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Multi-scale sustainability indicators system for mariculture assessment in Brazil

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Dr. D. Ricardo Haroun Tabraue, Dr. D. Marcus Polette y Dr. D. Wagner Valenti, Investigadores de la Universidad de Las Palmas de Gran Canaria, Universidade do Vale do Itajaí y Universidade Estadual Paulista, respectivamente, informan:

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“Multi-scale sustainability indicators system for mariculture assessment in Brazil”

Nalu Franco Gerent

Doctorado en Acuicultura: Producción Controlada de Animales Acuáticos.

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Las Palmas de Gran Canaria, 2017

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Dr. D. Ricardo Haroun Tabraue

Dr. D. Marcus Polette

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anexo 2

Com todo meu amor,
aos meus pais.

"I used to think the top environmental problems were biodiversity loss, ecosystem collapse and climate change.

I thought that with 30 years of good science we could address those problems.

But I was wrong. The top environmental problems are selfishness, greed and apathy...and to deal with those we need a spiritual and cultural transformation

–and we scientists don't know how to do that"

Gus Speth

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Resumen

La acuicultura ha sido reconocida como una importante herramienta para el desarrollo sostenible. Puede contribuir a solucionar los problemas de la sobrepesca, a la vez que provee a las necesidades humanas de alimento y desarrollo socioeconómico. La acuicultura sostenible es la que cultiva los organismos, generando renta y beneficios sociales, sin afectar negativamente al medio ambiente (Valenti 2002).

Brasil posee un gran potencial para el desarrollo de distintas modalidades de maricultura, aunque, dada la actual situación política y económica que afronta, los sectores de la pesca y acuicultura no figuran como prioridades importantes de gestión. La inclusión de la maricultura como un poderoso agente en el desarrollo sostenible de zonas costeras, requiere una herramienta de evaluación adecuada para medir su sostenibilidad. El uso de indicadores, más concretamente de indicadores de sostenibilidad, es una herramienta ampliamente utilizada para cumplir con ese propósito.

En esta tesis se ha enfocado en la sostenibilidad de la acuicultura marina (= maricultura) en Brasil. Esta memora de Tesis Doctoral busca contribuir para el entendimiento de la complejidad de la realidad de la maricultura en Brazil, y proveer herramientas de evaluación. De este modo, se propone: 1. Revisar el desarrollo histórico de la maricultura en Brasil; 2. Presentar un método mixto para el desarrollo de indicadores y un sistema de insicadores multi-escalar para evaluar la sostenibilidad de la maricultura en Brasil. 3. Evaluar el nivel de sostenibilidad de la maricultura, utilizando el sistema de indicadores en distintos estudios de caso.

Reunir información official y fiable sobre la maricultura en Brasil es todo un desafio. A pesar del poco interés en la maricultura, por parte algunas esferas del gobierno, el sector académico ha fomentado el desarrollo de la maricultura, reflejado en el gran numero de publicaciones sobre esta temática. El desarrollo de la maricultura en las costas brasileñas ha afectado el modo de vida de sus habitantes. El cultivo de camarones es el sub sector de la maricultura que más ha provocado daños ambientales y conflictos. Aún existen numerosos desafíos legales y tecnológicos que impiden que el país alcance su potencial de desarrollo de una industria acuícola robusta y sostenible.

En el desarrollo del sistema de inicadores multi-escalar se ha adoptado un protocolo Delphi. Se han seleccionado 29 indicadores que incluyen la diversidad de los sistemas de cultivo existentes en el país, a ser aplicados en el nivel del cultivo, del estado, y a nivel nacional. El conjunto de los indicadores ayuda a enfatizar los valores que deben ser reforzados en el desarrollo de actividades en la costa, a fin de promover la integración de la maricultura en el desarrollo de las zonas costeras. La evaluación de la implementacion y eficiencia de la gestión y de las politicas relacionadas al sector, en las diferentes escalas, facilita el desarrollo de soluciones en el nivel que corresponde.

Esta investigación es pionera en la valoración de la sostenibilidad de la maricultura en Brasil en las diferentes escalas. Dos cultivos de bivalvos, y una empresa de producción de alevines fueron evaluados. A nivel estatal, se consideró el estado de Santa Catarina. En general, la sostenibilidad del cultivo #1 y del laboratorio, resultaron en un nivel de sostenibilidad “Regular”, mientras el cultivo #2, fue evaluado en “Bajo”. El estado de Santa Catarina presentó una sostebilidad de la maricultura “Baja”. A nivel nacional, los resltados obtenidos consideran que la maricultura posee “Muy baja” sostenibilidad.

La gobernanza ha resultado una dimension muy importante para la sostenibilidad de la maricultura, ya que afecta a las otras dimensiones. Se recomienda la inclusion de nuevos indicadores de gobernanza en el ssystema de indicadores. Además, se espera que el Sistema de indicadores propuesto sea periodicamente revisado para acompañar la evolución del sector de la maricultura y los requisitos de sostenibilidad.

Resumo

A aquicultura é reconhecida como uma importante ferramenta para promover o desenvolvimento sustentável. A atividade contribui para solucionar problemas relacionados à pesca predatória, e responder às necessidades humanas de alimentação e desenvolvimento socioeconômico. Uma aquicultura sustentável é aquela que cultiva organismos, gerando lucro e benefícios sociais, sem promover a degradação ambiental (Valenti 2002).

O Brasil tem um grande potencial de desenvolvimento de diversas modalidades de maricultura, porém, devido às recentes crises políticas e econômicas, o setor não tem sido reconhecido como prioritário. A inclusão da maricultura como poderoso agente de desenvolvimento sustentável de zonas costeiras, destaca a necessidade de uma ferramenta de monitoramento adequada para avaliar a sustentabilidade da maricultura. Indicadores de sustentabilidade têm sido amplamente utilizados para avaliar processos de desenvolvimento no contexto do desenvolvimento de zonas costeiras.

Esa tese será focalizada na sustentabilidade da maricultura no Brasil. O projeto busca contribuir para o entendimento da complexidade da realidade da maricultura no Brasil, e oferecer ferramentas para a sua avaliação. Logo, é proposto: 1. Revisar o histórico do desenvolvimento da maricultura no Brasil; 2. Apresentar uma metodologia mixta para o desenvolvimento de um conjunto de indicadores e um sistema de indicadores multi-escalar, para avaliar a sustentabilidade da maricultura no Brasil; e 3. Avaliar o nível de sustentabilidade da maricultura no Brasil, aplicando o sistema de indicadores em alguns estudos de caso.

Existe um grande desafio na aquisição de informação oficial e confiável sobre a maricultura no Brasil. A pesar do escasso interesse de algumas agencias governamentais pela aquicultura, o setor acadêmico tem contribuído para o desenvolvimento da maricultura, dado o alto número de publicações no assunto. O desenvolvimento da maricultura ao longo do litoral brasileiro influenciou o estilo de vida das comunidades. A carcinicultura é o sub-setor da maricultura que mais provocou degradação ambiental e conflitos. Ainda existem grandes desafios legais e tecnológicos que impedem que o país alcance seu máximo potencial de desenvolvimento de uma indústria aquícola robusta e sustentável.

Para o desenvolvimento do sistema de indicadores, se adotou um protocolo Delphi. Foram selecionados 29 indicadores, que compreendem a diversidade de sistemas de maricultura existentes no país, nos níveis de cultivo, estadual e nacional. O conjunto de indicatores ajuda a realçar valores que devem ser reforçados, buscando a integração da maricultura no desenvolvimento costeiro. A avaliação da implementação e da eficiência da gestão e de políticas nas diferentes escalas, facilita a geração de soluções no nível correspondente.

Esta pesquisa é pioneira em medir a sustentabilidade da maricultura no Brasil, em diferentes escalas. Foram avaliados dois cultivos de bivalves e um laboratório de produção deb alevinos. Na escala estadual, foi avaliado o estado de Santa Catarina. Em geral, os cultivos #1 e o laboratório de alevinos, #3, presentaram sustentabilidade "Média", e o cultivo #2, "Baixa". Santa Catarina apresentou um nível "Baixo", enquanto o país como um todo, apresentou sustentabilidade "Muito baixa" no setor da maricultura.

A governaça foi considerada uma dimensao muito importante na sustentabilidade, já que afeta às outras dimensões. Se recomenda a inclusão de novos indicadores de governaça no sistema proposto. Além disso, se espera que o sistema de indicadores apresentado seja periodicamente atualizado, para acompanhar a evolução da maricultura e os requisitos de sustentabilidade.

Abstract

Aquaculture has been recognized as an important tool for promoting sustainable development. It may help solve the problems related with over-fishing, while attending human needs of nurture and socioeconomic development. A sustainable aquaculture practice is one that rears organisms, generating profit and social benefits without degrading the environment (Valenti 2002).

Brazil has a huge potential for the development of many modalities of mariculture activities, but due to a growing political and financial crisis, the fisheries and aquaculture sectors are being neglected. The embracement of aquaculture as a powerful agent in promoting sustainable development of coastal zones emphasizes the need for a proper monitoring tool to evaluate aquaculture sustainability. Sustainability indicators are widely used as tools to assess diverse processes regarding coastal development issues.

This thesis will be focused on marine aquaculture (mariculture) sustainability in Brazil. This project aims to contribute to the understanding of the complexity of the reality of mariculture in Brazil and to provide tools for its assessment. Thus, it is proposed: 1. To review the historic development of mariculture in Brazil; 2. To present a mixed approach methodology for the development of a set of indicators and a multi-scale indicators system to evaluate the sustainability of mariculture in Brazil; and 3. To evaluate the level of mariculture sustainability in Brazil, by applying the indicators system in a few study cases.

It is challenging to gather reliable and official data on mariculture in Brazil. Despite the low interest shown in mariculture issues by some governmental authorities, the academic and research sectors aims towards mariculture development, given the high number of publications. Development of mariculture along the Brazilian coasts has influenced the lifestyle of the local communities. Shrimp farming is the main subsector within mariculture to cause environmental degradation and conflict. Still there are many legal and technological challenges that prevent the country to achieve its full potential to develop a robust sustainable mariculture industry.

For the development of the multi-scale indicators system, a Delphi protocol was adopted. It resulted in a set of 29 indicators, which comprise the diversity of existent mariculture systems in the country, to be applied at farm-level, in the state or considering the whole country. The set of selected indicators helps highlight values that should be reinforced in the development of coastal activities, in favor of mariculture integration in coastal development. Assessment of implementation and effectiveness of management and policies at the different scales facilitates the development of solutions at the level of the incumbent authority.

This research is pioneer in measuring the sustainability of mariculture in Brazil at different scales. Two bivalve farms, and one fingerling nursery were assessed. The state of Santa Catarina was evaluated at regional level. Overall, bivalve farm #1 and fingerling farm #3 both presented “Average” level of sustainability, while bivalve farm #2 scored “Low”. The mariculture sector in Santa Catarina was considered to have a “Low” sustainability level. Furthermore, considering the sector at national scale, Brazil presented a “Very low” level of mariculture sustainability.

Governance resulted to be a very important dimension for mariculture sustainability, since it affects the sustainability of the other dimensions. The inclusion of new governance indicators in the proposed system is recommended. Furthermore, it is expected for the indicators system proposed to be periodically updated according to the evolving situation of the mariculture sector and sustainability requirements.

Sumario

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BFT – Biofloc Technology

DPSIR – Driver-Pressure-State-Impact-Response

EPAGRI – Empresa de Pesquisa Agrícola e Extensão Rural de Santa Catarina/ Agriculture Research and Rural Extension Company of Santa Catarina

FIPERJ – Fundação Instituto de Pesca do Estado do Rio de Janeiro/Fundation Institute of Fisheries of the state of Rio de Janeiro

FURG – Universidade Federal do Rio Grande/Federal University of Rio Grande

IBAMA – Instituto Brasileiro de Meio Ambiente e dos Recursos Naturais Renováveis/Brazilian Institute of Environment and Renewable Natural Resources

IBGE – Instituto Brasileiro de Geografia e Estatística/Brazilian Institute of Geography and Statistics

ICZM – Integrated Coastal Zone Management

IMTA – Integrated Multi-Trophic Aquaculture

LMM – Laboratório de Moluscos Marinhos/Marine Mollusks Laboratory

MMA – Ministério do Meio Ambiente/Ministry of Environment

MPA – Ministério de Pesca e Aquicultura/Ministry of Fisheries and Aquaculture

PLDM – Planos Locais de Desenvolvimento da Maricultura/Local Plan for Mariculture Development

PNGC – Programa Nacional de Gestão Costeira/National Program for Coastal Management

UFSC – Universidade Federal de Santa Catarina/Federal University of Santa Catarina

1. Introduction

1.1. Contextualization/Background

1.1.1. Aquaculture

Fisheries' productivity has declined due to overexploitation of fish stocks. Whereas fishing intensity increases in all regions, captures are either stabilized or declining since the mid-1990s (McClanahan et al. 2015). Watson et al. (2013) document a 10-fold increase in the fishing effort in offshore waters while catch per unit power in 2006 was half of what it was in the 1950s. Depletion of fish stocks has caused diverse impacts on the marine and oceanic ecosystems. Molfese et al. (2014), for instance, report that large, high trophic level species have been increasingly replaced by smaller, low trophic level fish and invertebrates. Environmental impacts or degradation of such nature, may ultimately affect the ecosystem's ability to deliver its food security services (Agardy and Alder, 2005). Thus, the environmental impacts are cause of social conflicts due to competition for space or resources (Chuenpagdee et al. 2016). Facing this situation, it becomes necessary to implement conservation measures (FAO 2016a; McClanahan et al. 2015). Conservation and sustainable management of oceans and coasts promote ecosystem's productivity, and hence, the basis of a sustainable economy (UN 2012).

Aquaculture is defined by FAO (2017) as the farming of aquatic organisms, including fish, crustaceans, mollusk, reptiles, amphibians and plants. Aquaculture requires some form of intervention to enhance production, such as feeding, protection, stocking, etc. Rabanal (1988) describes four theories on the origins of aquaculture: 1. Oxbow theory, in which the naturally formed oxbows would be artificially enclosed to trap the fishes inside, taking advantage of the geographic characteristics and flooding regimes; 2. Catch-and-hold theory, where the water areas, previously built for other purposes such as recreation or defense, were also used to grow fish. Some species, such as the common carp, adapted better to this artificial environment than others, and with time, species selection, stocking density and feeding systems were perfected; 3. Concentration theory, which regards to flooded areas in rainy seasons, which would gather fish and other aquatic organisms. In the dry season, the floodlands would gradually recede, leaving only a few watered depressions. Some juvenile fish would be left, or transferred to other more suitable areas, for growth and reproduction. This method is still practiced in some regions in the African continent; 4. Trap-and-crop theory, which refers to brackish and marine areas that are affected by tide oscillations. The tidal pools, natural or artificial, that would be exposed at low tides, would trap marine invertebrates and fishes which could be easily captured. As this practice expanded, the amount of organisms collected declined. A periodic "closure" management practice was then established. The pools would be harvested once every one to three months, allowing organisms to grow bigger. With time, constructions of such tidal pools were optimized to fit more fish and invertebrates.

Records from ancient Egyptian tombs suggest that fishing and farming and growing of fish in lakes and dams have been practiced for over 4000 years (FOESA 2011). There are some registers of farming of aquatic plants and fishes in China from earlier than M bC. Carp culture was an important economic and development activity for centuries in the Asian country (Nash 2011). In the Mediterranean, the Etruscan had basic farming structures to grow marine organism as early as the VI bC. In the Adriatic sea, marine farming had already developed more complex structures where they farmed mullets, sea bass and sea bream (FOESA 2011). White et al. (2004) describe that it was only after World War II that aquaculture gained importance as a potentially large scale industry. As the global economy boosted, a higher demand for aquatic products was observed. In the 1960s, Asian aquaculture transitioned from a small-scale community practice to become a profitable activity.

According to FAO (2016a), aquaculture sector has outpaced human population growth. In each region, however, aquaculture development presents its own characteristics. Asia is the biggest aquaculture producer. 98% of fish for human consumption in the past two decades are originated from Asia. Aquaculture contributions from Europe and Oceania have slightly decreased, while Africa and America have increased their respective shares in world total production.

FAO (2016a) reports that seafood and seafood products are the most traded global food commodities. The proportion of harvested and cultured fish being internationally traded has progressively risen in value terms, from 8 billion in 1976 to 148 billion US Dollars in 2014. These quantities represent around 36% (live weight equivalent) of total fish production. This has caused an impact in people's diets around the world, by diversifying their source of animal protein. In 2013, fish accounted for 6.7% of all protein consumed, being 17% of animal-source protein. In other words fish represented almost 20 % of the average per capita intake of animal protein for over 3.1 billion people.

Fishstat J Software data (FAO 2016b) show that currently, aquaculture represents 51.66% of total fisheries production. China alone contributes with 58.13% of global aquaculture production. A larger portion of this produce corresponds to freshwater fish, though the single most important species farmed in China (in tonnes) is the *Laminaria japonica* seaweed. In 2014, only in China, over 6.8 million tonnes of Laminaria were produced, which represents 6.73% of the total world aquaculture production. Worldwide, in 2014 aquaculture production reached over 101 million tonnes, of which 47% were produced in marine waters, 46% from freshwater origin, and the remaining 7% belongs to brackish water cultures. The single most important farmed product in volume, is the marine *Euchema spp* seaweed, which accounts for 9% of total production.

FAO (2016a) reports that, in general, aquatic plants account for one-quarter of the total aquaculture production in volume. Nonetheless, in terms of value, aquatic plants are worth less than 5% of the whole production. Nonetheless, fed species have grown faster than non-fed species. Even though, aquaculture of non-fed species is more desirable in relation to food security and the environment. Despite being generally less-costly, non-fed aquaculture is undeveloped in Africa and Latin America. Expansion of non-fed aquaculture, through species diversification may be useful for boosting nutrition and improving food security.

FAO (2016a) data also show that over 18 million farmers are engaged in the aquaculture sector. In 2014 total aquaculture production was valued in more than 166 billion US Dollars (FAO 2016b). Some researchers defend that medium-scale enterprises are more effective at addressing poverty reduction and food security, but in fact it is estimated that between 70 and 80 percent of aquaculture ventures are considered small-scale, often family-based activities (HLPE 2014). The small-scale sector is especially important for rural development, employment and poverty reduction (FAO 2016; Subasinghe et al. 2012). Moreover, the contributions of small-scale operators to food security are often more important than economic accounting would indicate (FAO 2016). Currently, aquaculture practices may help address these issues, complementing fisheries production to provide food, support economies and still relieving pressures on fish stocks (McClanahan et al. 2015).

1.1.2. Sustainable Development and Integrated Coastal Zone Management

1.1.2.1. Nachhalitigkeit

Boff (2012) recopiles historically the concept of Sustainability. It was first used in 1560, in Germany, rising from the concern about the need for a rational use of the forests resources, so they could regenerate. In this context the word Nachhaltigkeit (sustainability, in German) came up. It wasn't until 1713, still in Germany, through Capitain Hans Carl von Carlowitz that it became a strategical concept. Carlowitz wrote "Silvicultura Oeconomica" where he stated limits for forest exploitation so that it can afford to keep growing. A few years later, Carl Georg Ludwig Hartig declared that the optimum use of the forests should assure that the future generations could appreciate the same advantages as the current. From these concerns forestry science was born.

Sustainability became a globally discussed issue with the Club of Rome's report "Limits to Growth" (1972). In the same year, the reflections raised on the interactions between humans and the environment lead the UN to organize the "Conference on the Human Environment", in Stockholm, where the United Nations Environment Program (UNEP) was created (UNEP 2014). Then, in 1984, the conference of "A global agenda for change" took place, originating the World Commission on Environment and Development (WECD). The WCED generated the famous "Our Common Future" report (also known as Brundtland Report) in 1987, which presented the most widely used definition of sustainable development. It states that sustainable development is the one that " (...) meets the needs of the present without compromising the ability of our future generations to meet their own needs." (WECD 1987). The ideas and disquietudes that came up continued the discussion through the Earth Summit, in 1992, in Rio de Janeiro. In this occasion, discussion over environmental problems brought light over other issues like global equity, poverty eradication, restoration and protection of the ecosystems, North-South relationships, and governance, as a responsibility of all States and individuals. There, two important documents were generated: the Agenda 21: Programme of Action for Sustainable Development and the Earth Charter (UN 1992). The Agenda 21, in its chapter 28, identifies the importance of local governments in reaching sustainable development objectives: "Local authorities construct, operate and maintain economic, social and environmental infrastructure, oversee planning processes, establish local environmental policies and regulations, and assist in implementing national and sub-national environmental policies. As the level of governance closest to the people, they play a vital role in educating, mobilising and responding to the public to promote sustainable development."

Sustainable development can be interpreted in different ways, as it is pointed out by Connely (2007). Such openness in the concept may lead to weak politics and lack of consistent actions. Naess (1973) accentuates the need for a view of the integration of all beings and systems, as well as the respect for all forms of life. Also, the author emphasizes on the importance of supporting diversity and complexity and improving the rational use and discharge of resources. Moreover, he calls attention to the need for reaching egalitarian societies and decentralization of politics and economy into local autonomy. In this sense, the democratic aspect of development, where stakeholders are involved in planning and deciding development strategies, is a very important feature of the process. It is against nature to impose a single way of production or thinking. The evolutionary cosmogenic process generates progressive complexity. It is needed to embrace the diversity of ideas, models and perspectives in a sustainable development process (Boff 2012). In sum, sustainable development processes require transparent, flexible and inclusive decision making (Reed 2008).

According to Boff (2012), to promote sustainability is imperative to promote care, respect and solidarity in our relationship to our planet. Deep changes in our ways of living and consumption are required. Even though the countries committed to improve its way of development towards sustainability, little has been done. In the Rio+5 Meeting, which was called to monitor the evolution of the process, it became clear that capitalist development is contradictory to the dynamics of the environment and balance of nature. The author also adds that for food production, not only the use of high technologies is important but primarily, a more equitable and solidary system of distribution is required to feed humanity. It is essential that the process of human development is harmonized and integrated with the ecosystems and that the distribution of goods and services is equitable among the population.

In light of this overview, we can accentuate the fundamental aspects of sustainability, as it is based on the equilibrium between three interacting systems: society, economy and the environment. Nonetheless, there is a fourth aspect that is intimately related to sustainability, as it directly influences society to permeate among the other two sustainability facets (economy and environment) (figure 1.1). Governance is a feature of how society (including institutions) participates in the decision making processes, and how the power of voice and vote is spread between all the actors in a society.

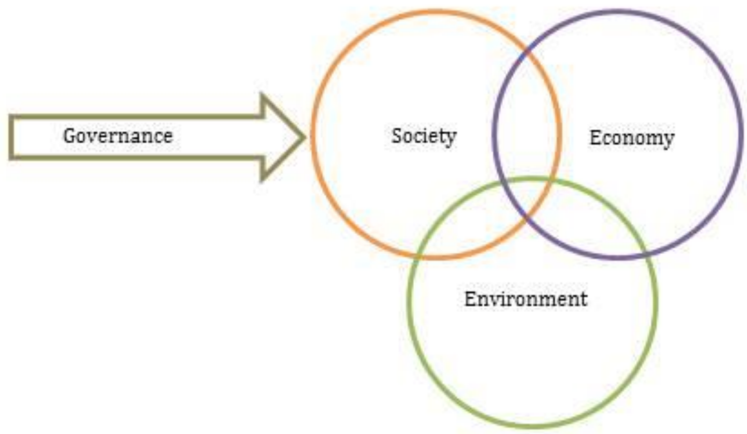

Figure 1.1. Four dimensions of sustainable development.

According to the World Bank definition, "Governance consists of the traditions and institutions by which authority in a country is exercised (…)". The United Nations define it as "the process of decision-making and the process by which decisions are implemented (or not implemented)." Thus, good governance is "(…) the processes for making and implementing decisions. It's not about making 'correct' decisions, but about the best possible process for making those decisions." (Good Governance Guide management committee, 2017).

For a sustainable development management the four dimensions that interact should accomplish some aspects. Governance, for instance, must embrace an appropriate legal authority and institutional arrangements; human, technical and financial resources; procedures for monitoring, evaluating and adapting management plans, among other factors (UNESCO 2003). A sustainable society is one in which the well-being of the population is cared for, social cohesion is reinforced, and values such as equity, justice and inclusion are promoted (Costa-Pierce 2010; DEDUCE Consortium 2007; UNESCO 2006). The economy dimension in a sustainable development processes, does not only seeks economic growth, but also an equitable distribution of the economic benefits and resilience of the economic activities, while respecting the ecological limits of the ecosystems (Allen and Clouth 2012; FOESA 2010; CONSENSUS 2006). And finally, environmental sustainability refers to a sound environment, where the exploration practices (inputs and outputs fluxes) are respectful with the ability of the environment to regenerate and provide its functions and services in the long term (FOESA 2010; DEDUCE Consortium 2007; UNESCO 2006; OECD 1993).

1.1.3. Integrated Coastal Zone Management

In the United States of America, during the 1960s, growing human pressures over the coastal zones stimulated concerns and contemplations on the planning and uses of this environment. The Stratton Commission (1969) Report analyzed the problems and opportunities of a national policy for the sea and coasts. It was recognized that a new approach for planning and decision making was needed to achieve a more effective management of the multiple pressures, different needs and institutional procedures of the coastal sites. Two recommendations were pointed out in the Report. The first was to promote a horizontal coastal management system, in which the roles and responsibilities of coastal zone authorities and the federal government were differentiated. The second was to endorse science and engineering research to generate knowledge and technology to face the problems and opportunities of the coastal zones. Such recommendations were later formalized in Coastal Management Act of 1972.

Twenty years later, in the United Nations Conference on Environment and Development, also known as the Earth Summit, in Rio de Janeiro the Agenda 21 was launched (UN 1992). In this document, a coastal management approach was presented, in which planning and decision making would account on sectoral integration to promote conservation and development needs. Still, the agenda failed to consider the incentives system adopted in the USA, but that were essential for the success of Coastal Management.

Agenda 21's chapter dedicated to oceans and seas contains the guidelines for sustainable development and provisions to face world problems in the XXI century. The document emphasizes the role of oceans in supporting life and providing opportunities for sustainable development. Through the Law of the Sea, rights and obligations of the States are set, and the basis to achieve protection and sustainable development of marine and coastal environment and its resources are provided. Nevertheless, it is recognized that, for an adequate marine and coastal management and development, it is required an integrated, precautionary and anticipatory approach. The document proposes policies and integrated decision making procedures and suggests actions to promote adequate resource management. An important achievement was made through the Agenda 21, in which the countries compromised with sustainable development and integrated management of the coastal and marine resources.
Within a coastal environment, to achieve a sustainable development, any activity requires adequate consideration of interactions among environmental, social, and economic factors that are inherent to the process (Chua 1992; NACA/FAO 2000). Integrated coastal management involves a multi-purpose approach, where the diverse activities and uses are synchronized to avoid conflicts and increase their efficiency. This process should be promoted through research, development, monitoring and incentive programs, inclusive community procedures, rural economic and social development actions and an integrated watershed and coastal management approach (Frankic and Hershner 2003). Furthermore, for an integrated perspective, is necessary to have an integrated information system based on objective data in order to reach the different visions and interests occurring in the coastal zone (DEDUCE consortium 2007).

1.1.4. The role of mariculture in sustainable development and management

The coastal zone represents the transition zone, between the continent that delivers nutrients and freshwater, and the ocean. This mixture increments the biologic productivity, and stabilizes the temperatures and meteorological characteristics. As a result, the value of the assets and services of coastal ecosystems are more important than the ones generated in the continent or the open ocean (Costanza, et al. 1997). But also, in the coastal zone, many pressures take place, from fisheries, to infrastructures, energy production, to wastes and pollution, among others (Olsen 2003).

In this context, aquaculture is seen as a tool for promoting sustainable development. It may help solve the problems of predatory fisheries, while attending human needs of nurture and socioeconomic development. Aquaculture supports traditional lifestyles, generates occupations and income, etc. In other words, it supports human development, in the broader sense of the word, parallel to nature and biodiversity conservation. Even though, not any aquaculture practice responds to sustainability's objectives. Aquaculture interacts with the environment on the use of resources and by generating excesses (figure 1.2.). Also, it can be a source of conflicts with other coastal users, and even result in environmental pressures due to economic speculation.

Figure 1.2. Integrated Multi-Trophic Aquaculture fluxes, inputs and outputs. (Fisheries and Oceans Canada 2013).

Valenti (2002) states that a sustainable aquaculture practice is one that rears organisms, generating profit and social benefits without degrading the environment. Corbin and Young (1997) add that it must conserve natural resources and biodiversity, minimizing environmental impacts through methods and technologies adapted to the place and situation, generate profit, economic benefits, minimize social conflict and satisfy community needs. Bardach (1997) highlights that aquaculture is a powerful tool to promote sustainable development. Sustainability is met in aquaculture, when these aforementioned factors are taken into consideration. Frankic and Hershner (2003) emphasize that the quality of the environment is equally important for aquaculture development, as it is for other users. There are several procedures that influence on the level of sustainability of an aquaculture venture. For instance, the choice and number of species farmed; the use of green technologies; wastewater management practices; number and origin of employees; community engagement; product commercialization modes; etc.

FAO (2015) has set some goals that should be met with aquaculture, which are convenient to Brazil's sustainable development. It includes increase of health and income of communities; increase of general welfare; and empowerment of farmers and women. These goals can be achieved through a robust strategy that assures a fair rewarding from farming to producers; costs and benefits to be shared equitably; promote employment and wealth; food accessibility to all; sustainable environment management; and sound organization of the sector within authorities and industry. Therefore, there are two important strategies to promote sustainable aquaculture. It is important to adopt sound criteria for farming location selection, according to the environment characteristics such as water fluxes, and assimilative capacity of the environment (FAO 2013; IUCN 2009; Primavera 2006; Frankic and Hershner 2003). Also, farming impacts can be reduced by recycling management and polyculture (FAO 2013; Abreu et al, 2009; Primavera 2006; Frankic and Hershner 2003).

Polyculture systems (also known as Integrated Multi-Trophic Aquaculture – IMTA) may help maintain carrying capacity levels. IMTA enhances the systems' capacity to recycle nutrients, avoiding environmental degradation, disease outbreaks, and reduced growth. IMTA techniques mix species from different trophic levels, so one species benefits the others: excess nutrients and excrements are used by filter feeder species (mollusks and seaweeds), while, these can be used as food to fed carnivorous/omnivorous or herbivorous species (fin fish, shrimp, etc.) (Edwards 2015; Chopin et al. 2010; Naylor et al. 2000). IMTA mimetizes the natural environment in the sense that the energy is recycled and redistributed throughout the systems flows.

1.1.5. The use of indicators for sustainability

Aquaculture sustainability faces former and new issues and challenges which demand innovative methods. One way of measuring and monitoring the development process of aquaculture is through the use of indicators. Indicators may help visualize the weaknesses and strengths regarding production, interactions with the environment, perception of the sector, market competition, legislation etc. (FAO 2013). The use of indicators makes easier for farmers and government institutions to cope with the debilities and to promote growth and resilience of the sector, as well as for consumers to support or persuade for sustainable products (UN 1992).

The need for developing an indicators system to assess sustainable development was first claimed at the Earth Summit, in 1992, materialized in the Agenda 21. It established there should be a global effort to elaborate indicators of sustainable development aiming to provide a solid basis for decision making at all levels (UN, 2007). In Europe and North America, diverse aquaculture indicators were proposed to assess the sustainability level of development of the aquaculture production. Aquaculture indicators are often related to coastal and marine development indicators.

Indicators are fragments of information, used to understand a broader, more complex reality. The impossibility and inconvenience of measuring all the parameters or variables that take place in a phenomenon has led to the adoption of indicators. The OECD (1993) defined indicator as: "A parameter, or a value derived from parameters, which points to/provides information about/describes the state of a phenomenon/environment/area with a significance extending beyond that directly associated with a parameter value." This, in other words, means it is a qualitative or quantitative measurement or observation used to describe a situation and assess changes and trends over time. In addition, indicators represent the portion of information we use to understand the world, make decisions, and plan our actions (Meadows, 1998). Desirable indicators are variables that simplify relevant information, expose the phenomena of interest, and quantify, measure, and communicate information (UNESCO 2006; Gallopin, 1997; OECD, 1993). They are powerful tools to assess an action plan, as an early warning signal about an emerging issue, or in providing a concise message for engagement, education and awareness (UNESCO 2006). Indicators are used to incorporate physical and social science knowledge into decision-making (UN, 2007). Furthermore, the selection of adequate indicators is crucial, as it was argued by Meadows (1998, "Indicators arise from values (we measure what we care about), and they create values (we care about what we measure)". In this context, she states that the indicator selected affects behavior: "The world would be a very different place if nations prided themselves not on their high GDPs but on their low infant mortality rates.(…) This feedback process is common, inevitable, useful, and full of pitfalls." In this sense, indicators are selected and defined according to a goal set, and a defined audience (Clément & Madec, 2006).

