct, is unquestionable.

However, most of the mathematical models used to evaluate the carrying capacity for fish production in net-cages were designed for species and conditions quite distinct from those found in Brazilian reservoirs. In addition, monitoring data series for long-term calibration models are scarce, so it is extremely important to develop and improve tools that help managers and regulators of water issuing for aquaculture in the country, thus contributing for the planning and organization the fish production in reservoirs to minimize possible impacts of aquaculture in the aquatic ecosystem.

In Brazil, the National Water Agency (ANA) uses Dillon and Rigler model to calculate carrying capacity in the reservoirs. However, this choice seems to be more a consequence of the data limitation and relative simplicity in estimating the parameters properly than for adequacy of this model. ANA will hardly abandon this methodology before there is conclusive studies on the effectiveness or appropriateness of other models to determine the carrying capacity of the Brazilian reservoirs.

The Brazilian Ministry of Fisheries and Aquaculture/MPA developed guidelines and standards, together with other ministries and agencies towards the standardization of data and methodologies for aquaculture parks implementation in federal waters, which is a unique prerogative of the Ministry. These studies have been carried out through agreements with institutions and universities, by contracting sector companies through public tenders and through public announcements, and implemented by research development agencies (CNPq and FINEP/MCTI), as well.

Thus, it is critical that it is necessary to have more incentives for universities and research institutions to develop studies about the issues related to aquaculture carrying capacity. The research should be centred in the studies on the digestibility of phosphorus and protein (nitrogen) for cultured fish species in cages; on analyses and methodologies for dispersion of nutrients and diets in the culture environment; in evaluating impacts to reservoirs waters resulting from the use and occupation of land (leaching of chemical fertilizers and organic farming and grazing, discharge of domestic and industrial effluents untreated livestock manure, among others). The important thing is to start this approach in Brazil to have a systemic picture and use of these environments. For this, it is important to establish the use of monitoring tools and management of the aquatic environment in real time to ensure consistency and quality of data. Furthermore, producers and entrepreneurs, feed mills, regulatory agencies, educational and research institutions need to define codes of conduct and management practices for environmentally responsible aquafarming.

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