In Brazil, even though there is an effort to promote sustainable and integrated aquaculture, reflected in the policies for planning and development of aquaculture, in the past years, due to a growing political and financial crisis, the fisheries and aquaculture sectors are being neglected. Also, there is no official guide or document aiming to assess the impacts and sustainability of the aquaculture sector. In this context, it becomes necessary to develop tools to assist in the evaluation and management of aquaculture sustainable development. An indicators system for the sustainability of aquaculture may complement the already existing policies, and support the development of the sector, and still, promote communication between consumers, farmers and decision makers.

1.2. Motivation

At these times, the world is facing many challenges due to an irrational and unrespectful use of nature's resources. The oceans are recognized for their role in regulating climate, carbon sequestration, food provision, and overall for sustaining life. However, our oceans are suffering several and interconnected impacts that range from changing climate to pollution and overexploitation of living resources. World's fishing resources have been depleted systematically over the past decades. According to the UN Food and Agricultural Organization (FAO) (2016), overfished stocks increased from 10 percent to 30 percent between 1974 and 2013. The Organization also adds that in 2013 "58.1 percent of the world's fisheries are reported to be fully exploited without the potential for sustainably increased harvest (…) the remainder are overfished with increases in their production only possible after successful stock restoration". It becomes evident that there is a real struggle to sustainably manage living marine resources while demand for fisheries products is increasing. The increasing human population only represents more intense and diverse pressures to our oceans, and to our planet. Nonetheless we also have the ability - and responsibility - to reverse this situation and create a more prosper, healthy, balanced and equitable world.

The present research project was born in order to offer a new perspective to face current development challenges. The authors' interests and passions on the oceans, nature, wellbeing and sustainability were brought together to create knowledges and understandings on the marine aquaculture (mariculture) sustainability in Brazil. This research is based on the belief that human happiness, community and environment wellbeing, nature preservation, and promotion of lifestyles of closer relationship to nature can be achieved through sound and sustainable mariculture activities. The creation and design of a tool to help assess and communicate the findings are the final outcomes desired.

1.3. Objectives

1.3.1. Main objective

In the light of this overview, this thesis will be focused on marine aquaculture (mariculture) sustainability in Brazil. This project aims to contribute to the understanding of the complexity of the reality of mariculture in Brazil and to provide tools for its assessment.

1.3.1.1. Specific objectives

To reach this objective, it is first proposed to review the historic development of mariculture in Brazil. The understanding of the history of mariculture allows for a broader view of the lessons learned, the challenges faced and the future trends of the sector. In this review it is proposed to identify literature gaps; describe the main environmental and social issues; and to characterize mariculture distribution along the Brazilian shoreline, regarding the species cultivated and its importance.

Further, it is aimed to present a mixed approach methodology for the development of a set of indicators and a multi-scale indicators system to evaluate the sustainable management of Brazilian mariculture sector. The method developed in this research intends to join a top-down and a bottom-up scheme. The top-down approach consists in a pre-selection of indicators from existing international indicators systems, based on the reality of the Brazilian sector and sustainability goals. The bottom-up procedure involves the participation of a group of experts/stakeholders to refine the objectives identified and select the most appropriate indicators to compose the evaluation.

Lastly, to reach a deeper understanding of mariculture sustainability in Brazil, a few case studies are presented, where the indicator system was applied. In this section, the indicator system is evaluated in practice. Also, it allows for the comprehension of mariculture development from real cases.

1.3.2. Research questions

1.3.2.1. Descriptive question

What are the remarkable moments of the implementation of mariculture in Brazil?

1.3.2.2. Explanatory question

Why are the indicators safe instruments for evaluating the sustainability of mariculture in Brazil?

1.3.2.3. Interpretative question

How can the indicators systems evaluate mariculture practices in Brazil?

1.4. Thesis structure

This thesis structure contains an opening section, where a brief outline of the issue is presented, along with the main concepts that permeate the research. In addition, the motivations of the author and objectives are stated. The research questions are also defined in this first section.

The second section of this work is the presentation on the first paper that offers a review of the development of mariculture in Brazil. This paper characterizes mariculture development, presenting key moments of its establishment, parallel to the main species and locations. Further, research gaps are identified, the Brazilian policy on mariculture is analyzed and the status and trends of the production is discussed.

The third section suggests a methodology for the selection, adaptation and development of indicators and an indicators system to evaluate the sustainability level of mariculture in Brazil. This paper summarizes the research on the international indicators systems for the sustainability of aquaculture and coastal management, which provided the basis for the development of the indicators and indicators system developed. And lastly, the paper presents the final indicators system, which is composed by the selected indicators and the evaluation methods.

The fourth section is the last paper produced in this research which contains the case study. The indicators system is validated through real-life cases. Brazilian mariculture sustainability is evaluated at the national level, where the national policy and management of mariculture is assessed; at the regional level, where the policy and management of mariculture is valued in the state of Santa Catarina; and at farm level, where the farming practices were analyzed. This final paper allows for an understanding of the sustainability level of mariculture sector in Brazil transversally through farming practices and government management policies and actions.

With the overview of the whole project, the key issues presented are briefly discussed. Finally, the main conclusions of this research are withdrawn.

"We must plant the sea and herd its animals using the sea as farmers instead of hunters. That is what civilization is all about – farming replacing hunting."

Jacques Cousteau (1910-1997)

2. A review on the mariculture development in Brazil

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Abstract

The understanding of the different effects from mariculture development is essential for the sustainable management of coastal resources. Thus, it requires high quality information to assist in the policy design and structuring of management strategies. However, it is challenging to gather reliable data on mariculture in Brazil, since information is fragmented in several documents. The main objective of this research is to provide a complete overview of the development and production of mariculture in Brazil. A systematic research in two of the most used databases online was set, at SCOPUS and Web of Knowledge. There is a great interest towards improving mariculture development, reflected on the high number of publications on new technologies, species, or innovative approaches. Brazil has proven to have an ideal environment for many modalities of mariculture. Currently, mariculture production reaches 90923 t (12% of total aquaculture production). Development of mariculture along the Brazilian coast has influenced the lifestyle of the communities. Still there are many legal and technological challenges that prevent the country to achieve its full potential to develop a robust sustainable mariculture industry. The sector could benefit from this research in order to achieve solutions and more sustainable methods for production. We hope to inspire further research to fulfill the literature gaps, with information regarding production issues and the main impacts from mariculture development.

Key words: mariculture in Brazil, sustainability, mariculture impacts

2.1. Introduction

Aquaculture is one of the fastest growing food production systems in the world (FAO 2014). It raised the per capita provision from 0.7 kg in 1970 to 19.7 kg in 2013 (FAO, 2011; FAO 2016). In 2014, Brazil was the 14th in the rank of aquaculture producers (FAO, 2016). The country leans largely on freshwater aquaculture, which consists of 88% of total production (FAO, 2016). Its potential for developing mariculture remains untapped. The Brazilian shoreline comprehends over 8000 km, almost 4.5 million km^2 of Exclusive Economic Zone and 2.5 million ha of estuarine zones (MPA 2015). The large extension of the Brazilian coast, from latitude 4°30' N to 33°44' South, is situated in intertropical and subtropical zones. Together with a wide environment heterogeneity and high biodiversity, these characteristics favor the implementation of diverse marine farming techniques and culture of different species.

As any human activity, mariculture impacts the environment and the society. Thus it is fundamental to comprehend, identify, predict and interpret the outreach and level of these impacts in order to prevent and minimize the negatives and to accentuate the positive ones (Barbieri *et al.*, 2014). Coastal regions are vulnerable to human pressures, and in general it experiments unplanned development and poor management given the diversity of the activities it embraces. The understanding of the different effects from mariculture development helps evaluate the consequences and priority actions to approach the situation. It is essential for the adequate sustainable management of the coastal resources, through the launching of projects or actions regarding the implementation of mariculture (Silvestri *et al.*, 2011).

In this scenario, it becomes obvious the need for high quality information to assist in the policy design and structuring of management strategies. It is challenging, however, to gather reliable data on mariculture in Brazil because information is fragmented in several different documents. Official production statistics from the national government are inconsistent. Statistics from 2010 and 2011 were both published with two years of delay. 2013 and 2014 statistics are available through the Brazilian Institute of Geography and Statistics (IBGE) website. Further information was provided by FAO (2016) with the FishStatJ application. Some production data vary slightly according to the source of publishing.

This is also true for the data on mariculture effects and interactions. Also, most of the information found is from the last decade, and only a small part of the bibliography available is current data. This review paper is the result of a throughout data mining in the available bibliography as well as in official databases with statistic values on aquaculture production and many electronic documents. A considerable effort has been made on compiling information from different levels of administration: federal/national, regional and local. Parallel to this, some local and state authorities, as well as diverse stakeholders and researchers related to mariculture have provided historical data and relevant information on the actual situation of this productive sector in Brazil, its implementation and development.

The main objective of this research is to gather an overview of the development of mariculture in Brazil and identify literature gaps for further researches. Thus, the historic perspective, the development and the current status of mariculture in Brazil was described and the main environmental and social issues are discussed. Also it is meant to characterize mariculture along the Brazilian shoreline, harmonized with the geographic distribution of the different marine farming sites regarding the species cultivated and its importance. Finally, we would like to propose actions to enhance a responsible and sustainable management of this sector in Brazil. We have proposed to answer to three questions: 1. How was the process of mariculture development in Brazil?; 2. What is the production status of the different modalities of mariculture in Brazil?; and 3. What are the implications of mariculture development to society and the economic contribution of the sector?

2.2. Data survey

To answer the three main questions proposed in this review, a throughout research was employed. A systematic research in two of the most used databases online was set, at SCOPUS and Web of Knowledge. The search terms employed were “mariculture in Brazil”, “marine aquaculture Brazil”, “shrimp farming Brazil”, “mollusk farming Brazil”; “mollusc farming Brazil”; “bivalve farming Brazil”; “seaweed farming Brazil”; “macroalgae farming Brazil”, “finfish farming Brazil”; “marine pisciculture Brazil”; “marine fish farming Brazil”.

Yet, the results from the systematic research were not sufficient to answer the questions to be analyzed by the authors. Thus, a further data mining took place, to include other documents such as academic thesis and dissertations, other scientific publications, national and international statistics, as well as other sources as internet websites, journals (non-scientific) and personal communications with experts were included. The criteria used to include these documents were: 1. They provided information to answer or to complement the proposed questionings; and 2. They did not double the information already found on the systematic research.

Search results from the two selected databases (SCOPUS and Web of Knowledge) were then classified, according to the subject of the publication, into Themes. Each Theme involved a group of topics, as described in the table below. Also, publications were organized according to the year of publication. The publications were analyzed and those that provided significant information to answer the questionings were then summarized.

Table 2.1. Classification of the search results into Themes and their respective Topics.

Theme	Technical aspects of farming	Management and policy	Environmental interactions	Others
Topics	Farming potential	Risk assessment	Interaction with other species	Human health
	Farming techniques	Public policy	Pollution	Nutritional composition
	Disease	Spatial planning	Environmental effects	Other uses for wastes
	Consorted farming	Sustainability assessment		Certification
	Review articles			Social issues
	Alternative feeds			Production chain
				Market

2.3. Results

2.3.1. Retrieved Publications on Mariculture in Brazil

Most of the publications from the systematic research dealt with Technical aspects of farming, followed by Environmental interactions, Others, and in smaller proportion, Management and policy issues (figure 2.1). Around 68% of the results were publications regarding shrimp farming activities, 19% were on mollusk farming, while fish or seaweed farming were the subjects of 6% of the publications each.

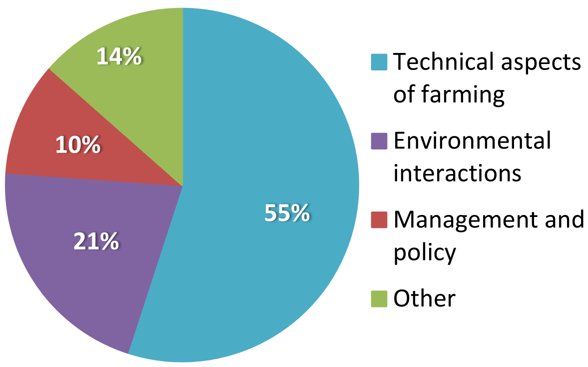


Figure 2.1. Proportion of the papers per theme covered.

2011 was the year with the largest number of publications (34 in total) was in 2011. We observe a more abrupt rise in publications since 2005 (figure 2.2). In the period from 1991 to 2005, results show a mean of 2.4 publications per year. In the following period, from 2006 to 2015, this number increased to over ten times, resulting in a mean of 24.8 publications a year. Five articles were published until the middle 2016, three of them on shrimp farming, and two on fish farming.

To complement the understanding on the development of mariculture in Brazil and to answer the questionings proposed, it was necessary to include a further "rough" research. An important part of the information was only available through grey literature. Thus, the present article brings out hidden information for the scientific community.

Publications on its historical development lack details on the steps taken in the process, or perhaps the information was not available in digital form. There is evidence that mariculture has started in Brazil in the XVI century by Dutch immigrants who built fish ponds in the intertidal zone for growing fish (Cembra, 2012). With time, culture techniques for marine species have evolved, diversified and adapted to the different regional characteristics. Nonetheless, there is a gap in the literature on how this primitive form of mariculture evolved and how it got extinguished. Literature is mostly focused on shrimp farming, with less extent on mollusk farming, and an important deficiency on seaweed and marine fish farming. Researches on environmental or socioeconomic impacts are also insufficient to fully understand the implications of the sector in these fields.

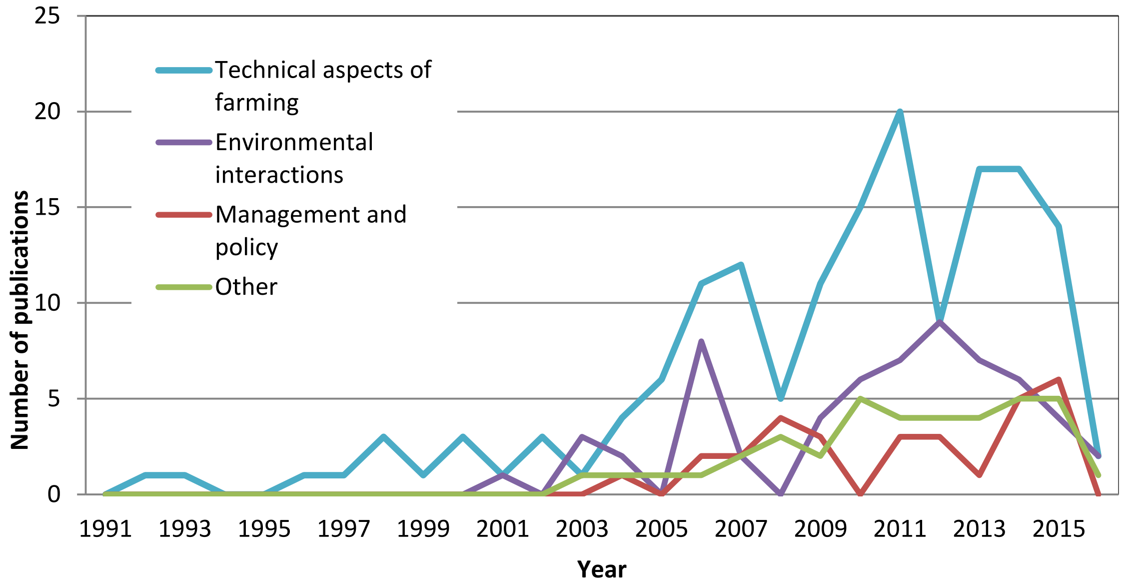


Figure 2.2. Evolution in the number of publications in the period from 1991 to 2016, according to the Themes of the publications.

Publications on its historical development lack details on the steps taken in the process, or perhaps the information was not available in digital form. There is evidence that mariculture has started in Brazil in the XVI century by Dutch immigrants who built fish ponds in the intertidal zone for growing fish (Cembra, 2012). With time, culture techniques for marine species have evolved, diversified and adapted to the different regional characteristics. Nonetheless, there is a gap in the literature on how this primitive form of mariculture evolved and how it got extinguished. Literature is mostly focused on shrimp farming, with less extent on mollusk farming, and an important deficiency on seaweed and marine fish farming. Researches on environmental or socioeconomic impacts are also insufficient to fully understand the implications of the sector in these fields.

Publications were mostly focused in studies that aimed to improve and develop farming techniques and methods. In this field, most of the researches covered “farming techniques” issues, followed by “disease” occurrence, diagnosis and mitigation and “farming potential” of new species, or areas. A majority of the researches covered issues regarding shrimp farming. It is expected that researchers would be more interested in the main farmed species, since it is the one with higher economic returns and with greater environmental impact potential. Number of publications regarding the type of animal farmed responded to this same logic. For some unknown reason – and not of specific interest to this research – from the year 2006 onwards, the number of published documents raised sharply at one order of magnitude.

2.3.2. Development of Mariculture Sectors and Production

Overall Brazilian mariculture summed an annual production of 90923 t in 2015 (IBGE, 2016). Production is concentrated in shrimp (77%) and mollusks (23%). The culture of finfish and seaweeds exist, but is incipient (less than 1%) (FAO, 2016). The production increased from 1997 to 2003 and then stabilizes around 80 thousand and a hundred thousand tonnes (figure 2.3).

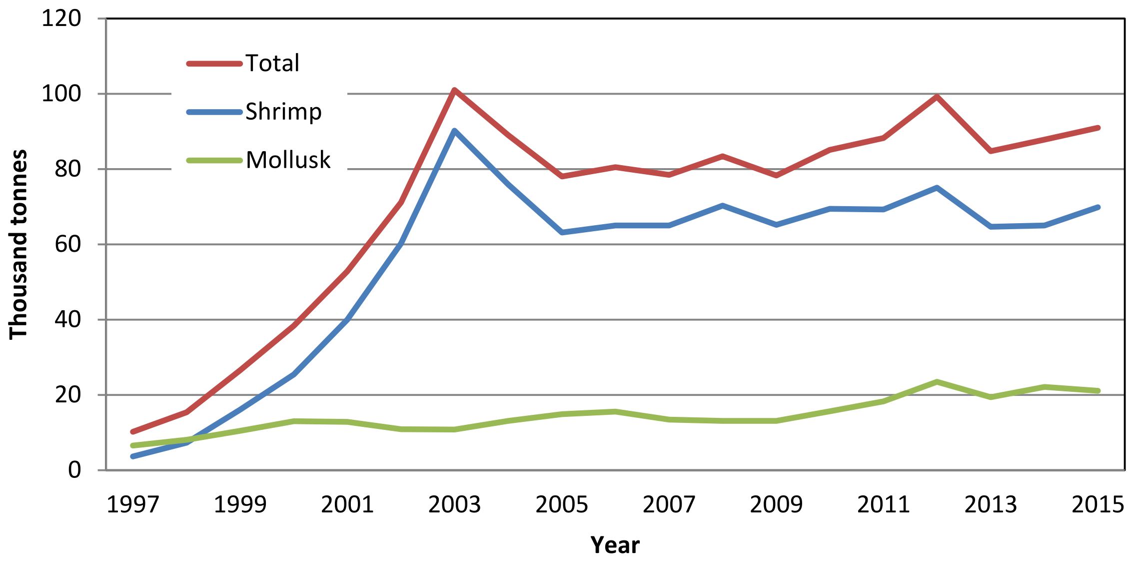


Figure 2.3. Evolution of mariculture production in Brazil from 1997 to 2014. Source: FAO 2016 and IBGE 2017.

Shrimp farming production has reached its maturity in 2003, but presented a fair decline in the following years due to disease outbreaks, and has maintained stable levels since 2005. Mollusk farming, on the other hand is still relatively growing, and appears to have much room for growth. It has grown more discreetly, but may have not yet reached its stability. It is expected that in the following decades, if trends are accomplished, a more varied array of mariculture modalities, including new species and farming systems, will change this scenario towards higher but sustained levels of production.

2.3.3. Mollusk farming

First trials with mollusk farming took place in Brazil in the 1960s. The species selected for culture were the native oyster (*Crassostrea spp.*)[1] and native mussel (*Perna perna*). The seeds were collected from the natural environment (Akaboshi, 1979; Paulilo, 2002; Rupp *et al.*, 2008; Siqueira, 2008; Baldan & Bendhack, 2009). Later, in the 1980s, Cabo Frio Project was launched in the states of Rio de Janeiro and Santa Catarina. The project was pioneer on experiments with the Japanese oyster (*Crassostrea gigas*) (Siqueira, 2008; Baldan & Bendhack, 2009). This species showed a good adaptation and the favourable results attracted interest from the scientific community for its production and research (Manzoni & Schmitt, 2006). In 1989, mollusk farming starts to emerge as an economic alternative to artisanal fisheries. It was first settled in Santa Catarina owing to incentives from the State Agriculture Secretary and Banco do Brasil (Federal Bank). The support from governmental authorities and technical improvements, allowed Santa Catarina to become biggest national producer of farmed mollusks (Siqueira, 2008; Suplicy, 2008). By the mid-90s, mollusk farming has extended to other coastal regions (Paulilo 2002, Rupp*et*

[1] Two native oyster species are frequently used in mollusk farms in Brazil, *Crassostrea rhizophorae* (Guilding, 1828) and *C. brasiliana* (Lamarck, 1819) Syn. *C. gasar* (Adanson, 1757). Both species are highly similar, and identification is done by DNA analysis. In this paper, whenever the term "*Crassostrea spp*." is used, it will be referring to *C. rizophorae* and *C. brasiliana/C. gasar*.

al., 2008). The projects that arise in this period aimed to foster the economy through education and support to farmers (Suplicy, 2006; 2008;2013; Rupp *et al*., 2008; Siqueira, 2008; Hoshino, 2009). Nevertheless, only a few of these projects received support from government and research institutions, which were decisive for success.

Currently, mollusk farming has spread to all coastal regions in Brazil (figure 2.4). Species are selected according to their adaptation to the environment in each case. The native oyster (*Crassostrea spp*) and the native green mussel (*Perna perna*) are farmed in all coastal regions. But in the warm waters of the North and Northeast, the introduced Japanese oyster *Crassostrea gigas*, did not adapt so well (Siqueira, 2008; Pontes, 2009). It is mostly farmed in the cool waters of the South and in the zones affected by the upwelling, in the state of Rio de Janeiro (RJ), in the Southeast. The most widespread bivalve culture corresponds to the native green mussel. It represents over 87% of the farmed mollusks (most recent data from 2010, MPA 2012). This species is found naturally at rocky shores along the Brazilian coastline. The least farmed species is the scallop *Nodipecten nodosus*, farmed only in the states of Santa Catarina (SC), and Rio de Janeiro (RJ). Still, it could be successfully farmed in other regions according to its environmental requirements for survival and growth.

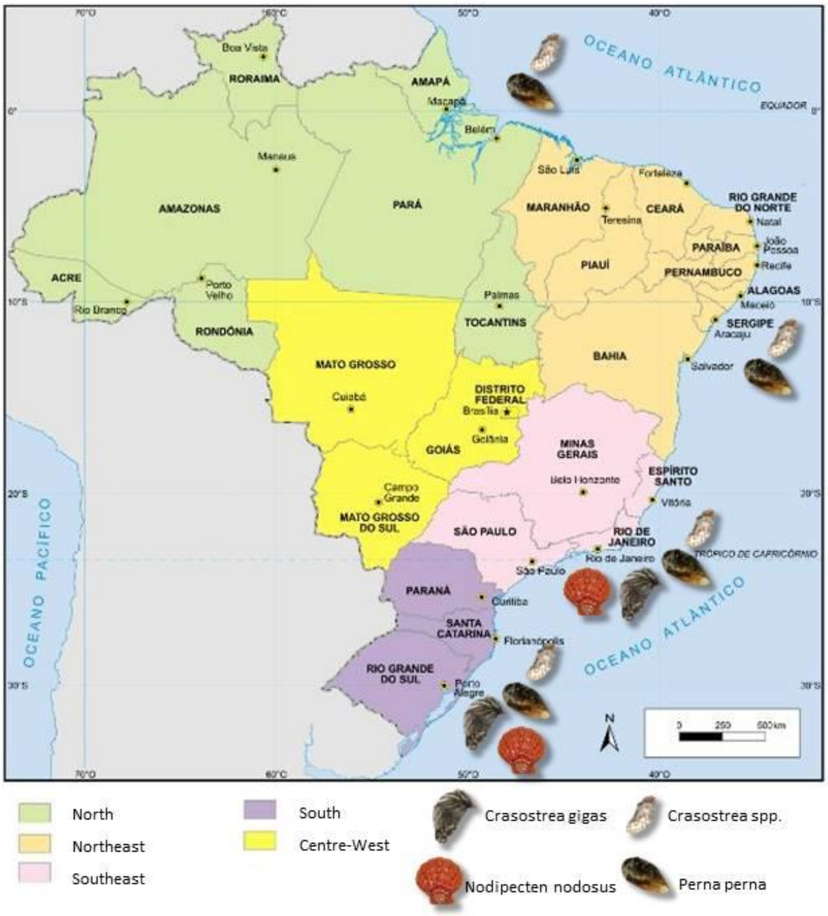


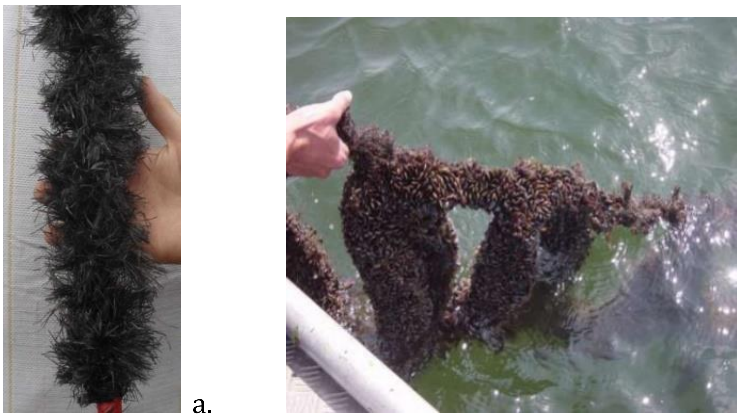
Figure 2.4. Distribution of farmed mollusk species in the coastal regions of Brazil

The farming methods vary according to the species and the environment characteristics. Rupp *et al*., (2008) describe that the most used system for the Japanese oyster, scallops and for mussels is the longline (Figure 2.5 a). It consists on a suspended floating rope of around 100 m long, at surface or subsurface, at 3m deep. In scallop or oyster culture, the organisms are placed in “linterns” (Figure 2.5 b) usually set in ten levels, attached to the main rope. In mussels culture, seeds are placed inside tubular nets attached to the longlines (Figure 2.5 c). In the native oyster farming, seeds are placed inside polypropylene bags at intertidal racks (Figure 2.5 d). Production is mainly manual and artisanal; most of the equipment used is reused material, like chemicals or beverage containers, or even PET bottles, used as floaters (Figure 2.5 e) (Suplicy, 2006-2013). In some regions, maintenance and harvesting are made at floating rafts (Figure 2.5 f).

Figure 2.5. From top to bottom: a. Mussel longlines from underwater (Suplicy, 2015). b. Oyster lintern being installed (Suplicy, 2015). c. Tubular nets for mussel growth (Suplicy, 2015). d. Intertidal oyster farming racks (Gerent, 2016). e. chemicals or beverage containers, and other reused materials used as longline floaters (Suplicy, 2015). f. Maintenance and harvesting raft (Gerent, 2016).

In the first stages of bivalve farming, in Brazil, the main limiting factor for its development was the provision of seeds. Initially, seeds were collected from the natural banks in the rocky shores, but natural growth rate was soon exceeded by extraction rate. Santa Catarina was the first state to suffer a decrease in production. The problem was addressed in two ways. The first was the development of artificial collectors for wild seeds (figure

2.6), including a study of the best sites to install the collectors. This is currently the most widespread method adopted, although in some places, seed extraction from natural environment is still used (Suplicy, 2008). The second solution, which required more resources and technology, was the creation of hatcheries. In 1994 the Federal University of Santa Catarina was pioneer in producing laboratory seeds, followed later by other two institutions. (Table 2). With the production of seeds in laboratory, seed availability became stable, and it allowed the expansion of bivalve farming. Also, production of Japanese oyster seeds made possible the establishment of this type of culture.



a. b.

Figure 2.6. a. artificial collector substrate in detail (Suplicy, 2015). b. artificial collector ready for harvesting (Suplicy, 2015).

Table 2.2. Current mollusk hatcheries in Brazil presented per state, and species produced.

Laboratory	State	Species	Source
Laboratory of Marine Mollusks - Federal University of Santa Catarina (LMM-UFSC)	Santa Catarina (SC)	*C. gigas, P. perna, Crasostrea spp., N. nodosus*	Paulilo, 2002; Rupp *et al.*, 2008
Centre of Production and Propagation of Marine Organisms, from the Pontiphical Catholic University of Paraná (CPPOM-PUCPR)	Paraná (PR)	*Crasostrea spp.*	Rupp *et al.*, 2008; Baldan & Bendhack, 2009
Ecodevelopment Institute of Baía de Ilha Grande (IEDBIG)	Rio de Janeiro (RJ)	*N. nodosus*	Rupp *et al.*, 2008

More recently, another challenge faced by farmers is related to water quality. Water contamination and red tides endanger production and commercialization of mollusks and offer health risks (Lovatelli et al., 2008). This issue required the Ministry of Fisheries and Aquaculture (MPA) and the State Secretary of Agriculture and Rural Development to implement the Program of Hygienic and Sanitary Control of Bivalve Mollusks, in the state of Santa Catarina in 2008. The program aims to secure product quality and safety of the products, making them more attractive in national and international markets. It controls sanitary and hygienic issues from the regulation of farming areas, harvesting methods, processing operations, distribution, through to commercialization chains (Cembra 2012). The significance and success of the Program lead it to reach country-wide level by 2012 with the implementation of the National Program of Hygienic-Sanitary Control of Bivalve Molusks by the MPA. The inexistence of such program had restricted the production from accessing the international market in the previous years. (Suplicy, 2006-2013).

The creation of hatcheries allowed production to grow steadily over the past decades (figure 2.7). In 1989, before hatcheries, scarce 130 t were produced (FAO 2016). By 2015, production reached 21064 t (IBGE, 2016), denoting a mean growth of 21% each year. After the mussel, the species with the highest production is the pacific oyster, and in a smaller scale the native oyster (Rupp et al., 2008). The scallop presents a modest production of only 144 t in 2008 and 2009, and suffered an important decline in 2010, when only 5.2 t were produced (MPA, 2012; Suplicy, 2006-2013). Though, since 2011, statistics are not available for each species, as mollusks are grouped together, so it is impossible to speculate on the development of each type of culture. Santa Catarina is the leading state in mollusk farming, contributing to 95% of the production. Behind it there is Rio de Janeiro, São Paulo and Bahia. Most of the production comes from the South or Southeast. But recently, statistics reflect that the states in the North and Northeast are starting to become more important, presenting an increase in production (IBGE, 2016).

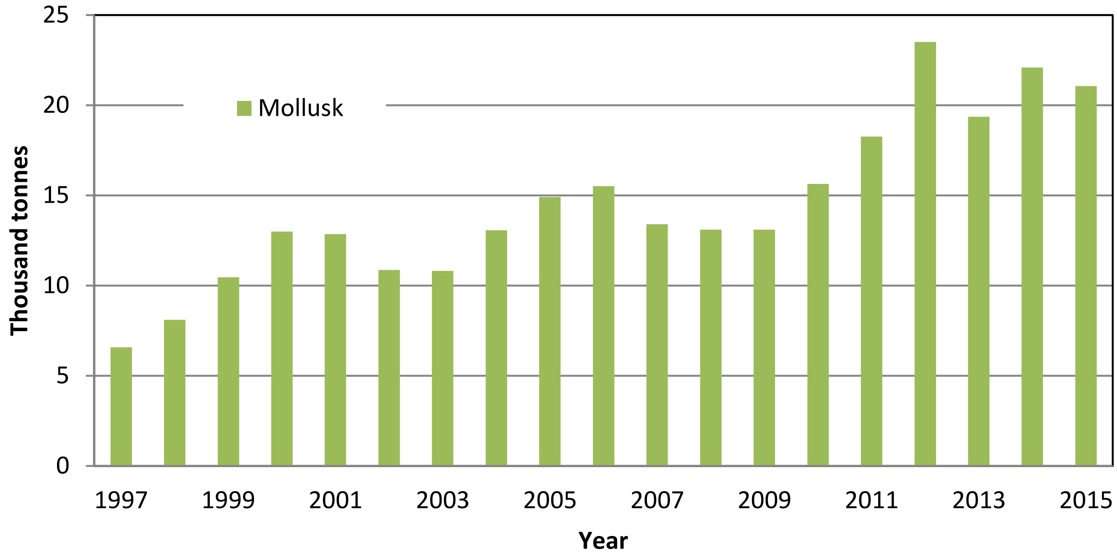


Figure 2.7. Mollusk farming production in Brazil from 1995 to 2014. Source: FAO 2016 and IBGE 2016.

mollusk culture initiatives in Brazil started with the financial and technical support from government and research institutions. Conversely, in the following years, with the expansion of the activity, producers were left without financial, technological or insurance backing. Still, the species and methods chosen worked out well from the beginning and producers did not face too many technological obstacles. The main advantages of mollusk farming rely on the ideal environment characteristics, and the good results from farming native species. Implementation and management of the farms is relatively cheap and simple, and it does not require high instruction levels for operation. This characteristic had an important effect on the social impacts from mollusk farming. It has reached a basal level of society, including traditional communities. It is an important source of income, since it can be combined with other activities, mostly fishing. Besides it engages the whole family unit in the operation of the farm. Moreover, it has contributed to the establishment of traditional communities in its original land (Manzoni, 2005). Nonetheless, there is insufficient number of publications on the importance of mollusk farming to the local economy and how it affected the communities, especially in other regions than Santa Catarina. A deep diagnosis on the main challenges and lessons learned would be helpful to assess decision makers and researchers on finding ways to promote sustainable growth of the activity country-wide.

Currently, efforts to improve mollusk production are concentrated in the states of the South and Southeast. Even so, some policy issues are affecting negatively the development of this sector. High bureaucracy and lentitude in the regulation process are hindering the expansion of mollusk farming in other coastal states.

2.3.4. Shrimp farming

Experiments with shrimp farming started in the 70's, in Santa Catarina (SC), in the Southern region and in Rio Grande do Norte (RN), in the Northeast, simultaneously. In Santa Catarina, the focus was on obtaining post-larvae of *P. schimitti* and *P. paulensis*. Meanwhile the government of Rio Grande do Norte was launching the pioneer "*Projeto Camarão*" ("Shrimp Project"), which was the first to implement shrimp culture in Brazil (Moles & Bunge, 2002; SEBRAE, 2008). The activity emerged as a replacement to the extinct salt production industry, which left people unemployed and many ponds available for the use in shrimp culture in RN (Nunes, 2001).

Difficulties with the first two species drove researchers to experiment with *F. japonicus*, which laboratory reproduction was better understood at the time (IBAMA/MMA, 2005). The state agency, EMPARN (Empresa de aquicultura do Rio Grande do Norte) was created to supply farmers with post-larvae. Nevertheless, state government changed, and shrimp farming was no longer one of the priorities, then producers were left neglected (Moles & Bunge, 2002). This project, however, opened way for many other experiments, with different *Penaeus* species, by Research Institutions or private initiatives. In a second period, other exotic species were introduced such as P*. stylirostris, P. monodon* and *L. vannamei* (Igarashi, 2008). Production results did not go as expected, as further research was necessary. This drove the sector to direct efforts back towards native species such as *F. subtilis, L. schimitti, F. brasiliensis* and *F. paulensis* (Fries, 1991; Nunes, 2001; IBAMA/MMA, 2005; SEBRAE, 2008). Again, most producers lacked support from private and public organizations, which prevented the industry from developing profitably at this stage (Moles & Bunge, 2002; Poersch *et al*., 2006; Cavalcanti, 2012).

By this time, some researches with *L. vannamei* presented optimistic results (SEBRAE, 2008). It was the case of the experiments done by the Rural University of Pernambuco (UFRPE), in collaboration with Ralston-Purina and of a program by the SUDEPE (Superintendencia de Pesca) agency, financed by state bank BNCC (Banco Nacional de Crédito Coorporativo (Nunes, 2001; Moles & Bunge, 2002). One of the requirements to participate in the program was the adoption of *F. japonicus* in the cultures, with an exception for the largest project, at Maricultura da Bahia, that was allowed to use *L. vannamei* (Nunes, 2001; Moles & Bunge, 2002). According to Moles & Bunge (2002), *F. japonicus*, however, was too delicate, and most of the projects failed to keep a sufficient survival rate, and ceased. By 1985, attempts to farm *F. japonicus* were completely extinguished in Brazilian tropical conditions. The white leg shrimp (*L. vannamei*), though, presented high productivity, including for hatchery. Nevertheless, research results from both initiatives, at UFRPE and the SUDEPE program, were kept secret from the scientific community and from other producers (Nunes, 2001; Moles & Bunge, 2002).

In 1992, Aquatec Company, in Rio Grande do Norte, switched the species used in the culture from *P. subtilis* and *P. schmitti*, to adopt the exotic *L. vannamei* (Thomaz, 2014). At fisrt, post- larvae was provided by Maricultura da Bahia, but the necessity for having reproducers *in situ* leads to the most crucial moment to the industry, when Aquatec imported broodstock from Panama. An adapting period to the new species was necessary, but positive results were immediate. Adoption of the white leg shrimp, *L. vannamei*, launches the industry into another stage of development. The species is robust, adapts well to diverse climatic and environmental conditions, and grows fast (IBAMA/MMA 2005). At this stage, new farms are installed and old ones are reactivated. Production grows fast, even though some producers persist on farming native *P. subtilis* (Moles & Bunge, 2002).

When the industry was well-established, production got controlled by the market conditions. Currency value oscillations drive production to the exportation or internal market alternately, affecting many levels of the production and distribution chain (Moles & Bunge, 2002; Cembra, 2012). In 1999, shrimp farming industry experiments another development boost, and the activity expanded to other states, even to the subtropical conditions in the South region (Poersch *et al*., 2006; Freitas *et al*., 2009; Cavalcanti, 2012). In Rio Grande do Sul, with support from the Foundation Federal University of Rio Grande (FURG), the Marine Aquaculture Station established low cost farming in shallow estuarine waters, rearing the native species *F. paulensis* (Poersch *et al*., 2006).

In the following period, Brazilian production responded mainly to environmental conditions and ocurrence of disease, resulting in some important oscillation in productions (Rocha, 2011). Extreme weather events caused generalized floodings, and significant production loss. Additionally, outbreaks of Infection Mionecrosis Virus (IMNV) and Whitespot Disease also damaged shrimp production. In Santa Catarina, in the South, most farms were desactivated before the incapacity to fight the diseases. In Rio Grande do Norte (Northeast), the Primar farm move to organic system and achieved the first certification of organic shrimps and also a certification of the first multitrophic shrimp farm in Brazil in 2003. Since then, this farm have been obtained profitable production and does not face outbreaks caused by diseases.

The literature on shrimp farming industry in Brazil does not cover appropriately the outcomes it has had on the environment or society. There is little attention given to the paths required to achieve a sustainable development of this sector, as well as proposals of strategies on how to implement new and innovative systems. To fulfil these gaps in literature would help decision makers and producers to achieve a new market niche through responsible and sustainable production, providing benefits at broader levels. In this sense, first steps are being taken. Recently, a trend for a better quality product is observed. It is reflected in the accomplishment of shrimp producers of Costa Negra region, Ceará, who achieved the first Designation of Origin certification for shrimp in Brazil, since 2011. This certification benefits producers, by adding value to the product, as well as consumers, which account on a higher quality and more sustainable product. Currently, around 9000 t of this shrimp with the brand Costa Negra is commercialized in Brazil and in the foreign market, especially Europe (Cembra, 2012). In another case, in Rio Grande do Sul, farmers have achieved native pink shrimp production in agreement with the standards for obtaining an “organic seal” certification (Cavalli *et al*., 2007).

The methods of farming are varied in Brazil. Most of the farms are shrimp ponds annexed to estuarine or coastal areas. According to Nunes (2001), and Costa & Sampaio (2004), farms can be classified as extensive (in intertidal areas), semi-intensive and intensive. Most of the production is reared in medium (15-25 individuals/m^2) and high (>25 individuals/m^2) semi-intensive systems. These systems require mechanized aeration, inorganic fertilization and use a tray-feeding system, up to 5 times a day, depending on the stage of farming. In the Northeast, farmers can achieve up to 2,5-3 cycles each year. In Rio Grande do Sul, however, the environmental characteristics allow a different method of farming than in the rest of the country. In this situation, shrimp was cultured in low-intensity systems, in pens inside coastal lagoons, using fisheries by-products to feed the prawns. Nowadays, this system is extinct because of the lack of native post-larvae availability. The culture using zero water exchange biofloc technology (BFT) emerged.

In recent years, there has been a growing interest for using biofloc technology in Brazil, reflected in the number of publications on this subject (Ferreira *et al*., 2016; Brito *et al*., 2015; Silva *et al*., 2013; Souza *et al*., 2013;Emerenciano *et al*., 2012; Emerenciano *et al*., 2011). Acccording to Sampaio *et al.* (2010) biofloc technology has a lot of advantages in relation to the traditional farming techniques. It allows a higher productivity while using smaller areas; higher biosafety; less water consumption; higher system stability; less amount of protein in feed; decrease the environmental impact; among others. A few shortcomings, however, have to be faced, regarding installation and operation costs, and toxicity. In the BFT system, the microbial aggregates (biofloc) are useful for maintaining water quality and besides, it serves as food source for reared shrimp (Emerenciano *et al*., 2012). It is considered a viable alternative for future shrimp farming development in Brazil (Sampaio *et al.*, 2010).

In conclusion, similar to the case of mollusk farming, governmental, financial and institutional support played a significant role in ensuring the success of the shrimp industry. Shrimp farming industry faced many difficulties from the start, but the efforts finally paid out as it placed Brazil on the top 3 farmed shrimp producers in 2003, and currently conserves the 9th position in the world rank (FAO 2016). Two decades of trial and error took place before the match with the ideal species and technology was combined. The competitive character of research and development, where researchers and institutions adopted a secretive attitude hindered the first period of development. Then, once the industry controlled the technology to produce post-larvae, the farming system became consolidated and allowed the expansion to other states in Brazil. The solidification of shrimp farming industry owes to the adoption of white leg shrimp. The industry has developed according to the market conditions, which drove the production back and forth from export to internal market, and attracted many investors to the sector. The main advantages Brazil offers for this industry are the large extensions of the ideal environment for shrimp production. The growth and development characteristics of the white leg shrimp adapted well to the country's climatic and environmental characteristics in the Northeast region, even though it can be produced in a broader latitude extension. Still, disease outbreaks and extreme weather events, have negatively affected production, nearly extinguishing shrimp production in some regions, and leaving a mark on its development. These circumstances have influenced the track of industry development, shaping its limits.

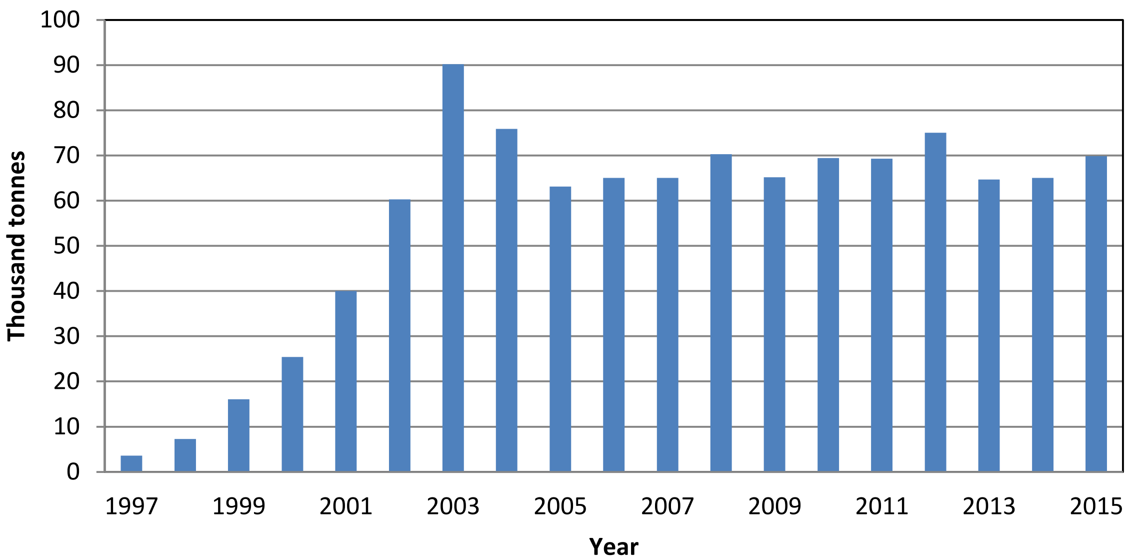


Figure 2.8. Shrimp farming production in Brazil from 1992 to 2015. Source: FAO 2016; IBGE 2016.

Since 1992, farmed shrimp production grew at a mean annual rate of 16 % (FAO 2015). It achieves its highest production in 2003 (Cembra, 2012; Rocha, 2011), when it reaches

90190 ton (figure 2.8). Production is concentrated in the Northeastern states, responsible for 95.2% of total amount (Suplicy, 2006-2013). The fluctuations observed from 2005 to 2009 are the result of Infectious Mionecrosis Virus outbreaks (IMNV), devaluation of the US Dollar, which reduced competitiveness in export market, and in 2009 due to flooding events. Since then, the industry has maintained stable production levels (figure 5) (FAO, 2015).

2.3.5. Seaweed Farming

In Brazil, seaweed farming appears as a response to overexploitation of natural stocks (Vidotti & Rollemberg, 2004; Lelis, 2006). Seweed products are required in the industries of biotechology, pharmacy, food, agrochemistry, energy, etc. (Pellizzari & Reis, 2011). It remains an incipient activity. Internal market demand is supported mostly by imports (Reis *et al*., 2016). The country's environmental and industry characteristics provide many advantages for the implementation a solid algaculture industry.

Seaweed farming emerged first in the Northeast, taking advantage of native *Gracilaria* species (Lelis, 2006). The pioneer experiments came through a project from Laboratory of Marine Sciences (LABOMAR) at Federal University of Ceará, in the 1980s. Given the good results obtained in the experiments, it became possible to develop commercial seaweed culture. There are currently two important algaculture projects taking place in Ceará. Both are an initiative from TerraMar Institute. The first one, accounted with the support of FAO, began in 1997. It is run by the Seaweeed Producers Association of Fleicheiras and Guajiru, Sustainable Development and Renewable Energy Institute (IDER) and TerraMar Institute. According to Rocha (2007), the farming of the native seaweed *Gracilaria birdiae*, engages the whole community in the entire process, from farming, maintaining, to harvesting, drying and even producing cosmetics or food from the seaweed. For benefaction of the seaweeds, a Centre for Seaweed Processing was installed in the community. It was designed to be solar powered. The improved product has increased its commercial value in 1000%. The second project is similar, in terms of adoption of sustainable production methods. It was started in 2001, with the participation of Brazil Citizen Foundation (Fundação Brasil Cidadão). Similarly, a *Gracilaria* species is also farmed in this project, but the different is it was proposed mainly for engaging women. It takes place in the municipality of Icapuí. It is known as "De Corpo e Alga" (of Body and Seaweed). The products are commercialized raw and dried for animal feed, restaurants, or in the own community as raw material for manufacturing cosmetics or food. The financial benefits are used partially for the farming itself and distributed among the participant families. As described by Monteiro et al. (2010), this seaweed farming project represents the most important source of employment and income in its host community. In summary, in the Northeast, seaweed culture combines market demand, community development, and eco-friendly production.

In the Southeast, seaweed farming experiments started in 1995. Researches tested the viability of two exotic species of the genus *Kappaphycus*: *K. alvarezii* and *K. striatum*. The latter was demonstrated not safe to be farmed in this area given it produced viable tetraspores (Bulboa *et al*., 2008; Pellizzari & Reis, 2011). *K. alvarezii*, on the other hand, presented a good adaptation with low invasion risks. With favourable results, commercial seaweed culture was introduced first in Ilha Grande, RJ, in 1998 and in 2003 in Sepetiba bay, RJ (Bulboa *et al*., 2008). In 2008 Brazilian Instituto for the Environment – IBAMA has restricted the licensing for farming of *K. alvarezii* only in the zone comprehended between Sepetiba bay, RJ and Ilhabela, SP. Furthermore, IBAMA has recommended the use of protocols for environmental monitoring, farming and quarantine. The warmer waters of the Northeast, where coral reefs are present, are not safe for the farming of this exotic species more due to higher invasion risk (Pellizzari & Reis, 2011). The adoption of exotic species requires close attention to potential risks, and protocols should be periodically reviewed and strictly followed.

Similar to the other mariculture modalities presented, seaweed farming too presented a different development process according to the geographic situation. In the Northeast, the pioneer projects aimed to propose a sustainable alternative to the seaweed exploitation which already existed (Salles *et al*., 2010; Costa *et al*., 2011). The projects achieved a profitable production of the native species, through community engagement. The examples from the Northeast are analogous to the development model observed in Tanzania (Buchholz et al., 2012) and at the Solomon Islands (Kronen et al., 2010). The implementing of extensive seaweed farming in small traditional coastal communities and gender inclusion has proven to be successful. Benefits are reflected in the whole community (Salles *et al*., 2010; Pellizzari & Reis, 2011). In the Brazilian case, a local increase in the fish production was observed, which raised awareness about preserving sea resources (Rocha, 2007).

In the Southeast region, however, seaweed farming has had a development process more similar to mollusk farming. It first had the assistance of research institutions to safely implement the exotic species, *K. alvarezzi*. Also, rather than being a community project, it is offered as an alternative source of income to fishermen. Besides, it presented a more discrete engagement effect on the host community.

This activity appears to be ideal as a development instrument. Researches have proven that the farming of other native species are profitable in many other coastal localities in Brazil (Faria & Plastino, 2015; Rebours *et al*., 2014; Hayashi *et al*., 2011; Bezerra & Marinho-Soriano, 2010; Pellizzari *et al*., 2007; Bulboa *et a*l., 2008; Hayashi *et al*., 2007; Reis *et al*., 2006; Pellizzari *et al*., 2006; Yokoya *et al*., 1992). It presents significant socioeconomic benefits with virtually no environmental damages. Furthermore, it helps complement marine goods production, compensating the oscillations in fisheries (Salles *et al*., 2010). Additionally, an important potential market exists. Unfortunately, the gap between producers and local government institutions combined with an ineffective management of public resources make difficult the adequate implementation of other seaweed farms. According to Reis *et al*. (2016), only less than 5% of the country's fishery resources are allocated for seaweed farming. The authors describe a few of the impediments to a successful algaculture industry in Brazil. The issues regarding safety of farming *K. alvarezii* are not sufficient. There is no official monitoring protocols and responsible institutions for managing quarantine have not been nominated. On the other hand, safe areas for farming this exotic species continue to be hampered. Farmers do not participate in cooperatives, which could increase profit over production. A continuous effort to engage and sustain community participation in algaculture is needed. And lastly, the authors mention the lack of research and training; integration among researchers and insufficiency of productive sector and public managers. The small number in publications regarding seaweed farming – less than 6% - reflects the little interest on this mariculture modality, even from the scientific perspective.

The statistics for seaweed production are supplied by FAO database (2016), for the period from 2008 to 2014 (Figure 2.9). Though, the information provided has a "not confirmed" status. There are no official production data from Brazilian institutions. Seaweed production, although still small, remains stable. *Kappaphycus alvarezii* is the main farmed species. It contributes with a share of 96% of the total production. There are no signs that the algaculture industry will grow in Brazil in the short term.

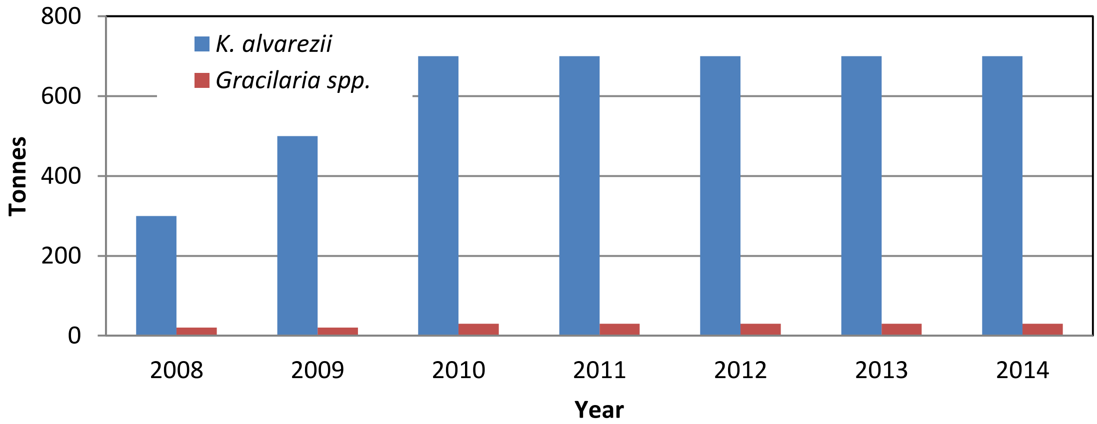


Figure 2.9. Production of farmed seaweed in Brazil, from 2008 to 2014. Source: FAO 2016.

2.3.6. Marine fish farming

In the 17th century, a rudimental form of marine fish farming was introduced by Dutch immigrants. It consisted of fishponds implanted in estuarine shallow areas which trapped wild fish (Von Ihering 1932). Schubart (1936) estimated the production reached 25 t in an area of around 43 hectares of fishponds. It flourished for a certain period, but was finally extinct by the 1930s.

In more recent years, many researches regarding the farming of marine fish have been going on. Currently, the only species that has been viable and profitable to be farmed in Brazil is the cobia (*Rachycentron canadum*) (Sampaio *et al*., 2011; Domingues *et al*., 2014; Bezerra *et al*., 2016). Experiments have been developed in three ways: land-based in indoor tanks or either in sea-based in near shore or off shore floating cages. In 2006, researchers obtained the first spontaneous spawn of confined cobia in Bahia (Carvalho Filho, 2006). Cobia is now the main species being researched, and the only one that is been produced at commercial scale (Sampaio *et al*., 2010[a]; Sampaio *et al*., 2011; Oliveira, 2012; LAPMAR, 2012).

In 2008, two projects were developed in Pernambuco. Aqualider company, was pioneer in achieving the first commercial scale production of cobia. It accounted with the first concession of Union Waters for aquaculture (Decreat 4895/2003). The pilot project has set the installations in offshore cages, in Recife, Pernambuco (Cavalli, personal communication, May, 5, 2015). Nonetheless, the project faced many financial, legislation and technical shortcomings and finally ceased (Cavalli et al., 2011). The second project, named "Cação de escama - cultivo de beijupirá pelos pescadores artesanais do litoral de Pernambuco" (scale shark –cobia farming by artisanal fishermen of the shore of Pernambuco), was financed by the MPA, and coordinated by the Marine Pisciculture Laboratory of Federal Rural University of Pernambuco (UFRPE) (Oliveira, 2012). The aim was to propagate marine fish farming among local fishermen, as well as to establish technology and environmental basis for the sustainable production of cobia in cages (Sampaio et al., 2010[a]). A new leadership of the MPA, however, decided to end the project two years after its implementation (Cavalli, personal communication, May, 5, 2015). Despite the interest of private initiative and research institutions in implementing cobia farming, logistic and institutional issues have delayed the launching of the industry.

In 2009, in Ilha Grande, RJ, an experimental production initiative from a private, public and academic junction was set. It was one of the first projects to close the productive cycle of this species through natural maturation in floating cages, followed by laying and fingerling production in indoor tanks, and posterior growing in near-shore cages (Sampaio et al., 2011). This opened way for other producers, which currently account for seven entrepreneurs of Cobia farming in the region between the southern coast of Rio de Janeiro and the north shore of São Paulo (Rombenso, personal communication, April, 18, 2015). The big metropolises, relatively close to the coast, represent their major market, which in fact, absorbs full production.

Experimental projects have taken place in other sites in Bahia, Santa Catarina and São Paulo. In Bahia, the aim is to develop technology to allow land-based farming. The common-ground to the different research institutions is focusing efforts into developing technology, knowledge, education and capacity building of the local communities (LAPMAR, 2012). Cobia presents one significant advantage to be produced in Brazil, which is the previous existence of farming technology, which only has to be adapted to the reality of the country (Bezerra *et al*., 2016; Sampaio *et al*., 2010[a]). Still, studies have found that there are several other native species with farming potential (Bezerra *et al*., 2016; Dotta *et al*., 2015; Peregrino *et al*., 2014; Sanches *et al*., 2014; Sanches *et al*., 2013; Sampaio *et al*., 2011; Sanches *et al*., 2009).

Bezerra *et al*., (2016) defend that the development of marine fish culture in Brazil could be encouraged by the government through decreased taxes. Also, they argue that an ideal strategy to support marine fish farming development is through the promotion of small- and medium-scale farms and a gradual increase in the production volume. This leads to the accumulation of experience and capitalization of the producers, which is also a result of the solidification of the production chain.

The information available to assess the development of marine fish farming in Brazil, and its implications are scarce. It is still a very recent activity, but with the potential to expand in the near future. The major constraints faced by this incipient industry are related to the costs of farming. Quality, availability and price of fish feed is one of the priorities that must be worked on. Additional research is needed to progress on the quality of the diets, particularly to improve the feed conversion (Sampaio et al., 2010[b]). Furthermore, cobia culture in Brazil depends on the establishment of fingerling production centers. It is expected that with time, fingerling will increase in quality and decrease in price. Nonetheless, the sector is not yet consolidated in Brazil, but the supply of fingerlings is a limiting factor. The production is not stable and the quality of the fry may be below optimal (Bezerra *et al*., 2016). Also, most of the materials used in the farming structures are still expensive, particularly net pens and meshes.

In general, fish farming, like other forms of mariculture, can contribute to a better food safety and poverty alleviation, better nourishment and wellbeing. This modality presents a high development and growth potential, and this trend is enhanced by developing of new species and forms of farming. The sector still faces challenges related to environment interactions, like water contamination, diseases outbreaks, reliance on fishery resources, escape risks, etc. The key for continuous growth relies on management practices that ensure its viability and sustainability in the long term. Thus, it is needed to reduce dependency on fishery resources and to develop technologies focused on omnivorous species (Tacon & Halwart, 2008).

In Brazil there are no official statistics for marine fish farming. It remains a very recent activity. Only two separate data were recovered in this research. The first refers to the first ever commercial-scale production of cobia in Brazil. In 2009, the pilot project from Aqualider company achieved a 49 t production (Cavalli, personal communication, May, 5, 2015). In 2014, the group of small scale producers in the coast of Rio de Janeiro (RJ) and São Paulo (SP) produced 25 t of cobia in near shore cages (Rombenso, personal communication, April, 18, 2015).

2.3.7. Management and Policy

Parallel to the development of the aquaculture sector, national National polices have evolved together with the aquaculture sector towards the support for the management and development of new aquaculture modalities. The policies have been adapted to new scenarios resulting from the expansion of aquaculture in Brazil. Nevertheless, the responsibilities over aquaculture regulation, monitoring and support has been fragmented and assigned to different government authorities over the years. In addition, institutions in municipal, state and federal levels overlap the competences to legislate, give permits and oversight aquaculture sector. This situation creates conflicts and uncertainties, which impaired the plain development of aquaculture in Brazil. For instance, the environmental licensing is a complicated process in Brazil and permits are given by state or federal institutions. In addition farms should match municipal regulations.

At the Federal level, the Brazilian Institute for the Environment (IBAMA), created in the 1980s, concentrated most of the tasks related to the aquaculture sector. The growth of aquaculture required the government to create, in 2003, the Special Secretary of Aquaculture and Fisheries of the Republic Presidency (SEAP/PR) which elaborated in joint with IBAMA the laws and rules for the use of water bodies, and the management of aquaculture. SEAP promoted important actions and mechanisms to boost and regulate the marine aquaculture sector. In 2004, the National Program for Coastal Management is launched, aiming to integrate and promote sustainability of the activities in the coastal zone, including aquaculture development. At this time, the Law nº 11.959, of Fisheries and Aquaculture, is published, setting the National Politics on Sustainable Development of Aquaculture and Fishery. In 2005, the National Program of Aquaculture Development was launched. The Program includes the Local Plans for Mariculture Development in each state (PLDM). It is one of the main tools developed to promote and regulate mariculture. It includes participative planning and aims to promote sustainable aquaculture development.

In 2009, SEAP was upgraded to become the Ministry of Fisheries and Aquaculture (MPA). The creation of the National Program for Hygienic-Sanitary Control of Bivalve Mollusks was considered an important action under the charge of MPA. The Program was long required to improve and diversify market and competitiveness of the sector market by regulating farming areas, harvesting methods, processing operations, distribution, and commercialization chains (Cembra 2012; Suplicy, 2006-2013). The ministry, however, only lasted for a short period. The economic and political crisis Brazil suffered in the recent years forced its extinction which is, since 2015, again entailed to the Ministry of Agriculture, Husbandry and Supply.

National Policy for Fisheries and Aquaculture conceive integrated sustainable development of the sector within communities; management and support of the activity; and environmental preservation and conservation. Still, there are some issues to be worked on regarding excessive bureaucracy and superposition of duties at different institutional levels in public management processes. Also, regularization of mariculture activities has been deficient and in most coastal regions, producers operate illegally. Mariculture was implemented unorganized and spontaneously, without planning of the use of coastal zones. This situation has impaired the activity and allows the generation of conflicts among users of the coastal zone. The main limiting factors for expansion of aquaculture, according to farmers, are related to environmental permits, credit access and insufficient public policies to promote the sector (Kubitza, 2016). The PLDMs were created one of the tools to respond to these problematics. Nonetheless, there are only a few states up to date with the elaboration of the PLDM. Santa Catarina was the first state to adopt this policy and start on the process of legalizing of the activity. This experience on implementing PLDM, within the Coastal Management program for the state (GERCO-SC), through the PZGC (Plan of Coastal Zone Management) and ZEEC (Coastal Ecological Economic Zoning) shows an effective way for mariculture regulation and management. Participative process on zoning aquaculture parks has promoted empowering of mariculture associations in decision making processes, and subsidized marine spatial planning (Vianna et al. 2012). Therefore, it is possible to attend the legal criteria, integrate institutions and promote democracy on coastal management. Regulation of mariculture allows on credit access and legal safety for farmers, while promoting a steady product supply and improved competitiveness. Legal issues remain one of the main bottlenecks for mariculture development (Cembra, 2012).

Promoting communication between farmers, the academic community and politics is important in the development of an integrated sustainable industry. In this sense, difficulties and problems faced by producers, or the negative impacts caused may be effectively addressed. Some academic studies have approached sustainability assessment issues that could be included in management policies (Elfes *et al*., 2014; Poersch *et al*., 2014; Muhlert *et al*., 2013; Lima *et al*., 2012; Ferreira *et al*., 2011; Lessa *et al*., 2009; Castello *et al*., 2008; Simões *et al*., 2008; Lopes, 2008; Wurmann *et al*., 2004). In the regions where research institutions and government were involved from the beginning of the mariculture development, a higher production and better organization of farmers are observed.

2.3.8. Environmental effects and interactions

Publications on studies over environmental effects from mariculture could be separated in two categories: 1. Those describing environmental impacts from the structures, effluents or introduction of exotic species (table 2.3); and 2. Those reporting interactions with other species (table 2.4). These interactions were mostly related to the use of farming structures as substrate or environment, in the case of organisms trapped inside shrimp ponds, and disease infection on wild fauna. Most researches on environmental impacts dealt with shrimp farming, but a few researchers also studied the effects from mollusk farming. In the diagrams below (figure 2.10) these effects are described.

Shrimp farming is reported to affect the environment in many levels at different stages of farming. The installation of the farms, hence the initial stage, in many cases damages the surrounding ecossystem, which often environmentally protected areas (such as mangroves, *apicuns*, etc.) (Tenório *et al*., 2015; Santos *et al*., 2014; Queiroz *et al*., 2013; Hamilton 2013; Guimarães *et al*., 2010, Grigio *et al*., 2009). These damages have contributed to erosion and sedimentation processes (Godoy & Lacerda 2014). Effluents from farms are stated to affect the geochemistry of the soil, promoting pH increase and decrease in the redox potential (Nóbrega *et al*., 2016; Suárez-Abelenda *et al*., 2014). Discharges from farmes have been related to higher concentrations of Nitrogen, Phosphorus, Mercury, Manganese, Lead, Cadmium, Copper, Aluminium, Iron and Zinc (Nóbrega *et al*., 2016; Nóbrega *et al*., 2014; Costa *et al*., 2013; Dias *et al*., 2013; Lacerda *et al*., 2013; Nóbrega *et al*., 2013; Marins *et al*., 2011; Lacerda *et al*., 2009; Lacerda *et al*., 2006a; Lacerda *et al*., 2006b; Silveira *et al.*, 2006; Silva *et al*., 2003.). Furthermore, salinity differences between effluents and receiving water body may cause short term reduction in chlorophyll a and consequently primary production (Cardozo & Odebrecht, 2014). In contrast, however, in the long term, an increase in chlorophyll a and primary production as well as in total plankton biomass is observed, promoting eutrophication (Almeida *et al*., 2012; Neumann-Leitão *et al*., 2003). Metabissulfite used in harvesting of farmed shrimp was reported to contaminate water and sediment adjacent to shrimp ponds, inducing toxicity and mutagenicity of organisms (Carvalho *et al*., 2011). Moreover, effluent discharges have reportedly altered the structure of the macrofauna on the adjacent environment, decreased heterotrophic counts of bacteria and increased *Vibrio spp*. counts in farmed waters (Canary *et al.*, 2009; Poersch *et al.*, 2007. Sousa *et al.*, 2006; Cruz *et al.*, 2015; Rudorff *et al.*, 2012; Netto & Valgas, 2010; Costa & Nalesso; 2006). Lastly, it was reported that the exotic farmed shrimp *Litopenaeus vannamei* was found in the natural environment sharing the same habitat and food items with other native species, presenting invasion potential (Melo *et al.*, 2010). Essentially, most of the environmental impacts from shrimp farming could be mitigated by improving effluent treatment and disposal on the natural environment.

Table 2.3. Main environmental impacts from mariculture indentifies in Brazil, presented by state.

Culture	State	Impact	Source
Shrimp	Ceará (CE)	Greenhouse gas emissions	Nóbrega *et al.*, 2016; Suárez-Abelenda *et al.*, 2014.
	Ceará (CE), Sergipe (SE), Maranhão (MA), Pará (PA), Pernambuco (PE)	Land use change	Tenório *et al.*, 2015; Godoy & Lacerda 2014; Santos *et al.*, 2014; Queiroz *et al.*, 2013; Hamilton 2013; Guimarães *et al.*, 2010, Grigio *et al.*, 2009.
	Ceará (CE), Rio Grande do Norte (RN)	Soil geochemistry and metal input	Nóbrega *et al.*, 2014; Costa *et al.*, 2013; Dias *et al.*, 2013; Lacerda *et al.*, 2013; Nóbrega *et al.*, 2013; Marins *et al.*, 2011; Lacerda *et al.*, 2009; Lacerda *et al.*, 2006[a]; Lacerda *et al.*, 2006[b]; Silveira *et al.*, 2006; Silva *et al.*, 2003.
	Pernambuco (PE), Rio Grande do Norte (RN), Rio Grande do Sul (RS)	Effects on plankton	Cardozo & Odebrecht, 2014; Almeida *et al.*, 2012; Neumann-Leitão *et al.*, 2003.
	Piauí (PI)	Environmental mutagenicity and toxicity	Carvalho *et al.*, 2011.
	Maranhão (MA), Piauí (PI)	Invasion	Loebmann *et al.*, 2010.
	Rio Grande do Sul (RS)	Effects on benthic environment	Canary *et al.*, 2009; Poersch *et al.*, 2007.
	Ceará (CE)	Effects on bacterial community	Sousa *et al.*, 2006.
Mollusk	Santa Catarina (SC), Sergipe (SE)	Effects on the benthic environment	Cruz *et al.*, 2015; Rudorff *et al.*, 2012; Netto & Valgas, 2010; Costa & Nalesso; 2006.
	Santa Catarina (SC)	Invasion	Melo *et al.*, 2010

Strangely, the approach from the Brazilian Association of Shrimp Farmers (ABCC) regarding environmental issues was rather controversial. They state that shrimp farming has actually promoted environmental benefits, and denied it causes mangrove deforestation, arguing that there has been an increase of 28.2% on mangrove coverage (Rocha, 2005). These arguments, however, are based on a study by Maia et al. (2005) that actually describes that this incrementing owes to sedimentation as a negative impact caused by shrimp farming. Moreover, the study defends that at a local level, expansion of the shrimp industry caused mangrove loss.

Site selection is a key issue in avoiding some negative effects from the shrimp industry. Preserved mangroves provide more valuable services and uses than when converted in shrimp ponds (Tenório *et al.,* 2015). Also, this ecosystem is protected by law as it is declared Permanent Preservation Area, and further, a resolution from the National Environment Council (CONAMA) prohibits shrimp farming in mangroves and adjacent environments. The studies reviewed highlight the need for future ventures to respect the legislation and the promotion of ecosystem restauration.

Some methods and technologies have been developed to address sustainability issues in shrimp farming. Adoption of "ZEAH" (Zero Exchange, Aerobic, Heterotrophic Culture Systems) or Biofloc Technology (BFT) can minimize many environmental adversities related to the feed inputs or diseases (Sampaio *et al*., 2010b). These approaches contribute to the renovation and resilience of the industry through innovative systems. Furthermore, production systems with Designation of Origin certification or other type of sustainability labelling, avoid the negative effects of shrimp farming regarding the well-being of traditional communities, contamination and deforestation, but also delivering a higher quality product.

Considering mollusk farming, the most important impact described in the literature is related to the first record of invasion of *C. gigas* in Brazil (Melo *et al*., 2010). Researchers, however, speculate that organisms probably reached Brazilian waters from Argentinean farms through the South Atlantic current. Still, in most cases, differently to shrimp farming, the environmental impacts from mollusk farming are not severe. Literature describes the use of the artificial structures and the mollusks themselves as substrate for diverse species, but also it have influenced water circulation, and thus, sediment deposition. In sites with weak hydrodynamics, density and diversity of meiofauna and nematofauna were smaller under the farms (Cruz *et al*., 2015; Rudorff *et al*., 2012;Netto & Valgas, 2010). In other cases, farms have caused slight alterations, causing no negative impact on the macrobenthic community (Costa & Nalesso; 2006). It is important to highlight, though, that most effects from the farming facilities in the benthic environment resulted in very little or insignificant.

Once more, site selection has played an essential role in this subject, where water circulation and depth were conditioning factors. Site selection has another important impact in mollusk farming, since most environmental interactions occur in the environment-culture direction. Currently, one of the main limiting factors for shellfish farming development is the water quality. As filter feeders, these organisms are subject to the impurities of the environment. Water contamination and red tides endanger production and commercialization of mollusks and offer health risks (Lovatelli *et al*., 2008). Several studies explored the susceptibility of the mollusks to water pollution and contamination (Yoshimine & Carreira, 2012; Yoshimine *et al*., 2012; Galvão *et al*., 2010; Sáenz *et al*., 2010; Zottis *et al*., 2004; Curtius *et al*., 2003). The major concerns, however, are the risks to human health, mostly in toxic algal bloom episodes, or the presence of pathogens in the farming waters (Silva Neta *et al*., 2015; Mafra Jr. *et al*., 2015; Ramos *et al*., 2014; Fernandes *et al*., 2013; Vieira *et al*., 2010).

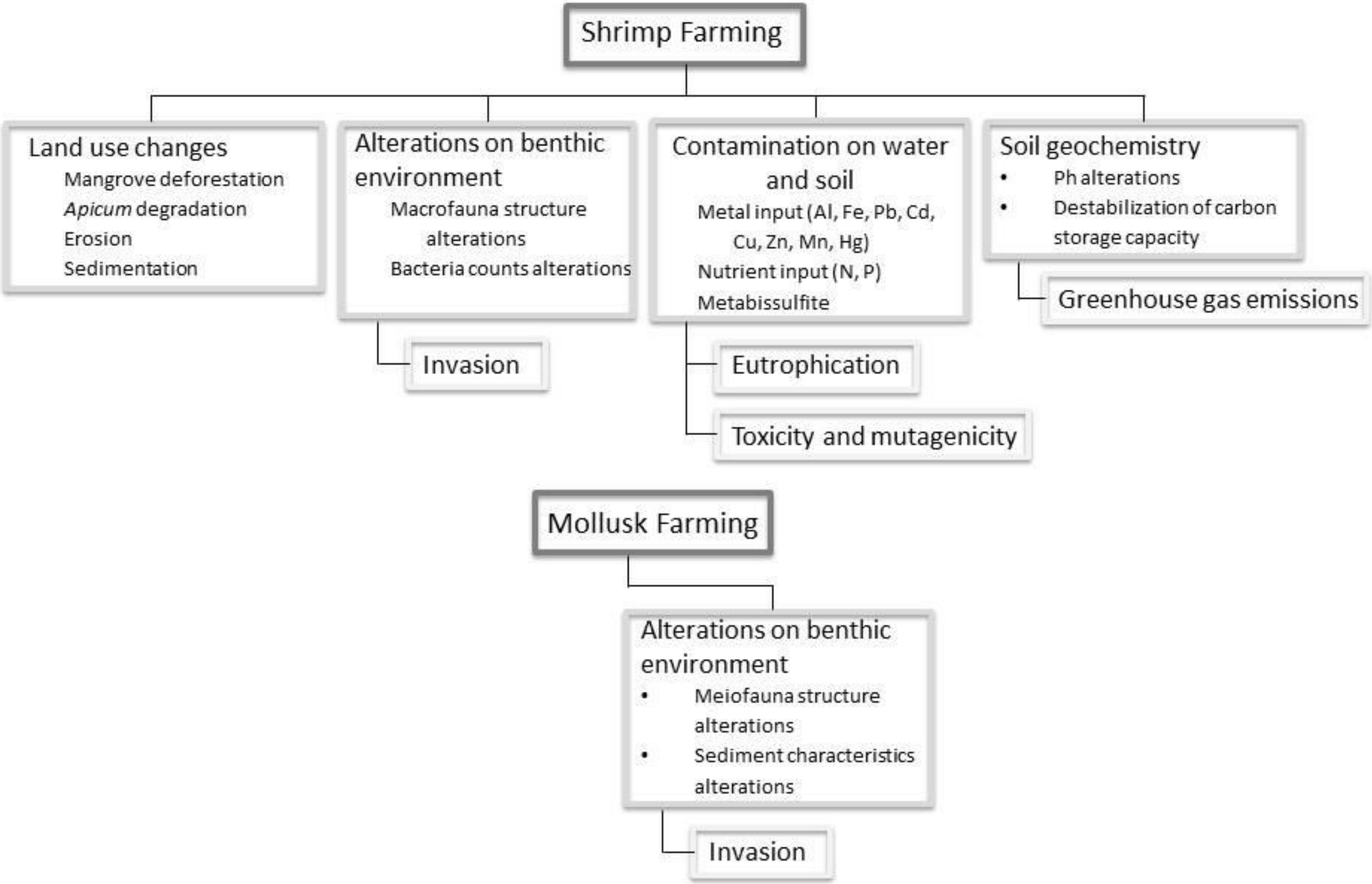


Figure 2.10. Effects from mariculture on the environment recorded on literature.

Through the systematic research were found 51 published studies on the environmental effects from mariculture in general. 67% of the publications dealt with shrimp farming effects, followed by the effects from mollusk farming (31%), and only one study over the environmental interactions regarding seaweed farming. There were no publications specifically dealing with fish farming effects. The studies on shrimp farming effects were mostly related to effluent discharge (59%), and land use changes (21%). Researches regarding the effects from mollusk farming focused on the use of mollusk farms as substrate from other organisms (69%) and the impacts of the farm on the benthonic environment (25%). The research on seaweed farming reported no alterations on the environment.

Table 2.4. Main studies on environmental interactions of mariculture with other species.

Culture	State	Source
Mollusk	Paraná (PR)	Possamai & Fávaro, 2015
	Paraná (PR)	Frigotto *et al.*, 2013
	Santa Catarina (SC)	Carraro *et al.*, 2012
	São Paulo (SP)	Bernadochi *et al.*, 2012
	Santa Catarina (SC)	Macedo *et al.*, 2012
	Santa Catarina (SC)	Kremer & Rocha, 2011
	Paraná (PR)	Marochi & Masunari, 2011
	Santa Catarina (SC)	Rocha *et al.*, 2009
	Espírito Santo (ES)	Sá *et al.*, 2007
	Santa Catarina (SC)	Gerhardinger *et al.*, 2006
	Ceará (CE)	Freitas *et al.*, 2006
	Santa Catarina (SC)	Branco *et al.*, 2001
Shrimp	Rio Grande do Sul (RS)	Cavalli *et al.*, 2013
	Rio Grande do Norte (RN)	Costa & Camara, 2012
	Santa Catarina (SC)	Costa *et al.*, 2012
	Santa Catarina (SC)	Marques *et al.*, 2011
	Rio Grande do Sul (RS)	Cavalli *et al.*, 2011[a]
	Rio Grande do Sul (RS)	Soares *et al.*, 2004
Seaweed	Rio de Janeiro (RJ)	Carvalho *et al.*, 2015

Most of the interactions related to mollusk or shrimp culture occur within the farming facilities (figure 10). In the case of mollusks, the farming structure functions as an artificial reef, providing habitat, shelter or substrate (Frigotto *et al*., 2013; Bernadochi *et al*., 2012; Carraro *et al*., 2012; Macedo *et al*., 2012; Kremer & Rocha, 2011; Marochi & Masunari, 2011; Rocha *et al*., 2009; Sá *et al*., 2007; Freitas *et al*., 2006) . In some cases, the empty shells are used as nesting places for the blenny *Hypleurochilus fissicornis* (Possamai & Fávaro, 2015; Gerhardinger *et al*., 2006). Also, the floaters from the farming structures are used as resting places for marine birds (Branco *et al*., 2001). The assemblage of floaters, ropes, shells and other materials used conform a non-natural habitat which attracts various species and diversifies the environment. Shrimp ponds, on the other hand, impacts on the natural habitat. Because ponds are controlled environments, the organisms that enter can be predated, or get trapped inside (Costa & Camara, 2012; Soares *et al*., 2004). Also, the diseases that commonly affect the cultured species can spread through the effluents and infect the organisms in the surrounding waters (Cavalli *et al*., 2013; Costa *et al*., 2012; Cavalli *et al*., 2011[a]; Marques *et al*., 2011). Again, the studies show that the effects from shrimp farming are considered more negative than those caused from mollusk culture. Studies on seaweed farming, however, showed no impacts or interactions with the environment (Carvalho *et al*., 2015).

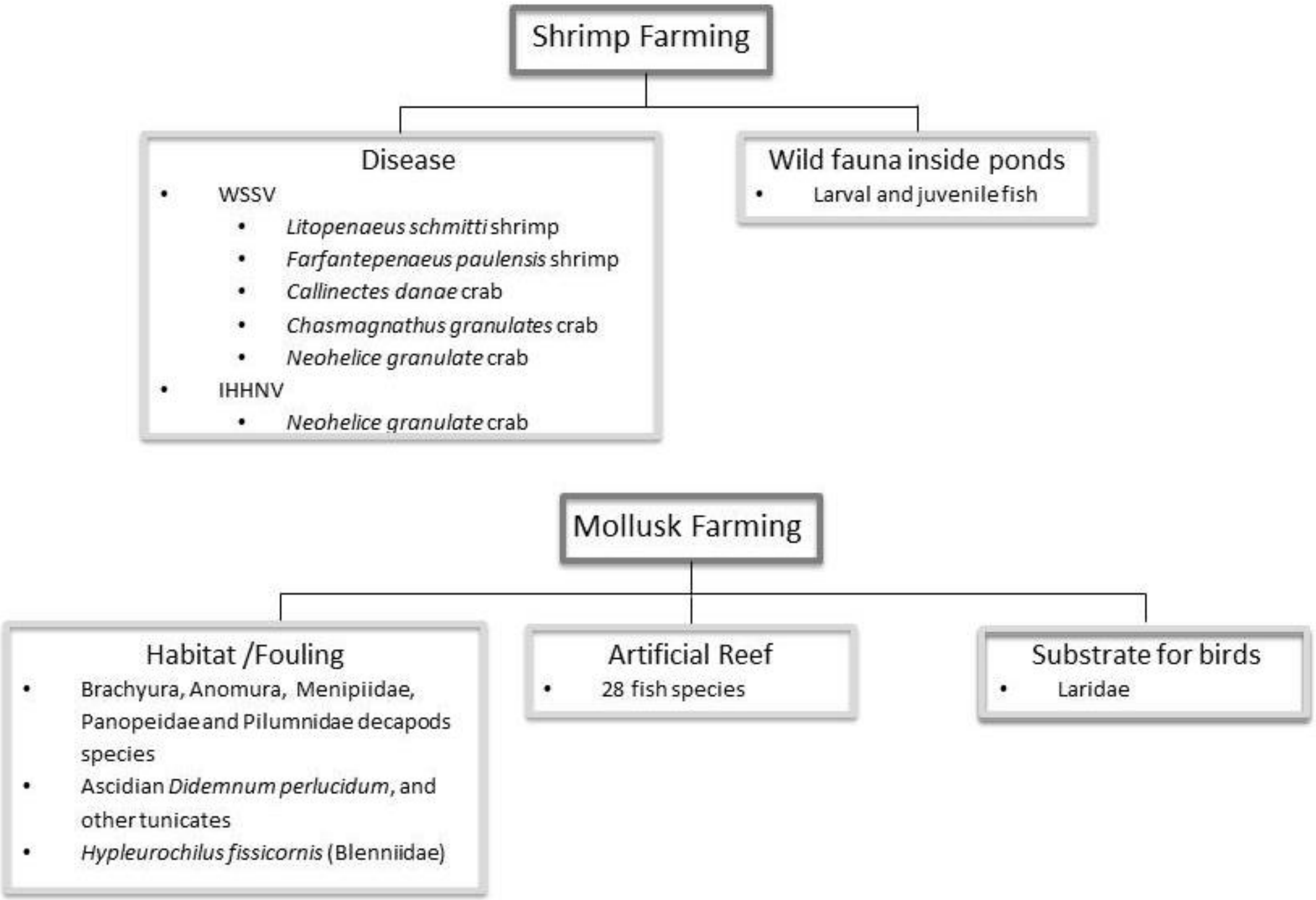


Figure 2.11. Mariculture interactions with other species reported on the literature.

2.3.9. Socioeconomic impacts

According to the Brazilian Institute Of Geography and Statistics (IBGE) (2016), mMariculture contributes with US $ 306 million (over 22%) to the total value of aquaculture production in Brasil (IBGE, 2016). The farmed mollusk production, in 2015 was valued in over 26 million US Dollars. Farmed shrimp production was even more important, valued in over 279 million US Dollars. Both productions showed increase in value, in comparison to the previous year. Despite not having an important participation in the national economy, the activity does play an important at a regional or local level. Still, shrimp consist of a large portion of the domestic aquaculture production (12%) (FAO, 2016). In the lights of a recent study, it was found that the shrimp farming and wild caught shrimp trade comprise an integrated market. In the sense, supply and demand fluxes are shared by both industries, so that the price oscillations are smoother and less volatile, benefiting consumers (Pincinato, 2016). This circumstance favours the expansion of aquaculture as it promotes its competitiveness.

There are no official diagnoses on the socioeconomic implications of the mariculture sector in Brazil. Yet, some researchers made an effort to gather local data that may help us understand these effects. Nonetheless, a great part of the available information is outdated. Most of this data concerns shrimp farming activities, but in a smaller proportion, there are some publications on the socioeconomic impacts from mollusk farming (table 2.5).

The table shows some of the most important socioeconomic benefits from mariculture at the local level. Usually, mollusk farming is a familiar business or a complimentary activity. Shrimp farming is generally a more organized activity, and contributes to full-time and seasonal jobs, requiring primary or secondary educational level. The adoption of higher technologies in shrimp farming (in some farms bigger than 10 ha) usually reduces the number of required employees.

The adoption of shrimp farming as a tool for local development has resulted in diverse socioeconomic benefits to the communities. Shrimp farming industry grew to become one of the best organized aquaculture sectors in Brazil (Suplicy, 2006-2013). In some municipalities in the Northeast, shrimp farming is the main source of employment and income (Sampaio et al., 2008; Costa & Sampaio, 2004). Shrimp farming has proven to have the potential to contribute to a decrease in regional disparities in Brazil. The participation of small, medium and large shrimp farms, as well as the different sectors that participate in the production chain impacts at different levels of society (Araújo & Okino, 2009; Cavalli et al., 2008; Sampaio et al., 2008; Martinelli & Freitas Junior, 2007; Vinatea et al., 2007; Costa & Sampaio, 2004). For each direct job generated in the three stages of the farmed shrimp production chain, approximately one job is generated through indirect and induced impacts (Costa & Sampaio, 2004). Indirect jobs are generated by sectors connected to the production chain, by suppliers of inputs and services, such as ration, water pumps, gas, aerators, packaging, transportation, etc.

Offering a different perspective, mariculture has also caused social conflict. The expansion phase in shrimp farming development was economic oriented, and the rapid growth of the industry was marked with many environmental damages (Tenório et al., 2015; Godoy & Lacerda 2014; Santos et al., 2014; Queiroz et al., 2013; Hamilton 2013; Guimarães et al., 2010, Grigio et al., 2009). One of the most illustrative examples is from Caravelas, in the state of Bahia (BA). Environmentally protected areas irregular occupations by shrimp farms have caused contamination and deforestation that ultimately led to access impediments to fishing areas, fish mortality at harvesting period, social exclusion and marginalization (Dias et al., 2012; CMADS, 2005; Silva, 2004; Carvalho Filho, 2004). The environmental effects have ultimately impacted significantly in the decline of social well-being of several traditional communities. The conflicts reached national repercussion, and ended up involving the entrepreneurial sector, politics, environmentalists, traditional communities, and academic members. A long and complicated lawsuit took place, the President of the Republic and the Ministry of the Environment decided to intercede. It ended with the decree that places the area as a Conservation Unit, protecting it from the implementation of shrimp farming, and other potentially damaging activities.

Table 2.5.Main socioeconomic effects from mariculture development identified in Brazil and presented by state.

Culture	State	Type of enterprise	Perceived benefits	Source
White leg shrimp	Ceará (CE), Rio Grande do Norte (RN), Pernambuco (PE), Bahia (BA)	680 farms: 75% small (<10 ha); 19% medium sized (from 10 to 100 ha); and 5% large (<100 ha); 28 hatcheries; 30 processing plants.	Increase and stability of employment; Increase in the income; Increase in the municipal revenues; Higher life quality in the municipalities.	Costa & Sampaio, 2004; Sampaio *et al.*, 2008
White leg shrimp	Rio Grande do Norte (RN)	Hatchery	Increase and stability of employment.	Araújo & Okino, 2009
Pink shrimp	Rio Grande do Sul (RS)	Extensive farming	Increase in the income; Positive attitude toward cooperative work.	Cavalli *et al.*, 2008
White leg shrimp	Pará (PA)	Semi-intensive farming	Increase profit;	Martinelli & Freitas Junior, 2007
White leg shrimp	Santa Catarina (SC)	Semi-intensive farming	Increase and stability of employment; Increase in the income; Increase in the municipal revenues; Higher life quality in the municipalities; Community support.	Vinatea *et al.*, 2007
Oyster	Paraná (PR)	Artisanal farming	-	Absher & Caldeira, 2007
Oyster	São Paulo (SP)	Artisanal farming	Increase profit; Poverty alleviation; Diversification of fisheries activities; Higher life quality in the municipalities; Maintaining traditional communities in the coastal zone.	Barbieri *et al.*, 2014
Oyster and mussel	Espírito Santo (ES)	Artisanal farming	-	Nalesso & Barroso, 2007
Oyster and mussel	Espírito Santo (ES)	Artisanal farming	Increase in the income.	Sousa & Doxsey, 2007

Regarding mollusk farming, studies have not recorded negative social impacts. On the contrary, it promotes the diversification of economic activities for traditional coastal communities (Barbieri *et al.,* 2014; Absher & Caldeira, 2007; Nalesso & Barroso, 2007; Sousa & Doxsey, 2007). In some cases, the farming engages more than one family member (Sousa & Doxsey, 2007). It was also stated that it contributes with poverty alleviation, by increasing profit, promotes life quality and supports the settlement of traditional communities (Barbieri *et al.,* 2014).

Still, the studies have also pointed out some difficulties faced by this sector. Many similarities were found in the studies by Absher & Caldeira (2007), Nalesso & Barroso (2007) and Sousa & Doxsey (2007). According to those three studies, the main challenges were related to the production chain, more specifically in the commercialization and product amelioration. It was mentioned that improving farmers' organization (in associations or cooperatives) would lead to a more homogeneous distribution of benefits. And lastly, they would benefit from the capacitation of farmers and technicians to assist in problem solving and optimizing production. These studies also mentioned legal concerns hindering the growth of the activity, and sanitary issues that may impair production. Nonetheless, the studies are outdated, and it is possible that the situation has changed in the past years, with the Local Plans for Mariculture Development and the National Program for Hygienic-Sanitary Control of Bivalve Mollusks.

In synthesis, the results highlight that social well-being is not only achieved by economic growth of the mariculture sector. To achieve sustainable socioeconomic mariculture development, it should be entangled within an integrated coastal planning and management strategy. Benefits from mariculture development must aim to be equitably distributed among the community, in order to help increase the life quality of the most sensitive social layers. Mariculture development must be planned transversally, including technological capacitation, regulation, administration, and also considering the interests of other groups of stakeholders (government, research institutions, farmers, other coastal users and industries, etc.). Besides, environmental preservation is essential for maintaining social wellbeing and to avoid conflicts over uses of the coastal zone.

2.4. Conclusions and recommendations

Brazil has proven to have an ideal environment for the development many modalities of mariculture. It has played an important role in many communities along the Brazilian coast. In most cases, it did not result in high incomes, but it has been enough to support hundreds of families. Yet, mariculture expansion has shaped the communities. It contributes to maintain the traditional communities in their lands; imposes the necessity of caring for the health of the coastal ecosystems; and reinforces a traditional lifestyle.

Mariculture progress presents two contrasting arrangements. Shrimp and fish farming have been developed following a more structured and organized pattern. These modalities are usually promoted through a founded company. Oppositely, mollusk and seaweed farming represent an informal, sometimes complimentary activity developed by fishermen, or traditional families. The level of organization observed between the different modalities is probably related to the complexity that each species requires for culture. The technologies, knowledge and investments required for feeding and reproduction limit the access to shrimp and fish farming business. In this sense, the social environment has marked the development of mariculture activities in each location. In the wealthiest regions, marine farming has received support from government and institutions, which has boosted mariculture growth, when compared to initiatives (regarding same modalities) in other regions.

The development of mariculture has intended to achieve higher production levels, without considering sustainability of the activity, mostly regarding shrimp farming production. This policy has led to an unorganized and irresponsible growth, leading many initiatives to fail. Poor management of farms has led to occurrence of diseases and environmental damages. It has caused economic loss to entrepreneurs, land owners and government (Valenti, 2008). Mariculture policy must embrace all levels of sustainability and support innovative approaches. It is necessary that policy is motivated by other objectives than economic growth or environmental protection. A new model is needed that integrates aspirations of society, through better governance. The market suggests there are many opportunities for inventive methods to achieve sustainable mariculture that could be supported with a different policy approach (Bostock et al., 2010).

Regarding the optimal environment for many modalities of mariculture, there is still much room for growth of mariculture in Brazil. The development of the full potential the country possess should be achieved when the producers can rely on credit access, legal safety, steady product supply and improved competitiveness, since it would reduce costs. The sector is also hindered by the absence of farmers-directed social policies; the inexistence of a marketing strategy directed to the commercialization of the products; and deficiencies regarding management, promotion and infrastructural issues (Freitas *et al*., 2009). The implementation and development of mariculture is supported by different sectorial institutions responsible for the licensing and regulation of the activities. Still, the reactive development of aquaculture policy caused the overlapping of responsibilities on regulating the activities. This situation provokes excess of bureaucracy, which delays the licensing process. In this regard, the expansion and growth of mariculture is hindered. The difficulty for obtaining permits causes producers to operate illegally. Legal issues still are one of the main bottlenecks for mariculture development (Cembra, 2012).

On the other hand, there is a great interest from academic institutions in improving this sector, reflected on the high number of publications regarding new technologies, species, or innovative approaches. The sector could benefit from more incentives to research and technology in order to help farmers achieve solutions and more sustainable methods for production. Historically, academic and research institutions have played a key role in the progress of mariculture, such as the development of technology, subsidizing decision on species to be adopted, and in controlling full life cycle of farmed species. The creation of laboratories to produce shrimp post-larvae, cobia fingerlings and mollusk hatcheries are examples of the importance of supporting research. Currently, it would be useful to facilitate ways for farmers to put into practice new farming methods that have shown various economic and environmental advantages from experimental studies. Thus, another step towards connecting science and community is to improve the communication between researchers, producers and politics.

Considering the absence of official publications from the government authorities regarding the status of mariculture production or an assessment of its main impacts reflect the lack of focus in mariculture. This information would make would help direct the development of the sector, in order to achieve higher benefits from mariculture ventures. In this sense, it is imperative to consider that different zones have diverse levels of sensitiveness to farming. There should be a search for balance of the negative effects of any mariculture entrepreneurship with socioeconomic benefits, through the adaptation of adequate farming methods to the site selected. Also, farming should be integrated with the various environmental services and functions of the place and to the diverse activities developed in the coast. This circumstance makes necessary the adoption of holistic approaches to assess the sustainability of mariculture. A management tool for the sustainability of mariculture, in such a way that it facilitates visualization of the main strengths and weaknesses of entrepreneurships, to improve integrating the activity in the hosting socio-environmental system should also be implemented. In many countries, the adoption of sustainability indicators is used to assess the sustainability level of the sector (FOESA, 2010; GFCM, 2011). In Brazil, Valenti *et al*. (2011) have developed a set of indicators to assess aquaculture sustainability that aims to fulfill this goal, and are currently being tested. Even so, it is recommended that further actions take place in this direction. For example it is proposed that a complementary indicators system specific for mariculture including assessment of management actions should be created to guide stakeholders and regulating institutions to achieve more sustainable and integrating development of the sector. This proposal could also serve as a communication tool to transmit information about mariculture sustainable development.

The present publication may help researchers and stakeholders understand the footprints mariculture is leaving in Brazil. We hope to inspire further research to fulfill the literature gaps, with the generation of information regarding production issues and the main positive and negative impacts from mariculture development. This study contributes with gathering of information that may help to create tools to improve the extent of the benefits and the solutions to the problems faced by this sector. Ultimately, it is desired that mariculture becomes a key tool for the integrated sustainable development of coastal communities.

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2.5. References

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"Caminante, son tus huellas
el camino, y nada más;
caminante, no hay camino,
se hace camino al andar.
Al andar se hace camino,
y al volver la vista atrás
se ve la senda que nunca
se ha de volver a pisar.
Caminante, no hay camino,
sino estelas en la mar."

Antonio machado (1875-1939)

AS INDAGAÇÕES

"A resposta certa, não importa nada: o essencial é que as perguntas estejam certas."
Mario Quintana (1906-1994)

3. A set of indicators for the management of sustainable mariculture development in Brazil: A mixed methodology approach.

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Abstract

Sustainability indicators are widely used as tools to assess development processes regarding coastal development issues. The embracement of aquaculture as a powerful agent in promoting sustainable development of coastal zones emphasizes the need for a proper monitoring tool to evaluate aquaculture sustainability. The present study aims to present a mixed approach methodology and a set of indicators to evaluate the sustainability of Brazilian mariculture. A Delphi protocol was used to select the most adequate indicators for the management of mariculture sustainability in Brazil. The procedure resulted in the selection of a set of 29 indicators, with the novelty that this system is specific to the Brazilian situation, but also general enough to comprise the diversity of existent mariculture systems, and policy actions. The set of selected indicators helps highlight values that should be reinforced in the development of coastal activities. The proposed set of indicators guides mariculture development management in favors of the integration of mariculture on coastal development.

Key words: integrated coastal development, Delphi protocol, mariculture policies.

3.1. Introduction

Achieving sustainable development is in the agenda of most countries. In recent decades, the environmental awareness of the international community has risen as major impacts on Earth, biodiversity as well as increasing pressures in ecosystem products and services have become common features in diverse regions and continents. In most cases, those impacts and pressures need to be addressed from the local to the international levels, through the implementation of diverse instruments.

The OECD (1993) defined indicator as: "A parameter, or a value derived from parameters, which points to/provides information about/describes the state of a phenomenon/environment/area with a significance extending beyond that directly associated with a parameter value." This definition, in other words, means it is a qualitative or quantitative measurement or observation used to describe a situation and assess changes and trends over time.

The need for developing an indicators system to assess sustainable development was first claimed at the Earth Summit, in Rio 1992, and was materialized in the Agenda 21. Then it was proposed to establish a global effort to elaborate indicators of sustainable development aiming to provide a solid basis for decision making at all levels (UN, 2007). The Agenda 21 also considers that to achieve a sustainable development of the coastal zones, an integrated approach is necessary. In this context, aquaculture is presented as a tool for diversifying and promoting sustainable economic activities in coastal areas.

In Brazil, these concerns were first shown in the National Plan for Coastal Management (PNGC) in 1990, which later constituted the guidance to develop and launch the National Program for the Development of Mariculture in Union waters in 2005. This Program aims to plan mariculture development through adequate marine or estuarine zoning at a local scale through the Local Plans for Mariculture Development (PLDM). However, the establishment of the site selection must be accompanied by a periodic evaluation of the development of mariculture activities regarding social (including governance), economic and environmental issues. This monitoring should aim to help assess decisions and action-taking in the management process (Asmus et al., 2006).

In Europe and North America, diverse aquaculture indicators were proposed to assess the sustainability level of development of the aquaculture production. Aquaculture indicators, given the nature of this activity, are many times related to coastal and marine development indicators. In this sense, indicators are selected and defined according to a goal set, and a defined audience (Clément & Madec, 2006). An indicator should comply with 3 basic criteria: policy relevance, analytical soundness and measurability (OECD, 1993). Desirable indicators are variables that simplify relevant information, expose the phenomena of interest, and quantify, measure, and communicate information (UNESCO, 2006; Gallopin, 1997). The usefulness of an indicators system to assess mariculture sustainable development is based on 1) the understanding of the mariculture activities interactions with the surrounding ecological, social, institutional, and economic systems; 2) the viability of reaching the data on the management processes of the mariculture sector at the different scales; 3) the ability to identify the main causes of the resulting situations and guide corrective or supportive actions; and 4) the possibility to adapt to the periodic changes inherent to the development process.

The present study aims to present a mixed approach methodology for the development of a set of indicators and a multi-scale indicators system to evaluate the sustainable management of Brazilian mariculture sector. The method developed here joins a top-down and a bottom-up scheme. This approach may be useful to achieve a balance between what experts believe to evaluate adequately sustainability issues and the needs of the stakeholders that deal with it in their daily lives. The scope the proposed indicators system intends to reach, embraces all types of marine aquaculture systems developed in Brazil, either in the coast or in marine/estuarine waters. It is focused into mariculture, rather than aquaculture in general, given the particularities of marine and coastal environment, and the specific regulation and monitoring policies. But it also comprehends multiple farming systems. In Brazil there are different farming methods and species. These differences among farming systems result in different interactions between mariculture and the environmental, economic, institutional and social environment.

3.1.1. Sustainability concepts

Sustainability is considered under four dimensions: Environmental, where the human activities take place and interact with the surrounding ecosystem; Social, which includes the human interactions; Economic, which refers to the material fluxes of human interactions; and Institutional (governance), which links the other dimensions, by organizing human activities and responses, and provide feedback to the development process. Mariculture is inserted within these dimensions, by promoting the fluxes of materials and energy that make the development process flow (figure 3.1). In sustainable development the four dimensions are in dynamic balance, where the importance of one dimension does not rest importance from another.

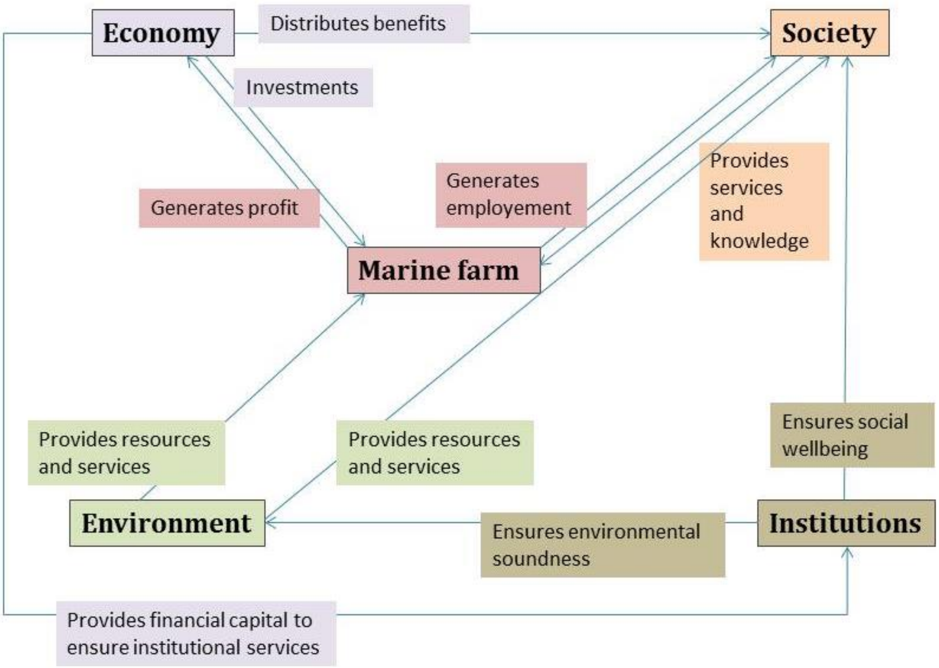

Figure 3.1. Mariculture's relationship with the four dimensions of sustainable development.

Most of published studies on sustainability, however, frequently focus on ecological aspects of sustainability. Ecological concepts or attributes are highlighted, along with their respective desirable properties (Dalsgaard et al., 1995; Gibbs, 2007; Pullin et al., 2007; Halide et al., 2009; Samuel-Fitwi, et al., 2012). According to Dalsgaard et al. (1995), diversity, stability, cycling and carrying capacity are core attributes of an ecological system regarding sustainability.

In the present study, these attributes are indirectly considered, as the proposed indicators set aim towards the maximization of these attributes. For instance, the incrementing (or maintaining) the diversity of a system benefits genetic conservation; minimization of risks; and helps control disease spreading. A system with higher biodiversity has potentially more interactions between organisms, and also enhances the natural diversity of the environment, benefiting the global health of the aquaculture-environment system.

Cycling is one of the most important issues raised regarding environmental sustainability of aquaculture. Nutrient cycling is essential to ecosystems dynamics. In aquaculture systems that require nutrient inputs, the excess or effluent are one of the main causes of degradation of the surrounding environment. In filtering organisms' culture, the depletion of nutrients in the water column and fecal depositions are causes of environmental problems as well. The ideal system is a closed-cycle system, where nutrients are generated and consumed by other components in the same system (as in IMTA) (Chopin et al. 2010). However, farming systems are considered open-cycle, since harvesting represents a "fissure" to the nutrient flow in the system.

Sustainability, in the sense of maintenance of a process along time, is closely related to stability or resilience of a system. The enhancing of the stability of a system in aquaculture systems is important in the mean that it will eventually face some sort of stress (Dalsgaard et al. 1995). The less external energy input necessary to keep this stability, the more efficient the system will be. But also, the aquaculture system should be integrated on the environment in order to preserve the stability or the equilibrium of the environment where the activity is inserted. Furthermore, stability can be achieved by increasing the diversity of the interactions within the system, and between the system and the exterior (Mollison, 1979).

In aquaculture systems, carrying capacity is mostly related to the quality of the water, in the sense of allowing and sustaining productivity. However it has a broader extension regarding the effects of aquaculture activities in the surrounding environment. In marine cultures, it is related to the interactions between the farming system and the marine environment. On land-based mariculture, as the complexity increases, it can also be related to the modification of the natural environment/vegetation in order to set up the installations, besides the interconnections with the external environment, regarding the effects of the effluents, for example. Carrying capacity is always related to the extension of the farming and its intensity in relation to the extension and support capacity of the natural ecosystem (FAO 2013[a]). It is desirable that the farming can maintain its productivity without significantly altering the natural services and functions of the surrounding area. A system with a given carrying capacity may have a high or low productivity depending on management and degree of resource exploitation, and a change in carrying capacity will, under a given management scheme, manifest itself in a corresponding change in productivity.

These concepts, nevertheless, can be translated also to socioeconomic fields, since they compose together the main pillars of sustainability. As in ecology, economic systems also benefit from diversification: diversification of market niche, diversification of products, in the sense that this diversification would lead to the diversification of responses to a challenging economic situation. Diversity is, therefore, intrinsically related to stability, as a higher number of different responses ensures the stability of the economy in terms of trade-offs (Altieri & Nicholls 2005).

Cycling however, is more intimately related to carrying capacity, since the more the flow of energy and material is conserved within the system, the less it will interact with the exterior. In socioeconomic term, it can be related to the profitability of the activity, and maximization of economic benefits within the community, and reduction of externalities. Some indicators that reflect these properties are associated with local employment, mariculture contribution to the local economy, production growth, consumption of mariculture products, etc. In other words, the economic feedback supports the production cycle.

In the social and institutional dimensions, other attributes were considered relevant for sustainability, such as those which influence on life quality and governance aspects of development. For instance, in the social dimension, some authors have considered employment, income and food security as important social aspects (Ahmed & Lorica, 2002; Bowen & Riley, 2003; Nobre et al., 2010). But also education and training, transparency, involvement in decision making and development processes, and legislation are reckoned to affect sustainable development (Hishamunda et al., 2014; Sandersen & Kvalvik, 2014).

3.2. Development of an indicators system for evaluating mariculture sustainability in Brazil

3.2.1. Objective definition

The top-down approach methodology consists in extracting the main sustainability issues from a previous review of the literature on the state of art of mariculture in Brazil. The review study by the authors (Gerent et al., submitted/2017), allowed the understanding of the Brazilian context, in terms of the status and trends of mariculture, policy and management issues. Through this analysis, the main sustainability gaps were identified. At this stage, the sustainability goals proposed to be achieved with the development of the mariculture indicators system were established (figure 3.2).

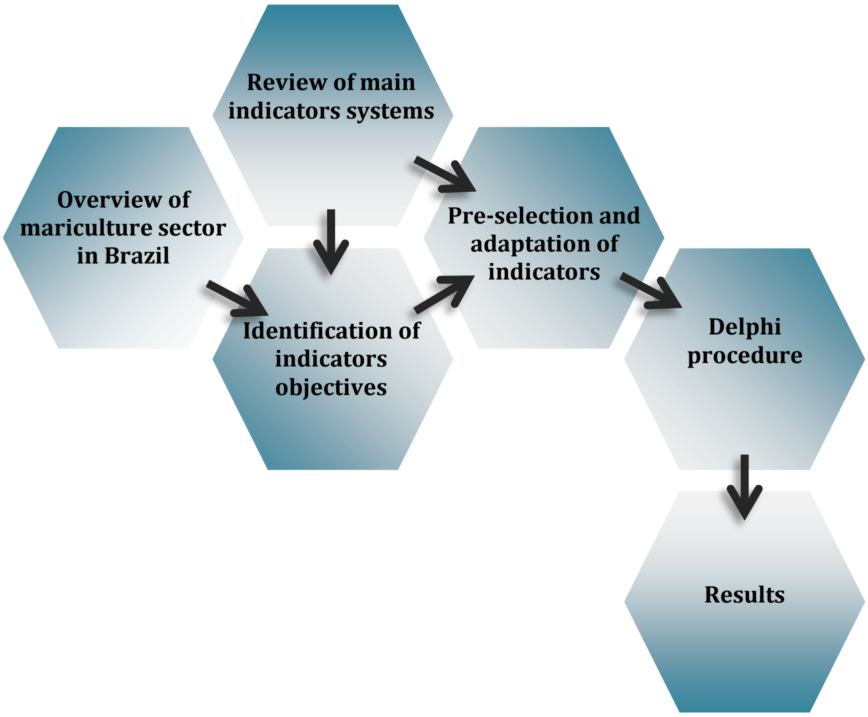

Figure 3.2. Flow chart of research method process.

3.2.2. Indicators systems revview

Furthermore, it was proceeded to review the most relevant indicators systems dealing with aquaculture, environment performance and coastal/marine fields already existent in the literature (table 3.1). The indicators that were found to be applicable to evaluate the sustainability of mariculture in the Brazilian context were pre-selected, and in some cases, adapted to the goals to be achieved. This literature review also contributed to the definition of the mariculture sustainability objectives mentioned above.

Table 3.1.Brief description of the indicators systems used as reference base to the present study.

Source	Description	Comments
OECD (1993) ***OECD core set of indicators for environmental performance reviews. A synthesis report by the Group on the State of the Environment.***	"Indicator development for the integration of environmental concern into sectoral policies, environmental and natural resource accounting and the development of indicators for use in environmental performance reviews. (...)Three basic criteria used in OECD work: policy relevance, analytical soundness and measurability."	Pressure-State-Response framework
CONSENSUS (2006) ***Defining indicators for sustainable aquaculture development in Europe.***	"Its strategic objective is to provide and demonstrate to consumers the benefits of high quality, safe and nutritious farmed fish and shellfish grown in sustainable conditions. (...)Development and implementation of sustainable aquaculture protocols based on production systems having low environmental impact, high competitiveness and being ethically responsible."	Presents 78 indicators for sustainable aquaculture in Europe.

Continued		
Source	**Description**	**Comments**
UNESCO (2006) ***A handbook for measuring the progress and outcomes of integrated coastal and ocean management.***	"This handbook was conceived in response to the need for improved approaches for monitoring, evaluating and reporting on ICOM progress and results, in particular in relation to: a) the institutionalization of monitoring and evaluation systems in ICOM ; b) the integrated consideration of governance, ecological and socioeconomic dimensions; c) the need to distinguish outcomes of ICOM initiatives from those of other initiatives, as well as from natural ecological variability; d) the linkages between ICOM reporting and state of the coast reporting; and d) consistency of approaches and comparability of progress and results of ICOM initiatives in different areas or countries."	Guide for development and use of indicators. Highlights relationship between goals and indicators.
DEDUCE Consortium (2007) ***Indicators Guidelines. To adopt an indicators-based approach to evaluate coastal sustainable development.***	"To prove the usefulness, viability and necessity of an integrated approach to information management by means of environmental and socioeconomic indicators for measuring the degree of sustainable development of the European coastal zones."	Integrates economic, social and environmental issues and conflicting interests in an indicator system to evaluate coastal development.
FOESA (2010) ***Definición de indicadores de sostenibilidad en la acuicultura mediterránea. (Definition of sustainability indicators in the Mediterranean aquaculture).***	"Definition and identification of global indicators able to measure aquaculture sustainability at the farm/Enterprise, national and mediterranean level; To provide decision makers and aquaculture producers with a technical tool and recommendations in the process of sustainable aquaculture development adapted to the Mediterranean reality; To raise consciousness on the considerations of sustainable use and management of social, economic and environmental resources available to achieve a sustainable balance in the management of the activity."	General aquaculture indicators proposed to be applied at farm, national and Mediterranean level.
FAO (2013[b]) ***Indicators for sustainable aquaculture in Mediterranean and Black Sea countries. Guide for the use of indicators to monitor sustainable development of aquaculture.***	"This Guide on the application of indicators for sustainable aquaculture in Mediterranean and Black Sea countries attempts to meet the need for a decision support tool for monitoring the sustainable development of aquaculture in all its dimensions, based on a set of practical indicators and reference points."	Economic, environmental, social and governance indicators for aquaculture development

Pre-selected indicators were considered under the Driver-Pressure-State-Impact-Response (DPSIR) framework (figure 3.3). In this model, "Driver", or "Driving forces" are human activities processes and patterns that impact on the sustainable development. "Pressure" comprises the actions that affect quantitatively or qualitatively the environment. "State" refers to observations of the system that is under evaluation. "Impact" includes the effects of the changes caused by the development process. "Response" embodies those reactions to the effects of development. The "Response" domain denotes the feedback loop to the beginning of the system.

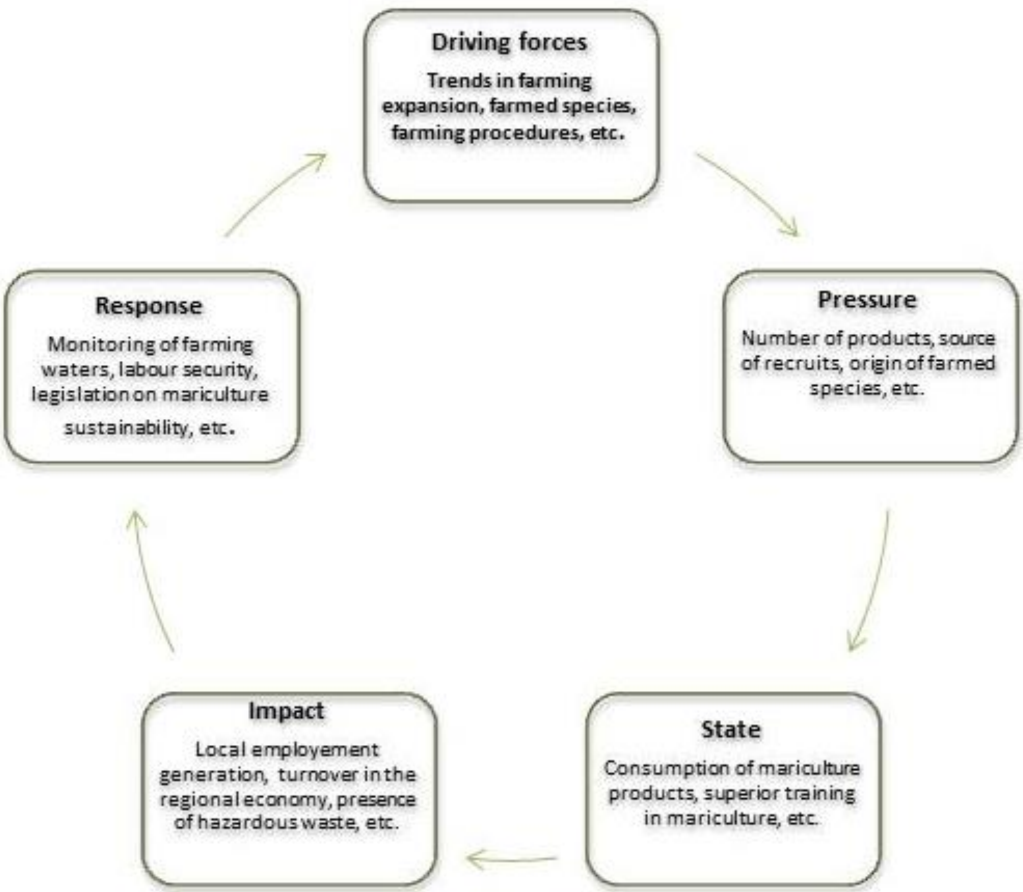

Figure 3.3. The DPSIR framework.

3.2.3. Delphi procedure and selection of indicators set

A Delphi protocol was set for the "bottom-up" phase of the methodology. This approach involves the participation of a group of experts/stakeholders (Delphi panel) to refine the objectives identified and select the most appropriate indicators to compose the evaluation. The Delphi panel was constituted of a group of eight participants, including experts in mariculture, policy makers and marine farmers. All experts were asked to answer a questionnaire about a set of 77 previously selected indicators, grouped in 12 themes of interest for mariculture. The results from the questionnaire provided the final set of proposed indicators to compose the evaluation system.

The questionnaire consisted in three steps. First, respondents were asked to ponder the themes of the indicators, numerating from 1 (most important) to 12 (least important) (table 3.2). Secondly, they were asked to ponder the characteristics of the indicators, numerating from 1 (most important) to 4 (least important) (table 3.3). Then, respondents were asked to analyze the characteristics of the indicators that were hierarchized in four levels, where it was assigned a weight according to how significant this characteristic would be for each indicator (table 3.4).

Table 3.2.Ponderation on the most important themes for the sustainability of mariculture

Category	Theme	Ponderation (1 to 12)
Economic	Production	
	Investment	
	Profit and sector growth	
Social	Integration and inclusion	
	Food security	
	Employment	
Environmental	Contamination	
	Biodiversity and animal welfare	
	Spatial planning	
Institutional (governance)	Stakeholder participation and conflict resolution	
	Research and education	
	Legislation	

Table 3.3. Ponderation over the most important characteristics of the indicators.

Characteristics	Description	Ponderation (1 to 4)
Efficiency	Represents the cost of the indicator, the easiness to obtain it, based on the reality of the Brazilian institutions that provide statistical data or other institutions.	
Efficacy	Represents the ability of the indicator in accomplishing its objectives, based on the Brazilian reality.	
Importance of socioenvironmental nature of the indicator	Considers how relevant the indicator is for the monitoring of the socioenvironmental reality for the development of mariculture in Brazil.	
Adaptability to Brazilian reality	Considers if the indicator can be applied to the four modalities of mariculture (farming of fish, mollusks, seaweed and shrimp) in all of the coastal regions in the country.	

Table 3.4. Characteristics of the indicators hierarchized in four levels, with their respective weights.

Characteristic	Very significant (weight = 3)	Significant (weight = 2)	Slightly significant (weight = 1)	Unsignificant (Peso = 0)
Efficiency	Low cost indicator, easy to be obtained according to the reality of the Brazilian institutions which provide statistical data.	Significant costly indicator, which demands institutional treaties.	High cost indicator, hard to be obtained for it demands elements of technical, institutional, legal or administrative analysis.	Impractical indicator.
Efficacy	Indicator that accomplishes consistently its objectives based on the reality of the Brazilian institutions and coastal zone management policy.	Indicator that accomplishes its objectives, but a complementary analysis with other indicator(s) is desirable.	Indicator that accomplishes its objectives partially, being a support indicator for other indicator(s).	Indicator that does not accomplish its objectives according to the Brazilian reality.
Importance of socioenvironmental nature of the indicator	Indicator considered very relevant to monitoring the socioenvironmental reality of the mariculture in Brazil.	Indicator that is relevant for monitoring the socioenvironmental reality of the mariculture in Brazil.	Indicator of little relevance for monitoring the socioenvironmental reality of the mariculture in Brazil.	Indicator that is not relevant for socioenvironmental monitoring.
Adaptability to Brazilian reality	Indicator that can be easily applied to all coastal regions and all farming modalities.	Indicator that can be altered according to the different coastal realities and/or different farming modalities.	Indicator that can only be applied to some coastal regions and/or some farming modalities.	Indicator that cannot be applied in Brazil.

And finally, the table with the indicators set was presented. Respondents were asked to assign a weight for each characteristic of each of the preliminary indicators, as presented in the example below (table 3.5), using the information presented in table 4 as reference.

Table 3.5. Weight assignment to the characteristics of each indicator.

		Relevance of the indicator (weight assignment: 0 to 3)			
Theme	**Indicator**	**Efficiency**	**Efficacy**	**Importance of socioenvironmental nature of the indicator**	**Adaptability to Brazilian reality**
Production	Evolution in the number of farmed species				

The answers received a numerical treatment, so that the most significant or important variables would corresponded to the highest number (12, 4 and 4, respectively for each step of the questionnaire), and the least valued variable would correspond to the smallest number (1, in all cases).

Having these values corrected to fit the equation, the mean value for each answer was calculated. Doing so, the following equation was applied:

$$TP=\log PTm+\Sigma CR$$

Where,

$$\Sigma CR=Ea\log(PCa)+Ee\log(PCe)+I\log(PCi)+A\log(PCA)$$

The TP means Total of Ponderation; PTm is the value of the theme ponderation; CR are the components of relevance; PC is the ponderation of the Criteria of Indicators; Ea is the weight of Eficacy; Ee is the weight of Efficiency; I is the weight for Socioenvironmental Importance; and A is the weight of the Adaptability of the indicator. The logarithm was included to achieve homogeneity in the values.
The highest and lowest possible values to be obtained by the indicators were 7,82 and 1,32 respectively. According to these limit values, a scale was conceived to classify indicators from Low/Poor indicator to High/Good indicator (table 3.6).

Table 3.6. Indicators classification scale.

Value	Classification
1,32<3,27	Low
3,27<5,87	Medium
5,87<7,82	High

3.3. Outcomes

3.3.1. Definition of indicators objectives

The objectives of the indicators system were identified in relation to the main strengths and weaknesses of the different aspects (categories) of mariculture development in Brazil. (table 3.7).

Table 3.7. Identification of objectives of the indicators system based on an overview of the mariculture sector in Brazil.

Category	Strenghts	Weakness	Objectives
Economic	High diversity of business size and type; Direct positive impact in the communities; Diversification of economic activities in the coastal area; Potential to grow;	Filter-feeders farms still have a poor participation in the economy, with exception of the Santa Catarina case; Product diversification could improve.	To improve economic benefits distribution in the communities; To improve economic resilience; To increase economic benefits; To increase sector expansion.
Social	Maintains traditional communities in original lands; Gender inclusion.	Conflicts over resource access and use.	To minimize conflicts and promote integration; To ensure high life quality of farmers and community; To ensure food security.
Environmental	Enviornmentally friendly farming methods are expected to increase; Adequate site selection reduces significantly the negative impacts.	Farming systems with feed input generate more and more severe negative impacts; The majority of mariculture production still depends on feed and is located in poor selected sites; Potential impacts from growth of marine fish farming are still unknown.	To monitor water quality; To monitor environment health; To improve environment protection; To ensure adequate site selection; To reduce greenhouse gas emissions; To maintain biodiversity.
Governance	Community engagement.	Stakeholder participation in decision making is below optimal. Need for more robust policies to support producer legal safety.	To ensure community engagement in the mariculture sector; To promote policies that support sustainable development of mariculture sector.

3.3.2. Delphi results

The Delphi procedure evaluated 77 indicators, comprising the themes of relevance to the sustainability of mariculture in Brazil. The lowest value attributed to an indicator was 4,15, and the highest valuation was 6,04, meaning all the indicators were valued from regular to good indicators (table 3.8). As the medium number between the most valued and the least valued indicator was 5,095, all indicators that received a valuation below this number were excluded. The adoption of this criteria resulted in a final set of 29 indicators (table 3.9). Two themes were not contemplated in the final set of indicators ("Investment" and "Stakeholder participation and conflict resolution") as they did not have any indicator valued above the threshold number.

Table 3.8. Set of indicators selected by the Delphi panel, with their respective values.

Theme	Code	Indicator	Value
Production	E1	Value of total production per year	6,04
	E2	Evolution in the number of farmed species	5,73
	E3	Number of products of mariculture origin	5,71
	E4	Evolution in the percentage of sales of local products with quality seal, nomination of origin, or similar certification over total production	5,32
Profit and sector growth	E5	Evolution in the number of licenses for farm installation and operation	5,40
	E6	Farm profitability	5,20
	E7	Turnover of mariculture in the regional economy	5,11
Integration and inclusion	S8	Transparency of the production processes	5,17
	S9	Promotion of the farming methods	5,13
Employment	S10	Evolution in the number of employees	5,29
	S11	Local employment generation	5,14
	S12	Labour security	5,14
Food safety	S13	Evolution of per capita consumption of mariculture products	5,59
Pollution	Env14	Sanitation monitoring of farming waters	5,69
	Env15	Wastewater treatment	5,64
	Env16	Strategies for minimizing waste generation	5,37
	Env17	Presence of toxic or hazardous wastes in farming waters	5,18
	Env18	Use of antibiotics for farming	5,18
	Env19	Energy consumption optimization policy	5,10
Biodiversity and animal welfare	Env20	Source of seeds/fingerlings (farm or artificial collector/fishing)	5,51
	Env21	Origin of farmed species (native/exotic)	5,39
Spatial planning	Env22	Marine and/or coastal monitoring programs	5,10
	Env23	Phase of implementation of the Local Plan for the Development of Mariculture (PLDM)	5,36
	Env24	Carrying Capacity Study (CCS)	5,36
	Env25	Implementation and periodic evaluation of the management plan	5,11
Research and education	G26	Periodicity of superior training in mariculture in the state	5,28
	G27	Official publications on the sustainability of mariculture	5,24
	G28	Existence of research centres on mariculture in the state	5,22
Legislation	G29	Legislation that supports sustainable development of mariculture	5,11

Table 3.9. Indicators system harmonized with the objectives established, the scale in which the indicator will be applied, and its classification according to the DPSIR framework.

Category	Theme	Objective	Indicator	Scale	Code
Economy	Production	To increase economic benefits	Value of total production per year	Farm, Regional and National	E1
		To improve economic resilience	Evolution in the number of farmed species	Farm, Regional and National	E2
			Number of products of mariculture origin	Farm	E3
			Evolution in the percentage of sales of local products with quality seal, nomination of origin, or similar certification over total production	Regional and National	E4
	Profit and sector growth	To increase sector expansion	Evolution in the number of licenses for farm installation and operation	Regional and National	E5
		To improve economic benefits distribution in the communities	Farm profitability	Farm	E6
			Turnover of mariculture in the regional economy	Regional	E7
Social	Integration and inclusion	To minimize conflicts and promote integration	Transparency of the production processes	Farm	S8
			Promotion of the farming methods	Farm	S9
	Employment	To ensure high life quality of farmers and community;	Evolution in the number of employees	Farm, Regional and National	S10
			Local employment generation	Farm	S11
			Labour security	Farm	S12
	Food security	To ensure food security	Evolution of per capita consumption of mariculture products	Regional and National	S13
Environmental	Contamination	To monitor water quality	Sanitation monitoring of farming waters	Farm, Regional and National	Env14
			Wastewater treatment	Farm	Env15
			Strategies for minimizing waste generation	Farm	Env16

Continued					
Category	**Theme**	**Objective**	**Indicator**	**Scale**	**Code**
Environmental	Contamination	To monitor water quality	Presence of toxic or hazardous wastes in farming waters	Farm	Env17
			Use of antibiotics for farming	Farm	Env18
		To reduce greenhouse gas emissions	Energy consumption optimization policy	Farm	Env19
	Biodiversity and animal welfare	To maintain biodiversity	Source of seeds/fingerlings (farm or artificial collector/fishing)	Farm and Regional	Env20
			Origin of farmed species (native/exotic)	Farm, Regional and National	Env21
	Spatial planning	To monitor environment health	Marine and/or coastal monitoring programs	Regional and National	Env22
		To ensure adequate site selection	Phase of implementation of the Local Plan for the Development of Mariculture (PLDM)	Regional and National	Env23
			Carrying Capacity Study (CCS)	Farm	Env24
		To improve environment protection	Implementation and periodic evaluation of the management plan	Farm	Env25
Governance	Research and education	To ensure community engagement in the mariculture sector	Periodicity of superior training in mariculture in the state	Regional	G26
			Official publications on the sustainability of mariculture	Regional and National	G27
			Existence of research centres on mariculture in the state	Regional	G28
	Legislation	To promote policies that support sustainable development of mariculture sector.	Legislation that supports sustainable development of mariculture	Regional and National	G29

3.4. Discussion

Recent works agree that indicators should present the following set of characteristics to fulfill its purpose: to be readily measurable; cost effective; directly observable and measurable; interpretable; grounded on scientific theory; sensitive to changes; responsive and; specific (OECD 1993; UNESCO 2006; FAO 2013[b]; UNESCO IOC 2014). These aspects were considered during the process of development of the proposed indicators system. The DPSIR framework links the human motivations with their impacts in the mariculture sector in the context of the coastal system. The model helps identify the relevant indicators that will assess the management of mariculture sustainable and integrated development. Furthermore, the viability of the indicators in the context of the Brazilian reality was also one of the main priorities for the pre-selection and adaptation of the indicators. In general, the indicators finally selected by the DELPHI panel are consistent with the assumption that a strong indicator can measure a situation or the evolution of a variable in relationship to the goal established (FOESA, 2010).

The mixed methodology involving bottom-up and top-down approaches enriches the outcomes of the indicators system by providing inputs from academia and the experiences from practice. The bottom-up approach can be time-consuming, and the indicators system developing process can be optimized by joining the top-down approach. The inputs from highly-technical experts deliver the science-based information necessary for framework definition and the set of indicators for an effective evaluation of the mariculture system's sustainability. While the consultation with those actors, that deal with the mariculture sector on a daily basis, provide the knowledge towards a more viable, realistic and efficient selection of indicators. The combination of both methods offers combined knowledge of multiple perspectives and ultimately improves the performance of the indicators system (Reed et al 2006; Bell & Morse 2010; Waas et al. 2014; Lu et al. 2016).

The Delphi panel has valued higher those indicators related to economy and environment, and have given less importance to indicators related to social and governance issues. Other proposed indicators systems tend to concentrate mostly on environmental aspects, with less attention given to economic or social parameters and even less on the governance facets of sustainability (Dalsgaard et al. 1995; Rigby et al. 2000; Samuel-Fitwi et al. 2012; Avadí & Fréon 2015). Even though, all the selected indicators reflect the main goals identified to achieve a more sustainable development of mariculture in Brazil.

3.4.1. Economy indicators

The referenced indicator systems either deal with environment or coastal management (OECD 1993; UNESCO 2006; DEDUCE Consortium 2007) or aquaculture development (Consensus 2006; FOESA 2010; FAO 2013[b]). The sources focused on coastal areas mostly present indicators of economic sustainability related to quality, benefiting (value-adding) and diversification of products. The indicators systems focused on aquaculture development, on the other hand, contributed more with indicators related to profitability, production and sectoral growth. The inclusion of both approaches to the indicators systems proposed in this study provides a more holistic and integrated vision of mariculture development management.

The economic dimension is at the core of the mariculture sector, since it is primarily an economic activity, and an important tool for regional development (Consensus 2006). The selected indicators for economic sustainability assessment were those involving production prosperity as well as profitability and sectoral growth. Profitability, total value, sectoral contribution and value-added have been used as indicators of economy in related researches (Herzog & Gotsch 1998; Pannell & Glenn 2000; Avadí & Fréon 2015; Germain et al. 2015; Moura et al. 2016; Grealis et al. 2017; Valenti et al. 2011). These indicators are related to the financial management of the farms. The indicators approach on the periodic changes of the economic parameters allows early warnings and provide action-guiding. Furthermore, indicator E4 relates to the quality of the product, based on the assumption that certifications (quality seals or nomination of origin) means adding value to the product, and achieving a differentiated audience. The use of branding or quality labels encourages consumer-responsive and a market-oriented production (FAO 2013[b]).

Indicators of economic diversity, as number of species farmed and number of products, and indicators of sectoral expansion, however, have been less popular in previous sustainability assessment researches. The importance to consider economic diversity in the context of sustainable development is related to the resilience of the system. The resilience of an economic sector is measured according to how diversely it may respond to stress (Consensus 2006; FOESA 2010; FAO 2013B). The incrementing on the number of species farmed and of products increases the probability of the company to resist when facing market hardships or farming adversities such as infrastructure damages, diseases, contamination or mortality of the crop.

Productive sectors are dynamic: new companies emerge, while other producers are initiated in the business. The evolution on the number of new licenses for mariculture installation and operation depends both on the interest of producers in starting or expanding their businesses as on the political interests in promoting one sector over another. Sectoral expansion of mariculture reflects the commitment of the competent authorities in supporting and promoting mariculture, while it manifests the entrepreneurial capacity of the sector (FOESA 2010).

3.4.2. Social indicators

Social indicators proposed in the previous indicators systems reviewed, mostly referred to employment (OECD 1993; Consensus 2006; UNESCO 2006; DEDUCE Consortium 2007; FOESA 2010; FAO 2013B[b]). Yet, the systems designed for aquaculture sustainability assessment further considered the consumption of mariculture products and farming transparency (Consensus 2006; FOESA 2010; FAO 2013[b]). Results from this research have corroborated the importance of the topics related to employment for mariculture sustainability. Employment generation and job security directly influences on the life quality of the community. Employment-related indicators are frequently used in most sustainability researches as indicators of social well-being (Herzog & Gotsch 1998; Valenti et al. 2011; Teh & Sumalia 2013; Avadí & Fréon 2015; Germain et al. 2015; Moura et al. 2016; Grealis et al. 2017;).

Additionally, other researches have confirmed that a desirable social environment involves building a relationship of the local community with the sector, (Bridger & Luloff 1999; FOESA 2010) here addressed by indicators S8, S9, S10, S11 and S12. This communication between the farmers and the community is beneficial for farmers, who may attract new customers, and for the society to contemplate whether it is a desired activity for the community. Awareness and information about mariculture activities and methods is important to develop a sense of identification with the sector (Cooke et al. 2013). Awareness and interactions between the society and the productive sector benefits economic development and engagement in decision-making processes, ultimately increasing local autonomy (Bridger & Luloff 1999; Cooke et al. 2013).

One of the most important goals of mariculture is to provide quality food for people, and help satisfy the demand for fisheries products. McClanahan (2013) discusses the need for evaluating the contribution of aquaculture to food security, claiming there are few studies that prove this assumption. Mariculture is an important source of high quality protein at a relative small price. Indicator S13 addresses the importance of mariculture in contributing to a better food safety to society. Valenti (2011) considers this indicator evaluates the trends in the food availability. Moreover, this indicator is also related to the perception of a positive image of aquaculture development (Consensus 2006).

3.4.3. Environmental indicators

Mariculture is related to the environmental dimension since it interacts directly and indirectly effects with the environment. The environmental indicators selected contemplate environmental pollution, the maintaining of biodiversity and maritime spatial planning. These issues are in accordance with a large number of publications that confirm that environmental impacts from aquaculture, such as water column contamination, wastes, introduction of exotic species and other environmental effects should be addressed in order to achieve a higher sustainability of the production (Frankic & Hershner 2003; Pullin et al. 2007; Simões et al. 2008; Silva et al. 2011; Samuel-Fitwi et al. 2012; Lazard et al. 2014; Suplicy 2015)

The sources referred in this publication have focused on indicators that may evaluate direct environmental effects from mariculture activities. Coastal and environmental management indicators systems are mostly dedicated to assess environmental quality in relation to contamination, biodiversity and water quality (OECD 1993; UNESCO 2006; DEDUCE Consortium 2007). The indicators systems dedicated to aquaculture sustainability assessment have also considered biodiversity issues regarding exotic or native species farming, seed/fingerling source; water quality, in terms of toxic wastes and effluent treatment; and environmental monitoring (Consensus 2006; FOESA 2010; FAO 2013B).

Several works highlight the importance of water quality for aquaculture (Pullin et al. 2007; Valenti et al. 2011; Samuel-Fitwi et al. 2012;). In the present study, the concerns over water quality issues are reflected on indicators Env14, Env15 Env16, Env17 and Env18. Water quality is also intimately related to other environmental effects, which justifies the selection of indicators Env22, Env24 and Env25, even though these indicators have a broader range.

Env24 conveniently addresses carrying capacity, which is argued to be one of the most important constraints on sustainable aquaculture development (Consensus 2006; McKindsey et al. 2006; FOESA 2010; Silva et al. 2011; Samuel-Fitwi et al. 2012; FAO 2013B; Lazard et al. 2014). It has been pointed as an adequate indicator of sustainability (Gibbs, 2007; Gibbs, 2009). When combined with indicators Env22, Env23 and Env25 it ensures an adequate evaluation regarding management of the coastal or marine space.

Indicators Env21 is related to the concerns of adopting exotic species. It is broadly argued that adoption of exotic species for aquaculture purposes is one of the main causes of invasion problems in marine ecosystems (Frankic & Hershner 2003; Pullin et al. 2007; Samuel-Fitwi et al. 2012). Likewise, overexploitation of biological resources also impacts biodiversity, which is contemplated by indicator Env20. Numerous studies have pointed to the effects of collecting seeds for mariculture production from natural stocks (Samuel-Fitwi et al. 2012; Suplicy 2015). It is recommended that these methods should be avoided in order to maintain natural populations.

The set of environmental sustainability indicators proposed here addresses the main environmental interactions from aquaculture activities, but also environmental-related policy. While other proposed indicators systems for aquaculture sustainability focus on physico-chemical assessments of water column and sediment (Valenti et al. 2011), in the present study, these are not contemplated. The importance of water quality analysis is undiscussable, but the indicators system proposed focuses on indicators that could be measured without the need for laboratory procedures. The approach of this research is towards the adequate management for a sustainable development of the sector, thus the inclusion of indicators of environmental management and monitoring programs. The integration of policy indicators on the indicators set is one of the main contributions this system provides in relation to the previously proposed indicators of aquaculture sustainability.

3.4.4. Institutional/governance indicators

Institutional or governance indicators are not too popular among the publications used as reference to the present study. However, some of them (Consensus, 2006; UNESCO, 2006; FAO, 2013) considered legislation to support sustainable development and training issues as important to evaluating the sustainability of mariculture. The previously proposed indicators were adapted to fit the situation present in Brazil.

The importance of promoting research and technology development for improving sustainability of mariculture is mirrored on indicators G26, G27, G28. Improving governance is crucial for a more equal development of the sector, while avoids conflicts and promotes more inclusive planning and decision-making (McClanahan et al. 2013) Governance can be enhanced when by involving public participation at different scales of sectoral development (Bell & Morse 2010; Mathé et al. 2010; Cooke et al. 2013; Sandersen & Kvalvic 2014; Bremer et al. 2016), and by spreading information and knowledge on mariculture issues. In other words, governance on mariculture can be improved through the participation of the local community in the scientific development of the industry (FOESA 2010; Bremer et al. 2016). Nevertheless, the existence and appliance of legislation that helps promote a sustainable development of mariculture remains equally important (FAO, 2013; Brasil 2015; Suplicy 2015). Together, these four indicators could help identify strengths and weaknesses and assess action taking when regarding governance aspects of mariculture.

3.5. Final considerations

Common goals of sustainable coastal and ocean development in relationship to aquaculture production consider the sustainable well-being of coastal ecosystems; sustainable quality of life in coastal communities and the improvement of governance processes. Current aquaculture activities need to develop a fundamental transition from management that is based on maximizing production to an integrated management of natural resources and ecosystems. Coastal policies must include aquaculture development as an essential tool for endorsing sustainable development, essentially as a key agent in modifying and interacting with the environmental, social, economic and institutional spheres.

The final indicators system generated in the research is composed of 10 environmental indicators, 7 economy indicators, 6 social indicators and 4 indicators of governance. Different combinations of those indicators are used at the different scales. The farm scale system comprises 19 indicators, but no indicators of governance. The regional scale system consists of 16 indicators, while the national scale system is constituted by 12 indicators, and in both scales, all indicator categories are included.

The results found in the present study are in line to the main international initiatives regarding sustainable aquaculture indicators systems (OECD 1993; UNESCO 2006; Mathé et al., 2010; FAO 2014; UNESCO IOC 2014). The novelty is that this study provides indicators that are suitable for the specific situation of the Brazilian reality, but also general enough to comprise the diversity of existent mariculture systems. Mariculture activities in Brazil differentiate according to the species farmed, which usually influences its structure, functionality and system. Moreover, the multi-scale characteristic of the system allows it to signalize not only what are the strong and weak areas of mariculture sector, but also, at what level it has to be addressed. The possibility to identify sustainability gaps at production or government level, facilitates the development of solutions and prioritize actions.

The methodology used ensures the effectiveness of the selected indicators, since it accounts with highly grounded on scientific theory, given they were primarily selected from strong references. Additionally, the participative approach ensures that the chosen indicators are the most adequate considering the Brazilian reality. The set of selected indicators helps highlight values that should be reinforced in the development of coastal activities. Even though measuring a process is one of the main aims of indicators, they can also be used for enhancing the overall understanding of environmental and social problems, facilitate community capacity building, and help guide policy and development projects (Reed et al., 2006). Moreover, sustainability indicators systems contribute to action-generating and promote effectiveness of public policies (Waas et al. 2014; Lu et al. 2016).

Another contribution of this study is the inclusion of integrated coastal management and aquaculture sustainability indicators. In general terms, the indicators presented comprise the management of mariculture activities. The system proposed comprehends the four basic spheres of sustainability which are the economy, society, environment and governance aspects of development. In this sense, it is possible to guide management actions to address the problems and strengths of mariculture development identified with the use of the proposed system. Additionally, the focus of the indicators system on the management of mariculture as a coastal activity helps promote the integration of mariculture within the context of the coastal zone and the multiple activities that take place in the area.

The system presented in this publication considers the life quality of the society, mitigation of environmental impacts, involvement of local people in mariculture activities and economic development. Furthermore, its main contribution beyond those from previously proposed indicators systems for the sustainable development of mariculture is that it includes the valuation of management actions and policies to promote mariculture integration and sustainability. Nevertheless, as in any management process, it is recommended that the set of indicators should periodically be reevaluated to adapt to the evolving situation of the development process.

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DAS UTOPIAS

"Se as coisas são inatingíveis... ora!
Não é motivo para não querê-las...
Que tristes os caminhos, se não fora
A presença distante das estrelas!"
Mario Quintana (1906-1994)

4. Case study of mariculture sustainability assessment in Brazil.

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Abstract

Mariculture in Brazil is an important activity for coastal communities. It has been used as a tool to promote sustainable development. Nevertheless, sustainability of the sector has not been measured before in Brazil. Indicators have been widely used to provide and communicate information regarding sustainable development. This research aims to provide an assessment of the sustainability level of the mariculture sector in Brazil through the use of an indicators system, applied at three scales: national, regional and farm-level. At farm level, two bivalve farms in the state of Santa Catarina, and one fingerling nursery in the state of São Paulo were assessed. Santa Catarina was the state taken as example at regional level. Overall, bivalve farm #1 and fingerling farm #3 both presented “Average” level of sustainability, while bivalve farm #2 scored “Low”. The mariculture sector at the regional scale in Santa Catarina was considered to have a “Low” sustainability level. Furthermore, considering the sector at national scale, Brazil presented a “Very low” level of mariculture sustainability. The reasons for achieving such outcomes are discussed.

Key words: mariculture sustainability, sustainable development, indicators system, multi-scale assessment tool.

4.1. Introduction

Marine aquaculture (or mariculture, from hereon) in Brazil is an important activity for coastal communities. It has been developed either as a subsistence activity, familiar business or in the form of enterprise. The overall production in the country has stabilized around 86000 t (mean value from 2003 to 2013) (FAO 2016). Shrimp is the most important farmed species, contributing with 77% of total production. Shrimp farming has reached its maturity in productivity, and remains the main driver in stabilizing production. Mollusk contributes with 23% of production. Mollusk farming has grown steadily since its implementation in Brazil, its production has reached 21064 t in 2015 (IBGE, 2016). Fish and seaweed farming are incipient in Brazil, and together represent less than 1% of total farmed volume (FAO, 2016). Overall Brazilian mariculture summed an annual production of 90923 t in 2015 (IBGE, 2016).

The Brazilian shoreline comprehends over 8000 km, almost 4,5 million km^2 of Exclusive Economic Zone and 2,5 million ha of estuarine zones (MPA 2015). The large extension of the Brazilian coast, from latitude 4°30’ North to 33°44’ South, is situated in intertropical and subtropical zones. This reflects a great potential for a diverse, sustainable and integrated coastal development based on mariculture activities.

Economically, mariculture contributes with 306 million US dollars (over 22%) to the total value of aquaculture production in Brasil (IBGE, 2016). Despite not having an important participation in the national economy, the sector does play an important at a regional or local level. Usually, mollusk farming is a familiar business or a complimentary activity. Shrimp farming is generally a more organized activity, and contributes to full-time and seasonal jobs, requiring primary or secondary educational level. Evidently, shrimp farming has brought diverse socioeconomic benefits to the communities, and is now one of the best organized aquaculture sectors in Brazil (Suplicy 2013). Nonetheless, its expansion has been economically oriented, and the rapid growth of the industry was marked with many environmental damages (Tenório et al., 2015; Godoy & Lacerda 2014; Santos et al., 2014; Queiroz et al., 2013; Hamilton 2013; Guimarães et al., 2010, Grigio et al., 2009). This reality has led to important social conflicts related to irregular occupations, contamination and deforestation that ultimately led to access impediments to fishing areas, fish mortality at harvesting period, social exclusion and marginalization (Dias et al., 2012; CMADS, 2005; Silva, 2004; Carvalho Filho, 2004).

Mariculture, can be characterized in Brazil, as two different models: classic capitalist or unipersonal business. In the first one, there are the businesses organized with a farm owner and employees, and in the other case it is composed by self-employment and it can be seen as a subsistence activity or familiar business. Either way, the activity is inserted within a context where the four dimensions of development interact (figure 4.1). Mariculture ignites the fluxes of materials and information that flow through the development process.

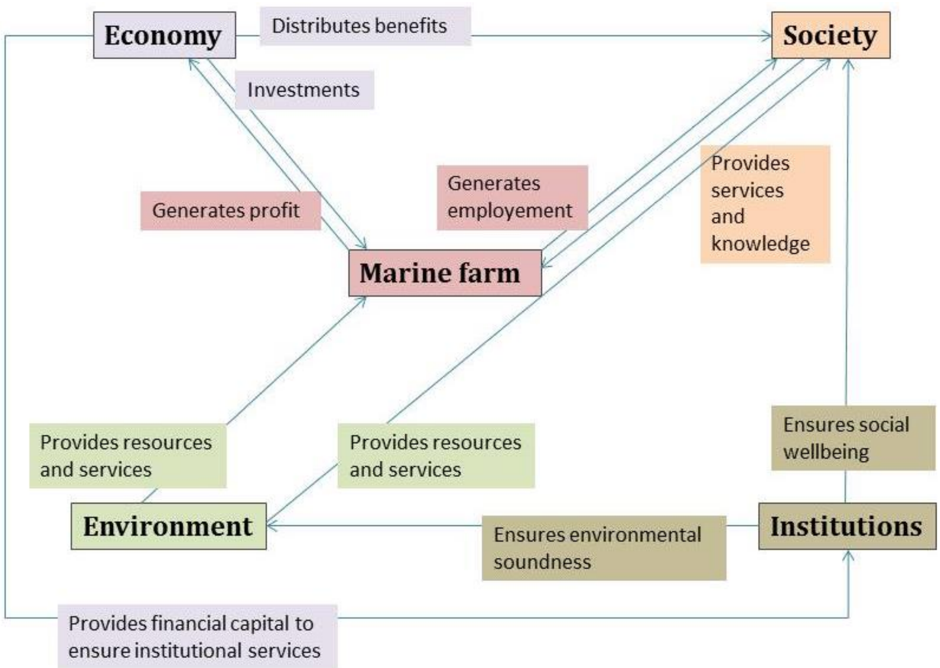

Figure 4.1. Mariculture and its relationship with the four dimensions of sustainable development

4.1.1. Mariculture interactions with the environment

Shrimp culture often presents more and more significant negative environmental impacts than mollusk farming. The impacts from the shrimp industry are present on different levels and stages of farming. Reported damages in Brazil have been related to ecosystem degradation, deforestation, erosion, sedimentation, contamination, pollution, disease spreading among wild organisms, eutrophication, etc. (Nóbrega *et al*., 2016; Cruz *et al*., 2015; Tenório *et al*., 2015; Cardozo & Odebrecht, 2014; Godoy & Lacerda 2014; Nóbrega *et al*., 2014; Santos *et al*., 2014; Suárez-Abelenda *et al*., 2014; Costa *et al*., 2013; Dias *et al*., 2013; Hamilton 2013 Nóbrega *et al*., 2013; Queiroz *et al*., 2013; Almeida *et al*., 2012; Rudorff *et al*., 2012; Lacerda *et al*., 2011; Lacerda *et al.* 2009).

Regarding mollusk farming fewer and less important impacts have been described. Most of the cases in Brazil, impacts were related to changes in the water circulation, which affects sediment deposition, and ultimately, benthic community structure (Cruz *et al*. 2015; Rudorff *et al*. 2012; Netto & Valgas 2010; Costa & Nalesso 2006). There has been also one record of invasion of *Crassostrea gigas* (Melo *et al*. 2010). Except for the invasion, these impacts tend to be localized and likely to allow the environment to regenerate to its original state once the farming structures are removed.

Site selection is a key issue in avoiding some negative effects from mariculture activities. From mangrove and other coastal ecosystem preservation, to other environmental interactions, and benthic alterations, impacts can be avoided through adequate spatial planning shrimp industry. Additionally, site selection has an important role, since the environmental interactions of concern mostly occur in the environment-culture direction. Currently one of the main limiting factors for shellfish farming development is the water quality. As filter feeders, these organisms are subject to the impurities of the environment. Several studies explored the susceptibility of the mollusks to water pollution and contamination, including red tides (Silva Neta *et al*., 2015; Mafra Jr. *et al*., 2015; Ramos *et al*., 2014; Fernandes *et al*., 2013; Yoshimine & Carreira, 2012; Yoshimine *et al*., 2012; Galvão *et al*., 2010; Sáenz *et al*., 2010; Vieira *et al*., 2010; Zottis *et al*., 2004; Curtius *et al*., 2003). Water contamination and red tides endanger production and commercialization of mollusks and offer health risks (Lovatelli *et al*., 2008).

Aquaculture may offer solutions for diverse modern problems. Growing human population increase the demand for quality protein sources, while fisheries are progressively collapsing (FAO 2016). In this context, aquaculture is an alternative to fishing and may offer many benefits to communities and the environment, but it must respect some guidelines for sustainable production (Naylor et al., 2000; Hambrey et al., 2001). Development choices should be based on the lessons learned over generations with the use of traditional and low technology farming approaches, combined with innovative methods and materials.

4.1.2. Sustainability assessment tools

There are countless forms of progress to achieve sustainable development, and rational choices must be made throughout the development process. To achieve this goal, a set of sustainability objectives have to be set and pursued. The Agenda 21, product of the UN conference, “Earth Summit”, in 1992, identifies the importance of local governments in reaching sustainable development objectives: “Local authorities construct, operate and maintain economic, social and environmental infrastructure, oversee planning processes, establish local environmental policies and regulations, and assist in implementing national and sub-national environmental policies. As the level of governance closest to the people, they play a vital role in educating, mobilising and responding to the public to promote sustainable development."

It was also in the Agenda 21 where the need for developing an indicators system to assess sustainable development, claimed at the Earth Summit, was first materialized. It established there should be a global effort to elaborate indicators of sustainable development aiming to provide a solid basis for decision making at all levels (UN, 2007). The use of indicators makes easier for farmers and government institutions to cope with the debilities and to promote growth and resilience of the sector, as well as for consumers to endorse or persuade for sustainable products (UN 1993). FAO has promoted this idea by developing methodology sheets on indicators in many fields.

The OECD (1993) defined indicator as: "A parameter, or a value derived from parameters, which points to/provides information about/describes the state of a phenomenon/environment/area with a significance extending beyond that directly associated with a parameter value." This, in other words, means it is a qualitative or quantitative measurement or observation used to describe a situation and assess changes and trends over time. In addition, indicators represent the portion of information we use to understand the world, make decisions, and plan our actions (Meadows, 1998). They are powerful tools to assess an action plan, as an early warning signal about an emerging issue, or in providing a concise message for engagement, education and awareness (UNESCO 2006). Desirable indicators are variables that simplify relevant information, expose the phenomena of interest, and quantify, measure, and communicate information (UNESCO 2006; Gallopin, 1997; OECD, 1993). Indicators are used to incorporate physical and social science knowledge into decision-making (UN, 2007). Furthermore, the selection of adequate indicators is crucial, as it was argued by Meadows (1998) "Indicators arise from values (we measure what we care about), and they create values (we care about what we measure)". In this sense, the indicators selected affects behavior: "The world would be a very different place if nations prided themselves not on their high GDPs but on their low infant mortality rates.(…) This feedback process is common, inevitable, useful, and full of pitfalls." Thus, indicators are selected and defined according to a goal set, and a defined audience (Clément & Madec, 2006).

Indicators have been progressively used for aquaculture assessment in many countries. There have been several initiatives internationally proposing indicators systems to assess aquaculture and coastal sustainability. The main challenge for the development and implementation of indicators systems is that they must be adapted to each situation. Each country or region should adopt an evaluation system that best fits its reality. The use of these indicators systems helps in guiding decisions towards a more sustainable and integrated development of coastal activities. In aquaculture, indicators systems aim to promote profit, social wellbeing and environment soundness. In Brazil, even though there is an effort to promote sustainable and integrated aquaculture, reflected in the policies for planning and development of aquaculture, in the past years, due to a growing political and financial crisis, the fisheries and aquaculture sectors are being neglected. Also, there is no official guide or document aiming to assess the impacts and sustainability of the aquaculture sector. The purpose of this research is to provide an assessment of the mariculture sector in Brazil and the viability of the indicators system developed. It is intended to achieve this result through the use of an indicators system to evaluate mariculture sustainability level applied at three scales: national, regional and farm-level. The indicators system is focused on management practices and policies that would improve mariculture sustainability.

4.2. Methods

4.2.1. Study area

This study considered three scales of the mariculture sector in Brazil as the scope of investigation. At the wider range, the whole mariculture sector in Brazil was considered, including the producers, research institutions and federal government. At the regional scale, the mariculture sector in the state of Santa Catarina was analysed, as it represents the most organized state regarding mariculture activities. Finally, at farm level, two bivalve farms were studied, both in the state of Santa Catarina, farm number one being in the municipality of Penha, and farm number two, at Florianópolis.

Brazil is the largest country in South America, sharing boundaries with all of them, except Chile and Equator, and is bordered by the Atlantic Ocean in the East (figure 1). Its coast is limited by the French Guyana in the North, and by Uruguay in the South. Brazil has eight major drainage basins, which compose one of the world's most extensive river systems, and all of them drain into the Atlantic Ocean.

Figure 4.2. Map of Brazil.

Santa Catarina is the state comprehended northern to Rio Grande do Sul, and southern to Paraná, bordered West by the province of Misiones, Argentina, and East by the Atlantic Ocean (figure 4.2). Florianópolis and Penha are both important producers of farmed mollusks (figure 4.3). The city of Florianópolis is the state capital, located at 27° 35′ 49″ South, 48° 32′ 58″ West. Penha, is located in the northeast of the state, at 26° 46' 10" South, 48° 38' 45" West.

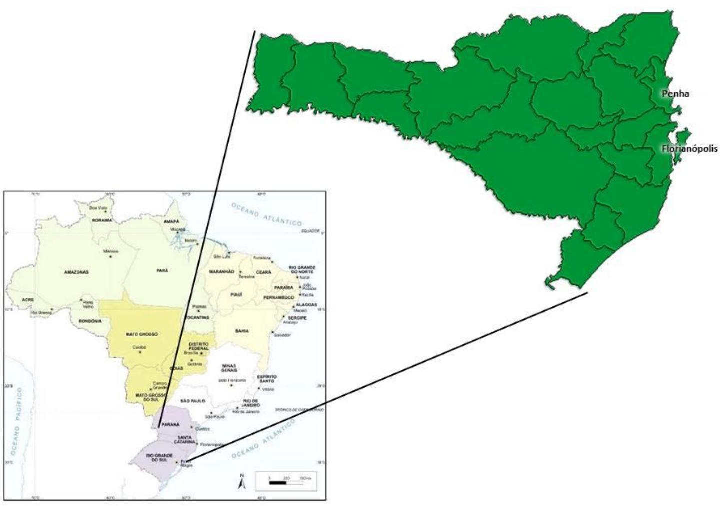

Figure 4.3. State of Santa Catarina, in Brazil.

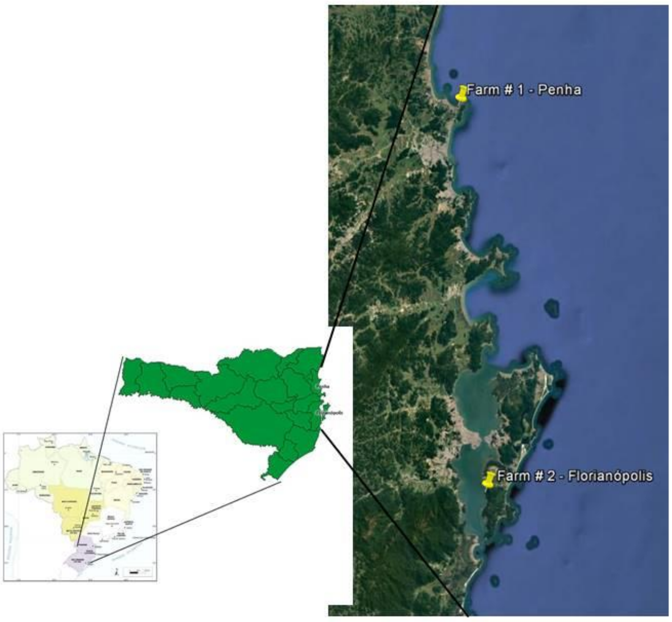

Figure 4.4. Localization of farm #1 and farm #2 in the state of Santa Catarina.

The state of São Paulo is located in the Southeast region of Brazil, comprehended between the states of Paraná, in the south and west borders, Mato Grosso do Sul and Minas Gerais in the north, and Rio de Janeiro and the Atlantic Ocean at the eastern limits. The capital of São Paulo is the city of São Paulo. Farm #3 is located at municipality-archipelago of Ilhabela at at 23° 46′ 43″ South, 45° 21′ 30″ West, in the northern coast of the state, 208 km away from the capital (figure 4.5).

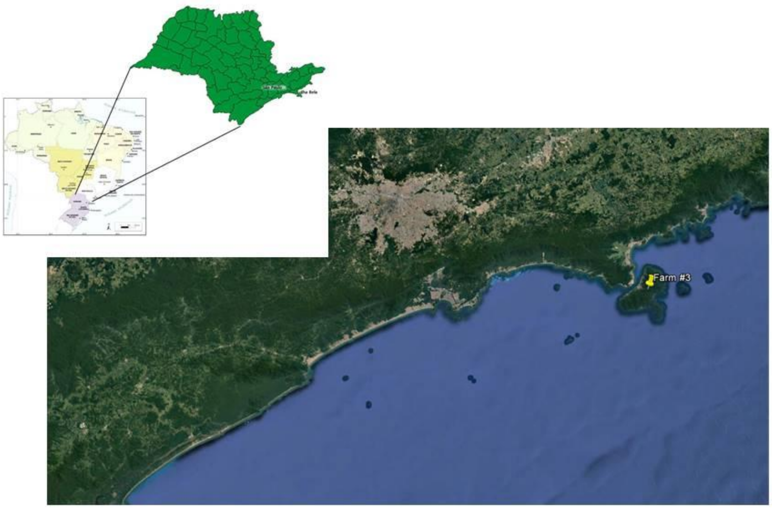

Figure 4.5. Localization of farm #3 in the state of São Paulo

4.2.2. Definitions

For this study, mariculture was considered as the commercial culture and production of organisms for human consumption in marine and/or brackish water. In Brazil, four modalities of mariculture are found, regarding the type of organisms: shrimp farming, mollusk farming, seaweed farming and finfish farming. Production is concentrated in shrimp (77%) and mollusks (23%). The culture of finfish remain incipient (less than 1%) (FAO, 2015).

4.2.3. Mariculture sustainability indicators system

The indicators system was developed through a pre selection of indicators of sustainability of aquaculture and coastal management used internationally. The pre-selected indicators were first adapted to the mariculture sector in Brazil, then, presented to a group of experts that evaluated them according to their significance, through a Delphi procedure. Finally, the most important indicators were chosen and the indicators system was constructed. Further information on the indicators development process can be consulted in Gerent et al. 2017.

Each indicator includes a calculation method (annex 1) that gives a numerical value to the accomplishment or non-accomplishment of a criterion. This numerical value corresponds to a valuation that has five scores, ranging from very low to very high. It is considered that the ideal situation in terms of sustainability would receive the maximum valuation. The maximum valuation (which varies with each indicator and each category: economic, social, environmental and governance) would correspond to a very high sustainability level, while the minimum valuation (zero), would correspond to a very low sustainability level. It was considered that the absence of the information necessary to calculate the indicator score was also valuated as “zero”, given that the collection and availability of information is essential for the support, promotion and management of mariculture in all levels. Each scale assessed (National, Regional and Farm) had a corresponding indicators system composed by a combination of the above mentioned indicators (table 4.1).

The indicators system was not initially designed to include nurseries, but since there was an opportunity to assess a fingerling farming facility, the indicators system was adapted to fit this specific situation. Indicators ENV14, ENV17 and ENV20 were dismissed, and indicator ENV15 was modified. The score valuation system was recalculated to include such changes.

4.2.4. Data collection

The information used to calculate the indicators were obtained through interviews in situ with representatives of farms #1 and #2, and by e-mail with representative of farm #3. The data corresponding to the regional scale was obtained through a visit to the state authority in mariculture issues in state, the Agriculture Research and Rural Extension Company of Santa Catarina (EPAGRI), and by document analysis. The information regarding the national scale was obtained by document analysis and e-mail conversations with a key informant recommended by the national authority on aquaculture issues, representative of the Ministry of Fisheries and Aquaculture (MPA).

Table 4.1. Table 1. Indicators system. The indicators are related to a theme of study within a category. Each indicator is to be applied at the descripted scales.

Category	Theme	Indicator	Scale	Code
Economy	Production	Value of total production per year	Farm, Regional and National	E1
		Evolution in the number of farmed species	Farm, Regional and National	E2
		Number of products of mariculture origin	Farm	E3
		Evolution in the percentage of sales of local products with quality seal, nomination of origin, or similar certification over total production	Regional and National	E4
	Profit and sector growth	Evolution in the number of licenses for farm installation and operation	Regional and National	E5
		Farm profitability	Farm	E6
		Turnover of mariculture in the regional economy	Regional	E7
Social	Integration and inclusion	Transparency of the production processes	Farm	S8
		Promotion of the farming methods	Farm	S9
	Employment	Evolution in the number of employees	Farm, Regional and National	S10
		Local employment generation	Farm	S11
		Labour security	Farm	S12
	Food security	Evolution of per capita consumption of mariculture products	Regional and National	S13
Environmental	Contamination	Sanitation monitoring of farming waters	Farm, Regional and National	Env14
		Wastewater treatment	Farm	Env15
		Strategies for minimizing waste generation	Farm	Env16
		Presence of toxic or hazardous wastes in farming waters	Farm	Env17
		Use of antibiotics for farming	Farm	Env18
		Energy consumption optimization policy	Farm	Env19
	Biodiversity and animal welfare	Source of seeds/fingerlings (farm or artificial collector/fishing)	Farm and Regional	Env20
		Origin of farmed species (native/exotic)	Farm, Regional and National	Env21
	Spatial planning	Marine and/or coastal monitoring programs	Regional and National	Env22
		Phase of implementation of the Local Plan for the Development of Mariculture (PLDM)	Regional and National	Env23
		Carrying Capacity Study (CCS)	Farm	Env24
		Implementation and periodic evaluation of the management plan	Farm	Env25
Governance	Research and education	Periodicity of superior training in mariculture in the state	Regional	G26
		Official publications on the sustainability of mariculture	Regional and National	G27
		Existence of research centres on mariculture in the state	Regional	G28
	Legislation	Legislation that supports sustainable development of mariculture	Regional and National	G29

4.3. Results and discussion

4.3.1. Farm level

Table 4.2. Evaluation of farm level indicators. Sustainability score of indicators at the farms assessed.

Category	Code	Farm #1	Farm #2	Farm #3
Economic	E1	2	0*	2
	E2	1	2	3
	E3	2	2	0
	E6	3	0*	0
Social	S8	2	2	2
	S9	1	0	1
	S10	1	0	2
	S11	2	2	1
	S12	0	1	1
Environmental	ENV14	1	1	0**
	ENV15	1	1	1**
	ENV16	1	0	3
	ENV17	0	0	0**
	ENV18	1	1	1
	ENV19	0	0	1
	ENV20	0	1	0**
	ENV21	3	1	3
	ENV24	0	0	0
	ENV25	0	0	0
Total score		21	14	21

*information not available
**not applicable or partially not applicable for this farming system

According to the results from the application of the present indicators system, sustainability assessment at farm level showed that, overall, farm#1 and farm #3 have reached an "Average" level of sustainability, while farm #2 presented "Low" sustainability (table 4.2). Farm#1 obtained a "High" score at economic and social sustainability, and "Average" environmental sustainability (figure 4.6a). Farm #2 presented the poorest score in relation to the other farms assessed, achieving a "Low" level of sustainability at the economic and environmental categories, and an "Average" level of social sustainability (figure 4.6b). Farm #3 was considered to have "Average" economic and environmental sustainability, while presenting a "High" level of social sustainability (figure 4.6c).

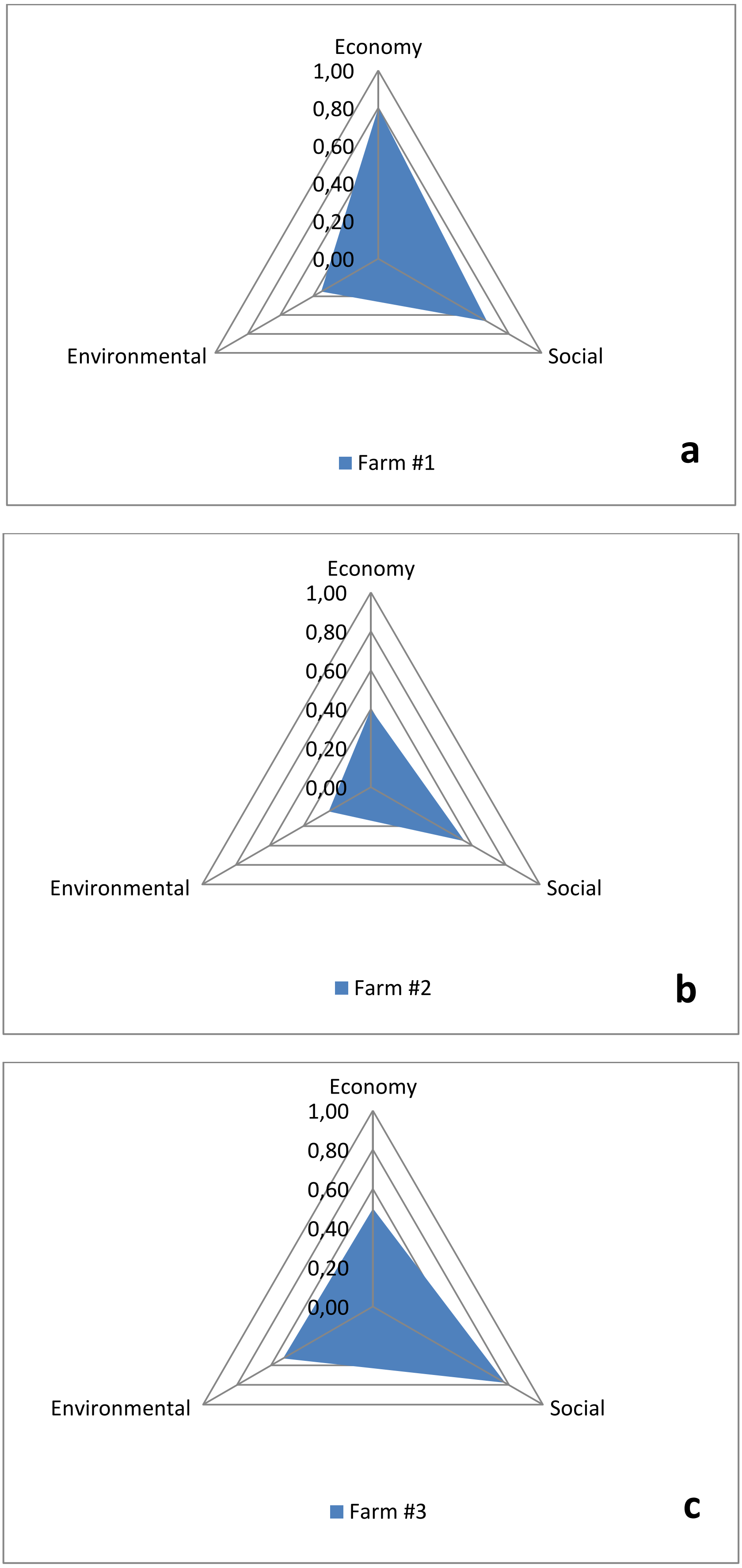

Figure 4.6. Results of the sustainability assessment at farm level. (a) and (b) correspond to bivalve farms, and (c) refers to the fingerling nursery.

4.3.1.1. *Bivalve farming systems – farm #1 and farm #2*

4.3.1.1.1. Economic sustainability

Farm #1 and farm #2 have many similarities apart from growing bivalves. Both use artisanal farming methods, and both are located in the State of Santa Catarina. These two farms are considered "informal businesses", for at least part of their operations are not controlled by the surveillance authorities.

Farm #1 is specialized in the farming of the native mussel (*Perna perna*), while farm #2 grows a consorted system with the native mussel and the Japanese oyster (*Crassostrea gigas*). Farm #1 grows the mussels at sea, and commercializes the product in a tent close to the farming site. Farm #2 too grows the mollusks at sea, but the farm owner also runs a restaurant next to the farming location. The products are used both as raw-material in the restaurant, and are also commercialized cooked fresh or frozen (for take-away) for the general public as well.

Indicators E1 and E6 scored "Very high" for farm#1. Farm #2, however, stated there is no control of the production value, including volume and price of the product. Indicators E1 and E6 could not be calculated due to lack of information, and therefore, scored "Very low" at this farm. In sum, despite presenting "Very high" score for most economy indicators, the culture of a single species at farm #1 fails to cope with adversities. The "Low" evaluation of indicator E2 has lowered the overall evaluation of economic sustainability of the farm. Farm #1 scored "High", while farm #2 scored "Low", in the Economic sustainability category.

4.3.1.1.2. Social sustainability

For the Social indicators, there have also been parallelisms between the two bivalve farms. Both farms are open to public visit, and often receive students in the installations and inform about farming operations and maintenance, etc. Still, both farm representatives have commented that they do not promote visits, but they are open to anyone who wishes to visit the farm. Farm #1 representative stated that they are contacted by journalists when there are red tides, which is usually once a year.

Regarding the indicators related to employment, in farm #1, the number of employees is stable from one year to another, but varies seasonally: from December to March, there are usually 6 employees, and from April to January, four people operate the farm. At farm #2, the number of employers has decreased in the past years. In both farms, employers are 100% local residents. Even though, farm #1 representative stated that in the past years, a growing number of immigrants from other neighbouring countries, or from other regions in Brazil, end up working in the farm, as native people are losing interest in the sector. In farm #1 often hires employers informally on day-shifts, while 100% of employers in farm #2 work legally under contract and signed labour card. Despite scoring "Very low" on indicator S12, overall, farm #1 presented a "High" social sustainability. Nonetheless, farm#2 score was considered "Average".

4.3.1.1.3. Environmental sustainability

The Environmental indicators were evaluated as overall "Average", at farm #1, and "Low" for farm #2. Indicators ENV 14, ENV15 and ENV17 are related to water management and monitoring. While indicators ENV16, ENV 18, ENV19, ENV20 and ENV21 refer to farming operation practices. Finally, indicators ENV24 and ENV25 evaluate environmental and farming management monitoring.

Indicator Env14 refers to the monitoring of the sanitary quality of the farming waters. Farm #1 and #2 are located under the regional monitoring area, which is done weekly by the Integrated Company of Agriculture Development of Santa Catarina (CIDASC). The sanitary control is part of the National Program of Hygienic-Sanitary Control of Bivalve Mollusks. Representative of farm #2 indicated that in 2015 the monitoring ceased in the region. Nevertheless, the regional authority responsible for the water monitoring indicates that farm #2 zone is currently included in the program (CIDASC 2017). Furthermore, some of the most important farms in Florianópolis, including farm #2, are in the process of getting a State Inspection Seal, to meet the microbiological requirements demanded by the European Union. The State Inspection Seal ensures the control of the hygienic procedures, packing, production and expiration date and traceability.

Indicator ENV15 considers the existence of effluent water treatment in single-species or consorted cultures including seaweed or mollusks. Still, it also contemplates the existence of sewage treatment in the farming area or municipality, since it directly affects the quality and safety of the mollusks. In the two bivalve farms analysed in this study, sewage treatment was absent in the farming area.

Considering solid wastes from the farms, farm #1 sends shell residues for reusing in the local construction industry, but discharged equipment or materials are not recycled. In farm #2, none of the residues from organisms or equipment maintenance are reused or recycled. The two farms and municipalities lack strategies for reducing waste generation. Farm #1 representative even stated that it is impossible to reduce it.

In Brazil, the mariculture waters are not monitored for the presence of toxic or hazardous wastes such as heavy metals, organic compounds, pesticides, radioactive residues, etc. Neither farms #1 or #2 account with control of toxic wastes in the farming waters or organisms, and these substances are not included in the monitoring program. The farms assessed also do not control the presence of these substances in water or in the organisms. Therefore, indicator ENV 17 scored zero in all cases.

In both mollusk farms, representatives have stated that the energy consumption has remained stable in the past years. Besides, there has been no shift towards more eco-friendly energy sources, such as eolic or solar. Thus, both farms scored “Low” in indicator ENV19.

The seeds used in farm #1 come mostly (90%) from natural banks in the rocky shores, and 10% come from the same culture ropes. The representative commented that the collection of seed from the environment is regulated, but there is no inspection. In farm #2, as the oysters are exotic species, 100% of the seeds come from the local hatchery, while the mussel seed are captured by artificial collectors.

In both farms there was no carrying capacity study previous to the installation of the farms. Also, neither of the two farms is supported by any type of management plan, and the farming procedures are mostly guided by intuition and previous experience.

4.3.1.2. Fingerling production – farm #3

4.3.1.2.1. Economic sustainability

Farm #3 is radically opposite to the first two farms. It produces fingerlings of cobia (*Rachycentron canadum*) and grouper (*Epinephelus marginatus*) for grow-out farms. Yet, in the period from 2013 to 2015, the production of grouper fingerlings was not viable, due to morphological deformities in the specimens. The representative of the farm mentioned that the production cycled protocol was achieved in 2016, and the results were finally successful to attend the demand.

In the past years, production value has presented many oscillations. It has decreased from 2012 to 2015. In 2016, however, it increased nearly 95% in relation to the previous year.

Despite this abrupt increase in sales value, the profitability of the farm (indicator E6) resulted negative in the past five years.

4.3.1.2.2. Social sustainability

Regarding the social indicators, the farm has promoted its activities through a website and frequently receives open visits from schools, community associations, universities, the regional Fishery Institute, the regional Oceanographic Institute and other groups. Also, the media has shown interest in the production. Farm representative has informed to give interviews for television and journals, generally, once a year. In this sense, indicator S8 got the highest score and S9 scored “Average”.

The number of workers in the farming system has risen gradually over the past years. Most of them (66%) were local residents at the moment of hiring. Lastly, all of them are working under signed labour card. Overall, farm #3 is considered to achieve a “High” level of social sustainability.

4.3.1.2.3. Environmental sustainability

The system is based on recirculation tanks, so there is a monthly water exchange. It goes through a purification treatment previous to discharge. The municipality lacks a wastewater network, but it does not affect the water quality of the culture system. The farm solid wastes are directed to recycling plants, or reused in the farming system. In the region, there is an association of collectors of recycling material that collects the residues, and environmental education campaigns. Farm representative added that there is no need for antibiotics in the fingerling production.

Indicator ENV19 evaluates the energy consumption behaviour of the farming system. Representative of farm #3, commented that the farming system requires a high energy consumption, and that it has remained stable through the past years. It was added that there was an attempt to use solar energy, but it resulted insufficient, therefore it was dismissed. Similarly to the previous mentioned cases, this indicator scored “Low” in Farm #3.

Similarly to the previous study cases presented, there has been no carrying capacity study of any kind prior to the farm installation. The representative failed to provide information about the management plan for the farm, so the indicator referent to this issue (ENV25) scored zero. In general, environmental indicators presented a “Low” level of sustainability for this farming system.

4.3.2. Regional Level

Santa Catarina presented an overall “Low” level of mariculture sustainability (table 4.3). The level of sustainability was heterogeneous among the different categories (figure 4.7). The recent decrease in production value, unavailability of certification mechanisms to promote excellence and lack of data on the importance of mariculture to the regional economy, and on the expansion of mariculture, has dragged down the economic sustainability to a level considered “Very low”. Social indicators have also scored “Very low” due to absence of information. There was also insufficient information to calculate all environmental indicators, which, altogether, showed “Low” sustainability. Finally, at the governance category it received the maximum evaluation, therefore, Santa Catarina is considered to perform “Very high” governance sustainability.

Table 4.3. Evaluation of regional level indicators. Sustainability score of indicators for mariculture assessment in the state of Santa Catarina.

Category	Code	Santa Catarina
Economic	E1	0
	E2	2
	E4	0
	E5	0
	E7	0*
Social	S10	0*
	S13	0*
Environmental	ENV14	0*
	ENV20	0*
	ENV21	2
	ENV22	0
	ENV23	2
Governance	G26	2
	G27	2
	G28	1
	G29	2
Total score		14

* information not available

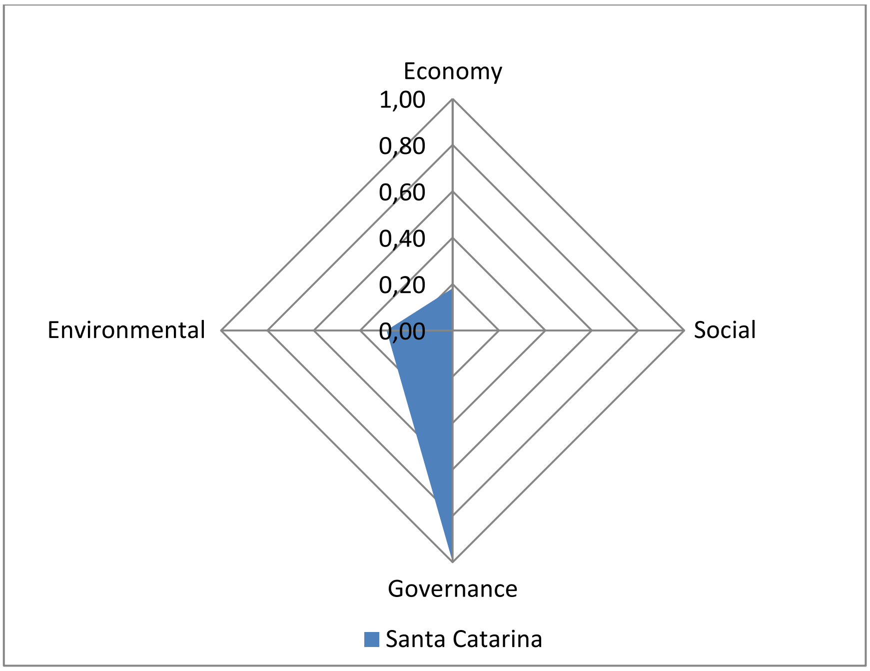

Figure 4.7. Results of the sustainability assessment of mariculture at regional level, in Santa Catarina.

4.3.2.1. Economic sustainability

In Santa Catarina, mariculture is based mostly on mollusk farming, and a mall proportion of shrimp. Mollusk production is dominated by mussels (84,5%), followed by oysters (15,3%) and an incipient participation of scallops (0,2%). Production value statistics are available until 2015, which registered lower values in relation to the previous year, therefore, indicator E1 scored zero. Given the diversity in the number of species farmed, and the fact it has been stable for many years, indicator E2 scored “High”.

In the state, no farms have been granted any type of certification that could be compared to "Designation of Origin" seal, or "Organic" certificate or anything similar, hence, indicator E4 scored zero for Santa Catarina. Indicator E5 evaluates the expansion of mariculture, and indicator E7 the contribution of mariculture to the economy. Both indicators scored zero given that the information necessary to evaluate them is not available. Additionally, it was informed that around 80% of mariculture sales are clandestine, thus, not controlled by the regional authority.

4.3.2.2. Social sustainability

In Santa Catarina there is no control over the number of jobs provided by the mariculture sector, which is the information collected by indicator S10. Regarding indicator S13, a large part of mariculture production is sold to other states. Furthermore, it is estimated that around 80% of the commercialization is clandestine, making it impossible to calculate the per capita consumption of mariculture products. In this sense, social indicators have scored "Very low" in this case.

4.3.2.3. Environmental sustainability

Regarding environmental sustainability, indicator Env14 refers to water quality management in mariculture areas. The representatives of mariculture management in Santa Catarina have informed that a study on monitoring sites has only been done for the region of Florianópolis, but not for the whole state. In the study, it was estimated the need for 45 control points in the studied area. However, there are currently only 30 monitoring sites in the Santa Catarina.

Water quality is monitored in mariculture areas, but it is limited to the sanitary quality of the waters. Other environmental characteristics such as primary productivity, physico-chemical aspects or even biodiversity are not included in the monitoring programmes. Yet, the percentage of marine farms that are under the monitoring zone is not controlled, so this information is inexistent.

Control of the source of seeds or fingerlings, evaluated by indicator Env20, is also missing. UFSC produces and distributes seeds of mollusks and shrimp post-larvae, (Shrimp post-larvae, Japanese oyster and scallop seeds are only available from hatcheries) but it is known that farmers also collect mollusk seeds from artificial collectors or natural banks. Additionally, 50% of the species farmed in Santa Catarina are native, resulting in a "High" score for indicator Env21.

Santa Catarina is also one of the few states that have implemented the Local Plans for the Development of Mariculture (PLDM). The Plan has already reached the last phase of the Plan, where the bidding process is being concluded. In this regard, indicator Env23 has scored "Very high".

4.3.2.4. Governance sustainability

All governance indicators, on the other hand, have scored "Very high". EPAGRI promotes several courses, trainings or workshops often, and works together with producers, developing and distributing information materials, good practices guidelines, farming manuals, etc. Also there are a few research and reference centres for mariculture development in Santa Catarina. Besides, there is an effort from the state government to encourage the sustainable development of mariculture, as it is considered an activity of social and economic interest. Moreover, in the past years, two state laws were published to reinforce the sustainable development and growth of the mariculture sector.

4.3.3. National level

According to the indicators system presented, mariculture sector at the national level was considered to have "Very low" sustainability (table 4.4). Most indicators scored "Very low" either because the information needed for calculation is missing, or the management programmes evaluated, or the government actions toward mariculture development are inexistent (figure 4.8). For instance, the environmental monitoring programmes assessed by the indicators are not present in a significant number of regions in Brazil. Also, legislation regarding mariculture sustainability, or dissemination of information have not been published in a few years.

table 4.4. Evaluation of national level indicators. Sustainability score of indicators for mariculture sector assessment in Brazil.

Category	Code	Brazil
Economic	E1	2
	E2	1
	E4	0*
	E5	0*
Social	S10	0*
	S13	0*
Environmental	ENV14	0
	ENV21	2
	ENV22	0
	ENV23	0
Governance	G27	0
	G29	0
Total score		5

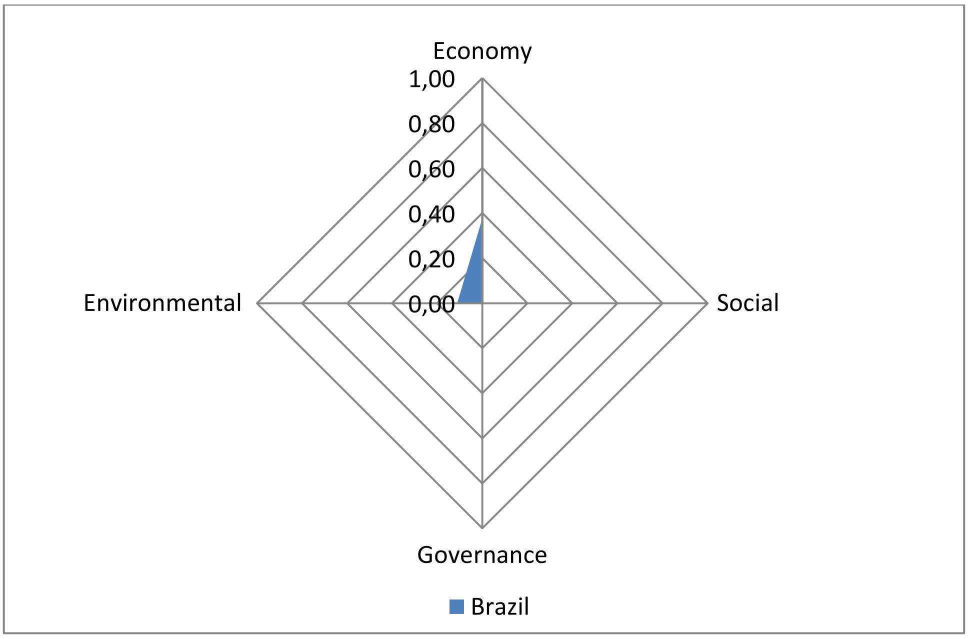

Figure 4.8. Results of the sustainability assessment of mariculture sector at national level, for Brazil.

4.3.3.1. Economic sustainability

Value of mariculture production in Brazil was higher in 2015, then in the previous year, giving it a "Very high" score for indicator E1. Indicator E2 refers to the evolution of species farmed. Brazilian mariculture is based mostly in shrimp (*Litopenaeus vannamei*) and mollusk culture (*Crassostrea gigas*, *C. rizophorae*, *Perna perna* and *Nodipecten nodosus*), but there is also a smaller participation of seaweed (*Kappaphycus alvarezii* and *Gracilaria spp.*) and fish farming (*Rachycentron canadum*). Fish farming was the last mariculture modality to be introduced in Brazil, with the first production cycle taking place in 2009. As the number of species has remained stable over the past 3 years, this indicator scored "Average".

The adoption of quality certification seals, Designation of Origin or similar certification is evaluated through indicator E4. Regarding mariculture, a group of shrimp farmers were granted a "Designation of Origin" recognition. It is the first certification of this kind for shrimp in Brazil was achieved by shrimp farmers of Costa Negra region, Ceará, in 2011. Official information on the value of contribution of sales of these products is not available, therefore, the indicator scored "Very low". Currently there is no official or extra-official information on other certified mariculture systems in Brazil. Data on the value of the certified production is also not available, nor gathered by the national authorities.

Likewise, there is no control on the number of new licenses for mariculture operation at national level. This information is evaluated through indicator E5, which considers the expansion of mariculture. Given the absence of data, the indicator scores zero.

4.3.3.2. Social sustainability

Social indicators follow the same trend observed for most indicators at the national level. There is no recompilation of detailed information in the aquaculture sector in general. It was not possible to calculate the number of employed in the mariculture sector (S10), neither the consumption of mariculture products (S13).

4.3.3.3. Environmental sustainability

According to the present indicators system, environmental sustainability of the mariculture sector in Brazil was considered "Very low". Indicators ENV14 and ENV22 have scored "Very low", given that Santa Catarina is the only state with an ongoing water monitoring programme, and it only includes sanitary quality of waters. Oppositely, indicator ENV21 has scored "High", since over 62% of the species farmed in Brazil are native species.

Indicator ENV23 evaluates the implementation of the maritime spatial planning for mariculture activities. The federal government, through the Special Secretary of Fisheries and Aquaculture, has established the criteria and procedures for the formulation and approval of the Local Plans for Mariculture Development (PLDM) in 2005 (Interministral Normative Instruction nº 6, of May 28th 2004). The indicator assesses the adherence of coastal states to the adoption and implementation of the Plan. At this moment, only four states, Santa Catarina, Paraná, Sergipe and Maranhão have it implemented. Together, they represent only 23% of the coastal states, therefore, the indicator scored "Very low".

4.3.3.4. Governance sustainability

The Governance indicators that are evaluated at the national scale are related to the publishing of official information (didactic materials, reports, etc.) on mariculture sustainability (G27) and legislations that promote the sustainable development of mariculture (G29). Both are calculated taking as reference the past two years. In both cases, no advances towards the promotion and support of sustainable aquaculture or mariculture practices have been taken by the federal government, thus the indicators presented "Very low" sustainability level.

4.4. Discussion

4.4.1. Mollusk farming and the regional context

Diversification in the number of species farmed could help the enterprise adapt better to moments of (environmental or market) crisis, new market situation and consumers requirements (FOESA 2010). In other words, reliance on a single-species increases the exposure of the producer (or the whole sector) in face of adversities. Single-species bivalve culture in France suffered a succession of crisis due to unexplained mortality, affecting the whole industry (Buestel et al. 2009). Apart from increasing vulnerability in case of diseases and environmental phenomena that may affect production, specialization implies dependence on market preferences (Vandermeer et al. 1998).

Increasing the assortment of products, may compensate the low species diversification in the sense that it adds value to the products, and varies the offering. In Santa Catarina, mussel farmers often commercialize the products raw (in natura) and cooked, fresh or frozen. Cooking the product also increases the conservation period of the product, at a higher profit for the producer. Cooked (shelled) mussel can achieve a price up to ten times higher, when compared to the raw product (Manzoni, personal communication). The market price for the raw mussel is low, and is often a problem in commercializing the yield (Suplicy 2015).

Regarding farm management plans, frequently, marine farmers respond to the situations without an organized planning, but simply reacting. The use of indicators could be helpful to promote adaptive management of farming practices and strategies. In this sense, through adaptive management, instead of improvising, a proactive thinking and acting takes place. In sum, a conscious process of examining the course of events (both its social and environmental components), and by events occurring at differing spatial scales will lead to a learning and adapting process that would more likely respond positively to changing conditions (Costa-Pierce & Page 2010).

The findings of this study reflect the widespread informality on the mariculture sector in Brazil. Most producers have no control on production costs and profit. Apart from the underground market, informality is also observed in workforce. Suplicy (2015) corroborates the present results by reporting that in most cases, family members are employed in the farm, while in the other cases, employees are hired part-time or on day-shift. Only a small portion of producers have regular employees. Furthermore, usually at Christmas and Easter season, the number of employees increases to keep up with the demand.

In relation to the environmental aspects, some things can still be improved through reinforcement by regulation authorities. Collection of mollusk seeds from natural banks was only permitted for farmers under compliance with the Terms for the Adjustment of Conduct (TAC) (IBAMA 69/2003) with the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA). The regional authority informed, however, that there is no longer any permission for collecting seeds from the natural environment, yet it is known that in the state's northern region, extraction is still a common practice. Furthermore, representative of farm #2 mentioned that the artificial collectors have been attracting undesirable organisms, such as ascidians and other species of mollusks. The "invasive" fauna ends up colonizing the farming structures, competing with the farmed species.

On the other hand, the Federal University of Santa Catarina (UFSC) and EPAGRI have backed mariculture growth through research and technology and development, and the creation of the Laboratory of Marine Mollusks (LMM). LMM is responsible for the production and distribution ofregular distribution of seeds of oysters, mussels, and scallops, and even shrimp post-larvae. The collaboration between the regional authority and the research institution through credit incentives, and research sponsoring, resulted in the recognition of excellence of Santa Catarina as the most traditional mollusk producer in Brazil. Furthermore, the government endorsed the sector by implementing public policies that favoured the local mariculture market. These joined efforts were essential for the current level of organization of the mariculture sector in the state, which is an exception in Brazil.

Nevertheless, there are still difficulties faced by the sector, such as the artisanal character of the production, which increases costs; generalized informality; low inversions in basic sanitation and low compliance with sanitary inspection, which increases health risk of consumption (Suplicy 2015; Andrade 2016). There is an intensive effort by EPAGRI to ensure the environmental soundness of mariculture areas in order to minimize the negative impacts to the ecosystems and to avoid health risks to consumers. These efforts have featured Santa Catarina as an example to other states, at the same time it is recognized that there is much room for improvement (Suplicy 2015). Slowness and poor efficiency of other interconnected sectors (such as sanitation) and the federal scale, limited funding, and excess of bureaucracy are the main reasons hindering the improvement of mariculture in the state.

According to Suplicy (2015), the added value on mussel products relies on its freshness and sanitary quality. The rules for processing food of animal origin are established by legislation. The farms that accomplish with the hygienic-sanitary requisites for commercialization are granted the Federal Inspection Seal. It requires the presence of a technician in the farm to ensure the quality of the product, thus, compliance with these regulations is costly. Despite incurring in health risks for the consumer, currently over 85% of mussel and at least 50% of oyster production are not inspected.

Another important issue raised in this research is the absence of carrying capacity studies prior to the installation of farms. Mariculture has developed in Brazil, generally spontaneously, with no planning on the occupation of the marine or coastal areas. The carrying capacity studies would help define the more suitable areas and management practices of production (McKindsey et al. 2006). With no carrying capacity studies, and no management plans of the farms, added to the poor control from regional authorities on seed collection, for example, the sector is developing "in the dark". There is no guidance, no limits stipulated or management practices defined to ensure that it has been developing with acceptable impacts to the environment. Luckily, mollusk farming tends to generate little and reversible impacts to the surrounding ecosystem. Researches that have studied the impact of mollusk farming in Brazil have resulted in little or insignificant effects (Cruz et al. 2015; Rudorff et al. 2012; Netto and Valgas 2010; Costa & Nalesso 2006) Even though, in order to promote an organized, efficient, integrated and sustainable development of aquaculture, carrying capacity studies are important to guide on spatial planning of maritime occupation, and farming practices and densities (McKindsey et al. 2006; Guyondet et al. 2010; Silva et al. 2011).

Site selection and spatial planning for mariculture activities is also intimately related to sanitary issues. As filter feeders, mollusks have a higher susceptibility to be contaminated by pathogenic organisms or toxic substances. Carraro et al. (2015) has addressed the problem of water contamination and health risks associated to the consumption of mollusks. In Brazil, insufficient or absence of sewage treatment is a widespread problem. In Santa Catarina, only 20% of the residual waters are collected through the public sewage treatment system (SNSA 2014). Improving sanitary management of residual waters has been pointed out as an important policy issue for the sustainable development of mariculture (Suplicy 2015).

4.4.2. Fingerling nursery peculiarities

The fingerling farming system is indoor-based, with a high control of the environment, contrasting with the first two farms that are based at sea, with zero control of the environment and overall conditions, and low maintenance. The costs of installing, implementing and production; management and operations, as well as the employers, and the activities developed are not comparable with the ones in grow-out farms. The low economic sustainability observed is probably related to the high investments to start this kind of entrepreneurship. Farm representative has stated that, although it still hasn't showed profit, the economic situation is improving and is showing signs of recovery. Furthermore, achieving the technological basis for viable production of grouper has implied an increase of nearly 100% on sales value.

The level of organization required to this production demands special attention to the social aspects related to employment. It is expected that the producer would follow the legal requirements regarding its employees. Besides, we can observe that the recent growth in the number of employees follows the improvements in the economic situation of the system, as mentioned by the farm representative. Still on social indicators, the farm has collaborated with the research sector, improving its transparency as it is also frequent in innovative sectors.

The "Average" score the farm was given regarding its environmental sustainability can be related with the indicators system not being designed to assess this type farming system, many of them are not applicable. For instance, the water supply comes from offshore waters, far from any source of contaminant or toxic residuals, and it is claimed that there is no need for monitoring. Furthermore, besides not providing information on farming management plan, since it is a very incipient and high-technology-based activity, it is likely that there is a high control of the production, and most probably, records of the parameters and procedures are kept. Also, as it has been informed that the grouper production has overcome some adversities, showing some improvements were required. It is probable that farming management and procedures have been adapted to face the challenges presented.

4.4.3. Mariculture at national level

At national level, there has been a poor organization and control of the mariculture sector. Mariculture was implemented unorganized and spontaneously, without planning of the use of coastal zones. Responsibility for the development and regulation of mariculture has been in hands of different institutions. This situation has impaired the activity and allows the generation of conflicts among users of the coastal zone. Creation of a Ministry of Fishery and Aquaculture was fundamental for organization and support of aquaculture in general. National Policy for Fisheries and Aquaculture conceive integrated sustainable development of the sector within communities; management and support of the activity; and environmental preservation and conservation. Still, there are some issues to be worked on regarding excessive bureaucracy and superposition of duties at different institutional levels in public management processes.

Brazil is currently going through an important political (and consequently, financial) crisis, which has left the fisheries and aquaculture sector neglected. The Ministry of Fisheries and Aquaculture which has been established in 2009 represented a great recognition of the sector to the economic and social development of the country. But since 2015, changes in the government and in the priorities of development have entailed the Ministry of Fisheries and Aquaculture to the Ministry of Agriculture, Husbandry and Supply. In 2016, the Ministry has downgraded to the status of Secretary of Aquaculture and Fisheries. More recently, through the Decree 9004 of March 13th 2017, the Secretary of Aquaculture and Fisheries has been moved to the Ministry of Industry, Foreign Trade and Services. This recent instability towards the sector is certainly cause for worries since it neglects the political advances and entailments the Secretary has with the Ministry of Agriculture, Husbandry and supply, and with the Ministry of Environment. This decision aims to give a more industrial character to the fisheries and aquaculture sector.

The instability of the recent situation, has affected the ability of the authorities in charge to monitor and promote management actions required for the progress of the sector. It has basically being developed on its own. For instance, we have observed that the value of total mariculture production in Brazil has increased significantly in the past years (IBGE 2016). But, on the other hand, other important data for the assessment of the economic sustainability of the sector have not been correctly responded. Official database is incomplete, as it is known about the existence of some species of seaweed and fish currently being farmed in Brazil that do not appear on the statistics. There is also no control about the expansion of the mariculture activities and licenses granted, and no database that can be accessed to review its historical evolution.

Furthermore, regularization of mariculture activities has been deficient and in most coastal regions, producers operate illegally. Government initiatives aim to regulate and improve the development of the sector. The importance of regulating the farmers relies on credit access and legal safety, promoting a steady product supply and improved competitiveness, since it would reduce costs. Legal issues still are one of the main bottlenecks for mariculture development (CEMBRA, 2012).

To promote an integrated planning and regulation of mariculture activities, the federal government approved the Local Plans for Mariculture Development (PLDM), under the National Program of Aquaculture Parks. It is one of the main tools developed to promote and regulate mariculture, and to assess the site selection issue. It includes participative planning and aims to promote sustainable and integrated aquaculture development, through the identification of opportune areas for the Aquaculture Parks delimitation. Nonetheless, currently there are few states that are up to date with the elaboration of PLDM. Management actions taken by the government include the Santa Catarina was the first state to adopt this policy and start on the process of legalizing of the activity through the elaboration of the PLDM. This experience on implementing PLDM, within the GERCO-SC (Coastal Management program for SC), through PZGC (Plan of Coastal Zone Management) and ZEEC (Coastal Ecological Economic Zoning) in Santa Catarina shows an effective way for mariculture regulation and management. Participative process on zoning aquaculture parks has promoted empowering of mariculture associations in decision making processes, and subsidized marine spatial planning (Vianna et al. 2012). Therefore, it is possible to attend the legal criteria, integrate institutions and promote democracy on coastal management.

The Normative Instruction, however, does not set a deadline to be accomplished by the states. It establishes the participative planning in the identification of the most adequate areas to delimitate the marine parks and of the preferred areas for traditional communities. The Local Plans for Mariculture Development lie in the basis for regulating and expansion of the mariculture sector. Even though the licensing of the marine areas is responsibility of the petitioner, the implementation of the PLDM also reflects the ability and commitment of the state authorities to the promotion and support of the mariculture sector.

4.5. Conclusions

In general, lack of attention from the federal government in promoting mariculture has resulted in poor and exacerbating management of the sector, starting with data collection. There is very little data on the socioeconomic aspects of mariculture, no reports or diagnosis of the sector, and environmental monitoring and management have also been deficient.

Sustainability of mariculture in Brazil could improve if the political forces would consider mariculture with the importance it has for promoting coastal sustainable development.

Santa Catarina is a great example that with political will, support to mariculture can promote several benefits to the population. Furthermore, the bare availability of information would most probably increase the valuation of mariculture sustainability according to the indicators system proposed.

It was observed that a very important dimension of mariculture is governance, which could be better assessed with the addition of more indicators into the assessment system. An indicator or index to evaluate the coverage and efficiency of inspection of mariculture activities, regarding commercialization, social security and taxes could be useful to assess and promote policy actions. It is important to consider this aspect, since the retribution of the producers to the state or nation, if properly directed, can result in better services, such as sanitation, monitoring, regularization, planning, an adequate environmental management, and social care, such as retirement and health coverages.

It is also proposed to include governance indicators that consider the social organization of the mariculture sector. Establishment of associations represents a strategic tool for economic and political strengthening of the producers, avoiding marginalization of smaller groups while also mediating relationships with institutional and economic agents (Soares & Ferreira 2005). And lastly another indicator of nested systems of governance that provides a measurement of the compatibility of the legislations at the different scales and government sectors. The identifications of such disparities have to be addressed in order to either change them or select goals and strategies that recognize that such contradictions must be accommodated or resolved. Costa-Pierce & Page (2010) argue that planning and decision-making must recognize and analyze conditions, issues, and goals in the context of the next higher level of governance.

Finally, it is expected that the proposed indicator system, or any improvements and updates made, could help authorities to make relevant decisions, evaluate the progress towards mariculture sustainability. Furthermore, it aspires to guide producers towards more favorable scenarios, as well as inform consumers and the general population on the sustainability of current mariculture situation and effectiveness of regional and national policies. The outcomes of such an indicator system provides a better vision of the strengths and weaknesses on the process of sustainable development and supports policy making in accordance to the main and most urgent needs of society (Lu et al. 2016).

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"The changes taking place [on planet Earth] are, in fact, changes in the human-nature relationship. They are recent, they are profound, and many are accelerating. They are cascading through the Earth's environment in ways that are difficult to understand and often impossible to predict"

Costa-Pierce & Page (2010)

5. Discussion

Mariculture has all the requisites necessaries to form an effective sustainable development tool in the context of Integrated Coastal Zone Management. It can be implemented in most coastal areas, in different production scales, and including a growing variety of species. The improvement of governance process is the number one requirement for mariculture expansion and sustainability in Brazil. The inclusion of scientific knowledge in coastal policies will lead to an adequate management of natural resources and ecosystems integrated with the many uses of the coastal zone.

Under the light of the state of art of mariculture production in Brazil, some key issues have been identified. First of all, it became evident that mariculture is a promising sector to be developed, and poses solutions in promoting local development of local communities. Traditional (and often poor) coastal communities are the most vulnerable social sector to the negative impacts of overfishing (McCarthy et al. 2014; Cinner 2010; Díaz et al. 2006; Kent 1997) and, at the same time, also the most likely to provide the solution for food security through mariculture in Brazil (Kawarazuka & Béné 2010; Halwart 2003; Ahmed & Lorica 2002).

Given the lack of regulation, planning and management in general, what could be an important industry in Brazil is still an undeveloped sector that relies on artisanal methods in most cases, except for the case of the shrimp industry. Mariculture activities have grown spontaneously in all coastal states, mainly as consequence of local fishermen looking for an alternative source of income. The most widespread modality of mariculture is bivalve farming, given its simplicity and low investment needs. Yet, the occupation of the coastal and marine space was disordered and unplanned.

Shrimp farming is the most important mariculture subsector, which it is concentrated in the Northeast States. It is considered the most organized and consolidated aquaculture modality in Brazil (Suplicy 2013). Given the nature of the organisms farmed – technology-based, need of feed, post larvae distribution, etc. – it requires an organized production chain and higher investments. Also, the development of this subsector was the result of the engagement and incentives of government and private initiatives, which supported the farmers to develop the technology and methods to make it a viable business.

In Santa Catarina State, support from the regional government has opted in for mariculture as a key strategy for coastal sustainable development in small scale. The financial incentives, development of technologies and methods, distribution of seeds, support to marine research, implementation of policies to encourage mariculture market are singular in this state, and probably an example to be followed in the rest of the nation (Andrade 2016). The set of actions adopted in this state has given its fruits as reflected in the first place for mollusk producers in the country and the recognition of excellence in its mollusk production. Furthermore, it has resulted in diverse socioeconomic benefits (Suplicy et al. 2015), while its environmental impacts are considered acceptable (Rudorff et al. 2012; Netto and Valgas 2010; Costa & Nalesso 2006).

These two examples (shrimp farming in the Northeast and mollusk farming in Santa Catarina) show how important is the role of government, research institutions and private sector engagement in implementing a successful development strategy for mariculture production. The states of São Paulo and Rio de Janeiro have also entangled with mariculture promotion, through the Foundation Institute of Research of Rio de Janeiro (FIPERJ) and the Fishery Institute, respectively. Involvement of state authorities has resulted in a more organized and productive sector. In other regions, where mariculture developed without government intervention, the sector does not present distinctions, and mariculture remains as a supplementary activity, with little organization. In other words, results of this overview clearly show that the potential of mariculture development in Brazil is such of a goldmine, but it takes political will to facilitate the growth of the sector.

Several difficulties have been identified in the history of mariculture development, and while many have been overcome, there are still challenges to be faced. The technological barriers that once haunted producers were left behind (or are currently being experienced by the fish farming pioneers). Current uncertainties are related to legal issues, improved management and services to ensure adequate environmental interactions (in both directions) and improve product quality. Nevertheless, it seems that aquaculture-related authorities lack the integration tools needed to organize and plan certain development actions (Vianna et al. 2012; Ostrensky et al. 2008). Mariculture sector growth is of common interest. It is determinant that governmental authorities realize its potential and significance, and take actions to develop the policies and implement the regulatory background that already exist, but are very often not used.

The Fisheries and Aquaculture sector in Brazil has been marked with instabilities and unaccomplished promises (Ostrensky et al. 2008). The Ministry of Fisheries and Aquaculture was created and extinguished in a short period (2009-2015). Change of governmental leaders has changed priorities, and currently we observe an increasing negligence in the sector, reflected in the recent events involving the fisheries and aquaculture authorities at federal level.

Subasinghe et al. (2009) argues that the contribution of aquaculture to sustainable development depends on a government's commitment to support the sector by providing a clear articulation of policies, plans and strategies and the availability of adequate funding and capacity building for their implementation. In Brazil, mariculture and coastal management tools are compatible with the dynamics of the Integrated Coastal Zone Processess (Vianna et al. 2008), but in some cases, the weak implementation of these tools have received some critics (Ostrensky et al. 2008). Altough this situation may describe the general Brazilian reality, we observe positive efforts in this direction, mainly in the state of Santa Catarina.

Often, governments fail to promote an adequate basis for aquaculture development by shifting government development priorities. Furthermore, it is also relevant to consider the profile of the governmental institution which is in charge of aquaculture management. Whether aquaculture is considered under fisheries institutions or under agriculture and food production institutions in a specific Brazilian state seems to be related to the actual conditions and physical areas used by the aquaculture sector as well as to the orientation of the sector, and should promote the integration of aquaculture to other sectors /users of the coastal zones (Subasinghe et al. 2009). Considering these circunstancies, we are concern that Brazil may be entering an obscure phase for the aquaculture sector, since the management of the major aquaculture institution, such as the Secretary of Aquaculture and Fisheries, has been transferred to the Commerce and Industry ministerial authorities.

The outcomes of this research have emphasized the little interest that most regional national spheres have placed on the aquaculture sector, despite its potential to promote solutions for coastal development. In order to help address the current situation, and to provide a realible mechanism for the generation of relevant information that may attract authorities' attention to aquaculture, a multi-purpose tool has been defined to evaluate mariculture sustainability through an indicators system. This tool for the assessment of mariculture sector sustainable development may close the gap among science, policy and general public and may help bring together those societal groups. Aquaculture policy for sustainable development should definitely be scientific grounded. In this sense, while the indicators system helps promote sustainability of mariculture, it communicates the strengths and weaknesses of each situation to guide management and planning (Waas et al. 2014; Lu et al. 2016). At the same time it reveals administration gaps in order to prioritize actions. In addition, the "Multi-scale sustainability indicators system for mariculture assessment in Brazil" here proposed, is aligned with the Bellagio principles for sustainability assessment and measurement (STAMP). The Principles are recognized to provide guidance for the development and use of sustainability assessment tools (Pintér et al. 2012).

Internationally renowned indicators systems for assessment of aquaculture sustainability or coastal management corroborate the indicators system proposed in this thesis. Some assessment systems consider similar indicators from the four sustainability dimensions such as in the present work (FAO 2013; UNESCO 2006; UNESCO 2003). Still, others have not included the governance dimension as a keystone element of the indicators system (FOESA 2010; Consesus 2006). Nevertheless, the international community has supported the idea that aquaculture sustainability assessment is relevant. It may provide improved approaches for monitoring, evaluating and reporting on sustainability issues and management efforts progress and results (Reed et al. 2006). Indicators systems offer a comprehensive tool for the support of decisions regarding the context aquaculture is inserted in order to maintain the sustainability of the sector for the development of each region (Lu et al. 2016; Waas et al. 2014; Garnåsjordet 2012; UN 2007). Furthermore, they contribute to the communication of the benefits of supporting sustainable aquaculture in terms of food security and socioeconomic growth (UNESCO, 2006; Gallopin, 1997). Moreover it is recognized there is no recipe that works for everywhere. Each set of indicators or assessment systems are to be considered under the context it is focused on.

By relating the conclusions from the review of mariculture history and state of art in Brazil with the set of indicators selected to compose the sustainability assessment system, it is possible to identify trends. As an example, the indicators regarded under the "Economy" category, reflect the concerns and, some how, the anxieties, reported in several studies. It included debates on the farming of new species, or expansion of mariculture to other areas to promote economic development (Bezerra et al. 2016; Dotta et al. 2015; Faria & Plastino 2015; Brandini 2014; Domingues et al. 2014; Rebours et al. 2014; Lavander et al. 2013; Lopes et al. 2013; Sanches et al. 2013; Hayashi et al. 2011; Sampaio et al. 2011; Bezerra et al. 2010; Igarashi 2010; Krummenauer et al. 2010; Pellizzari et al. 2007; Krummenauer et al. 2006; Reis et al. 2006; Peixoto et al. 2003); associated farming systems (Sanches et al. 2014; Hayashi et al. 2011; Salles et al. 2010; Marinho-Soriano et al. 2009; Ramos et al. 2008; Yoshimura et al. 2006; Lombardi et al. 2006; Marinho-Soriano et al. 2002); certification schemes (Campello & Costa 2006); or even socioeconomic benefits of mariculture development (Barbieri et al. 2014; Araújo and Okino, 2009; Cavalli et al., 2008; Sampaio et al., 2008; Absher and Caldeira 2007; Martinelli and Freitas Junior, 2007; Nalesso and Barroso 2007; Sousa and Doxsey 2007; Vinatea et al., 2007; Costa and Sampaio, 2004).

Burbridge et al. (2001) emphasizes the importance of assessing economic contributions derived from mariculture in order to formulate adequate policies that support integrated and sustainable development of mariculture. Besides, the desirable social impacts deriving from economic development of mariculture are included in the policy goals for sustainable development (Grealis et al. 2017; Pereira & Rocha 2015). Bowen & Riley (2003) add that measuring socio-economic indicators of sustainability is useful in achieving Integrated Coastal Zone Management by aiding managers towards more informed decisions on prioritizing projects and revising strategic plans. Yet, it is important to highlight that economic incentives should not be the main factor driving aquaculture development. It has been observed that in regions where highly valuable species are farmed, mariculture expansion has grown rapidly, but with no regard to the environmental compatibilities (Ostrensky et al. 2008; Burbridge et al. 2001). Other aspects such as site characteristics ("vocation") and its conservation status, sociocultural aspects and sustainability in general are to be equally considered.

Similarly, diverse social aspects related to mariculture that came out by the review study presented in the first chapter were addressed and are incorporated in the indicators system proposed. The indicators system invites to a better perception of the impacts and interactions of mariculture. Indeed, a further understanding of the social impacts of mariculture on local employment, or consumption of mariculture products, or even on the quality of job generated will possibly lead to bringing light to the significance of mariculture to the society. Thus, it helps policy makers drive their actions towards promotion of mariculture development and optimizing management practices. Furthermore, inclusion and integration of the general public in mariculture has been recognized to promote empowerment and interconnections (Bremer et al. 2016; McKenzie 2004).

A deep consideration of the indicators proposed points out to interactions between the categories assessed. For instance, some of the economic indicators proposed encloses environmental benefits, such as the case of most consorted farming systems or certified products. It is well known how polyculture systems such as IMTA, minimizes most environmental impacts from aquaculture production (Chopin et al. 2010; Abreu et al. 2009; Chopin 2006). The adoption of certification schemes is no different, since it ensures more sustainable practices are adopted, while providing a high quality product (IUCN 2009). Moreover, adopting and revising farm management plans may have economic consequences (positive or negative) (Burbridge et al. 2001). Management plans for a process of learning and adaptation which allows producers to anticipate problems and take early action (Costa-Pierce & Page 2010). Often, a rapid profit-based management plan is related to a tendency towards resource overexploitation (Pereira & Rocha 2015), which will ultimately lead to future economic loss. Thus, it is interesting that the mariculture practices follow previously established directions, rather than “going with the flow”, with precarious control over the farming practices and its outcomes.

Most of the environmental indicators selected have been recognized by the scientific community to play an important role on mariculture development. Among the international community, issues related to residual farming water and wastes (Edwards 2015; Gondwe et al. 2012; Abreu et al. 2009; Nickell et al. 2009; Chopin et al. 2001); antibiotics (Cabello 2006; Nogueira-Lima et al. 2006; Kim et al. 2004; Tlusty et al. 2001); exotic species (FAO/NACA 2012; Naylor et al. 2000; Beveridge et al. 1997) and carrying capacity (Guyondet et al. 2010; McKindsey et al. 2006; Frakic & Hershner 2003) have been frequently regarded to play an important role on mariculture sustainability. In Brazil, however, other subjects, such as sanitation of farming waters (Brito et al. 2016; Neta et al. 2015; Ramos 2014; Parente et al. 2011; Vieira 2010; Rigotto 2010); seeds source (Barbieri et al. 2014; Lavander et al. 2013; Bordon et al. 2011, Gallon et al. 2011); coastal monitoring (Mafra et al. 2015; Galvão 2012; Silva et al. 2016; Yoshimine & Carreira 2012; Yoshimine et al. 2012; Curtius et al. 2003) and regulation of mariculture areas through Local Plans for Mariculture Development (PLDM) compliance (Suplicy et al. 2015; Vianna et al. 2012; Cavalli & Ferreira 2010; Ostrensky et al. 2008) were further considered as significant factors for mariculture sustainability.

It has been recognized that both mariculture practices and a solid regulatory mechanism can mitigate most of the negative environmental impacts. Currently, IMTA is considered one of the most environmentally adequate and smart farming systems (Chopin et al. 2010; Abreu et al. 2009; Soto 2009; Chopin 2006). In Brazil, polyculture farming systems of this type are still scarce. Besides the inexistence of official information, we were able to identify one farm system (Maricultura Costa Verde, in Rio de Janeiro) that integrates seaweeds, mollusk and cobia.

Regarding regulatory mechanisms, the most important tool for mariculture planning in Brazil, the PLDM, has been considered highly efficient (Andrade 2016; Suplicy et al. 2015; Vianna et al. 2012). Its significance relies on the integration of environmental data, Geographic Information Systems, and stakeholder engagement (among other characteristics). In this sense, it promotes integrated development, considering the multiple uses of the coastal and marine areas. It has been argued that stakeholder involvement in mariculture management is desirable and effective means of promoting equitable development (Burbridge et al. 2001). Moreover, adequate site selection is key in avoiding conflicts, and ensuring mariculture sustainability by optimizing resources and avoiding negative impacts (IUCN 2009).

Even though the concept of sustainability comprises the four dimensions mentioned in this document (environment, social, economy and governance), sustainability studies frequently consider only the environmental sphere (Garnåsjordet 2012; Costa-Pierce & Page 2010; Beveridge et al. 1997). More recently, authors have recommended the inclusion of social and economic aspects (Samuel-Fitwi et al. 2012; Valenti et al. 2011; Costa-Pierce 2010; Bowen & Riley 2003). And even less popularity has been given to the concept of governance. Yet, recognition of the role of governance in sustainable development has been progressively increasing (Hishamunda et al. 2015; Lazard et al. 2014; Kalfagianni & Pattberg 2013; Subasinghe et al. 2009). Robust governance systems allow adequate resource allocation at the same time it stimulates the industry and avoids environmental damage (Hishamunda et al. 2015).

Governance issues were not frequently regarded on the review study made on the first phase of this work. The set of indicators that compose the assessment system proposed in the thesis, equally have a smaller contribution to the evaluation of mariculture sustainability. The results of the evaluation of mariculture sustainability have brought attention to the necessity of complementing the indicators systems with more governance indicators, to include relevant issues for aquaculture sustainability. Assessment of stakeholder organization, harmonization of legislation at the different scales and inspection of mariculture activities may contribute to a broader overview of mariculture at the institutional level. It has become evident in this thesis that government (poor) involvement with aquaculture sector is the key factor for the progress and sustainable development of mariculture. The inclusion of such indicators approaches some concerns raised by Vianna et al. (2012) regarding the need for a better institutional integration; more overreaching and transparent participative processes; and higher administrative efficiency.

Overviewing the process and outcomes of the development and use of the indicators system presented in this thesis, it is relevant to add that such assessment systems must evolve to follow mariculture development. The system presented is to be used in an adaptive management context (figure 1). Its advantage relies on its proactive nature, rather than reactive (Costa-Pierce & Page 2010). Even though it requires flexibility and stakeholder engagement, it will also facilitate knowledge sharing between the community and researchers (Reed et al. 2006).

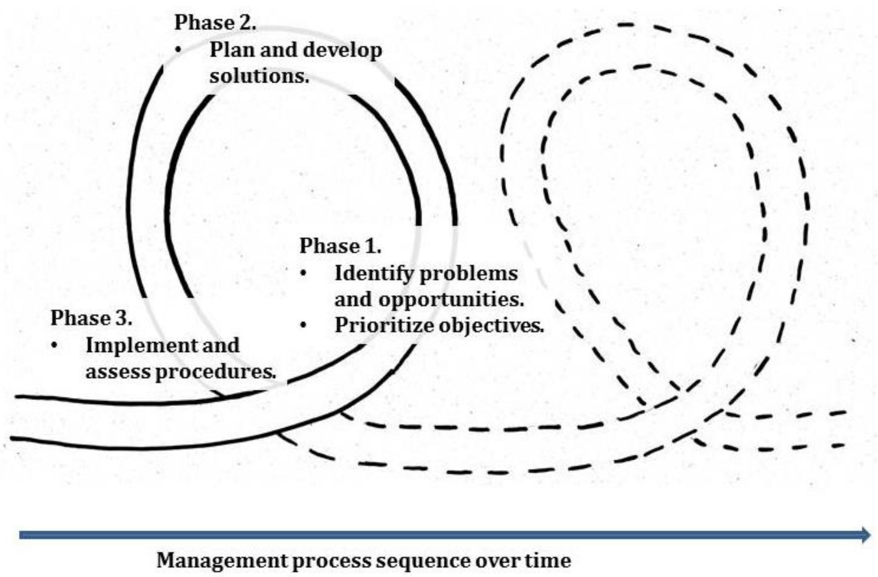

Figure 9. Phases of a simplified management process. Outcomes of each management phase feeds back to the following in a learning and adaptive process.

In sum, (Costa-Pierce & Page 2010) argue that a transparent, equitable and democratic approach combined with scientific knowledge are the basis for a successful and sustainable mariculture development. Sustainability management requires for linked cycles of identifying problems and objectives, planning, implementation and re-assessment. It approximates sectoral management to a holistic approach that considers interactions among sectors and ecosystems. The nature of the sustainability assessment system proposed in this work is coherent with the desired integrated, inclusive and adaptive approaches.

Periodic reevaluations, changes and adaptations to the indicators system proposed towards better fitting the new situations inherent to mariculture development, or inclusion of new insights in sustainability management are encouraged. Assessment systems are expected to mature following the evolution of human societies. In this sense, it will help fulfil the information gaps that obstruct the comprehension of the footprints from mariculture development, and inspire decision-makers into taking action.

Throughout this thesis, an overview of the mariculture development in Brazil has allowed to identify the main problems and opportunities related to the sustainability of the sector. In the second phase of the research, a methodology was developed in order to present one solution for the sustainability management of mariculture. Lastly, the solution proposed was evaluated and identified new issues that require attention. Phase 3 outcomes should be used to feedback the management loop. It is recommended that the presented results guide future studies to give continuity and improvement of the sustainability assessment of the mariculture sector.

Each member of society in the different scales and sectors play relevant roles that affect the world around us. Adoption of a holistic and integrative science-based management contemplates the interactions between society members among them and with the ecosystems within a long-term relationship. Applying the notions of sustainability science in aquaculture encourages the strengthening of such relationships (Costa-Pierce & Page 2010). It supports and promotes innovation and knowledge generation to achieve higher levels of sustainability.

Lastly, the ultimate challenge in achieving sustainability is by changing human behaviour. Kopnina (2017) states that an effective tool to promote behaviour transition is by educating about the differences between different levels of efficiency in sustainability models. It is hoped that this thesis contributes to reach this objective, and to help grow consciousness on how our actions and choices affect the world around us.

6. Conclusions

1- Brazil holds a great untapped potential for the development of several mariculture modalities along its 8000km coastlines and varied geographical diversity.

2- Mariculture has developed in Brazil in two mainstreams: shrimp farming, which poses a more structured and organized pattern; and bivalve culture, which has presented a lower level of organization, smaller-scale, and in many cases organized in familiar business.

3- In most cases, mariculture has expanded spontaneously throughout the coast, lacking planning and regularization.

4- Introduction of the White leg Pacific shrimp, and the Japanese oyster were cornerstones in the development of shrimp farming and mollusk farming in Brazil, respectively.

5- From an administrative point of view, mariculture policy has been reactive and insufficient. There are many gaps to be filled in order to achieve a higher efficient and integration of mariculture governance.

6- The development of coastal policies responded to the evolution of mariculture growth and expansion, shaping the goals and needs of the Integrated Coaztal Zone Management policies.

7- The creation of SEAP (Special Secretary of Aquaculture and Fisheries of the Republic Presidency) in 2003; the launching of PLDM (Local Plans for Mariculture Development) and PNGC (National Program for Coastal Management); and the creation and extinction of the Ministry of Fisheries and Aquaculture (from 2009 to 2015) were key moments for aquaculture development and organization.

8- Official data and statistics on mariculture production, methods, species, and socioeconomic status are, in most cases, deficient. Most of the information is inexistent, unspecific or unreliable.

9- An improved organization of the mariculture policies through the integration of sectoral institutional arrangements is crucial for supporting a more efficient sustainable development of the sector.

10- A significant interest from the academic sphere in the development of mariculture, reflected on the large number of scientific publications on new technologies, species, or innovative approaches for mariculture development.

11- This research provides a holistic overview of the mariculture sector regarding the environmental interactions, socioeconomic impacts, and policy analysis at national and, wherever possible, a regional levels.

12- Mariculture development management should be approached under an integrated management of natural resources and ecosystems, while also providing assets for social development.

13- The methodology used for preparing the indicators system is in line with scientific requirements, and the results are coherent with the main international initiatives regarding coastal management and aquaculture sustainability assessments (FAO 2013; Ehler 2014; FAO, 2013; Mathé et al., 2010; FOESA 2010; DEDUCE Consortium 2007; Consensus, 2006; UNESCO 2006; OECD 1993).

14- The final indicators system generated in the research is composed of 29 indicators of the different sustainability dimensions: environmental (10); economy (7); social (6); governance (4), arranged differently to assess the different scales of the mariculture sector. The farm scale system comprises 19 indicators. The regional scale system consists of 16 indicators, while the national scale system is constituted by 12 indicators.

15- The contribution of the proposed mariculture sustainability assessment tool is that it responds to the Brazilian reality, comprising all mariculture modalities, and includes indicators related to management activities.

16- Assessment of implementation and effectiveness of management and policies at the different scales facilitates the development of solutions at the level of the incumbent authority.

17- Sustainability of the mariculture sector in Brazil was considered overall "Very low", responding to lack of information availability and poor political commitment to the mariculture sector.

18- The state of Santa Catarina presented "Low" sustainability of the mariculture sector, although it scored "Very high" in the Governance category.

19- Sustainability of mariculture at the farm level was considered "Low" at farm #2, and "Average" at farms #1 and #3. There is much room for improvement regarding farm management and organization.

20- A very important dimension for mariculture sustainability is Governance. Improved governance will reflect in the improvement of sustainability at the other dimensions.

21- Other governance indicators are recommended to cover inspection, social organization and legislation compatibilities.

22- The "Multi-scale sustainability indicators system for mariculture assessment in Brazil" should be periodically updated according to the evolving situation of the mariculture sector and sustainability requirements.

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