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"Pathways for sustainable industrial fisheries in southeastern and southern Brazil"
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Preface

Pathways for sustainable industrial fisheries in southeastern and southern Brazil

"… *most of us never imagined that many of the questions that we would be asked would not even be about fish at all but would, instead, be about the behavior of people (fishers)*."

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BACKGROUND

Marine organisms have been a source of food for Brazilian coastal communities since pre-historical times. Spread along the nearly 8,500 km-long coastline, and in association with numerous coastal systems (*i.e*., coastal lagoons, estuaries, mangrove systems), these communities have historically developed diverse small-scale artisanal fisheries that at present sustain a significant proportion of the country's capture fishing production. Another comparable proportion of this production is attributed to the national's 'fishing industry', developed from the 1960's onwards, and concentrated on the northern and southern extremes of Brazilian coast (Paiva, 1997).

The onset of this development was motivated by the availability of a few productive and/or valued pelagic (*i.e.*, Brazilian sardine, *Sardinella brasiliensis*) and demersal resources (*i.e.*, pink shrimps, *Farfantepenaeus* spp., and sciaenid fish) over mostly shallow continental shelf areas. It also relied on the establishment of a legal framework, *i.e.*, a first decree to regulate explicitly fishing activity in Brazilian waters, and a program of incentives to promote the necessary fleet and processing structure expansion and technological improvement (Dias Neto, 2010). Throughout the 1970-80's fishing vessels built and equipped to operate offshore (Fig. 1) a) established an unprecedented exploitation regime of the most productive marine ecosystems of the country's Economical Exclusive Zone, and b) produced an increasing volume of captured seafood products, inserting them in both national and international markets. After a peak in 1985, when nearly 500,000 ton were landed, economic and social benefits started to decrease as the fishing industry experienced a general loss of productivity driven mostly by sharp declines on the abundance of the main target-stocks (mean annual catches decreased to 220,000 ton in the 1990's) (Freire *et al.*, 2015).

That scenario pushed Brazilian fisheries into a new development phase characterized by the rise of conservation policies that promoted profound changes in both economic incentives and biological management of existing fisheries (Dias Neto, 2010). These in turn responded to the limited abundance of targeted stocks and stringent regulations by changing their fishing behavior and diversifying their activities. In 2001, a new breadth of mostly demersal resources, fishing methods, fishing areas and métiers redefined the industrial fisheries operating off the southeastern and southern sectors of Brazilian coast (Perez *et al*., 2001). The emerging fishing patterns naturally required changes of the management system in place to cope with their additional and specific population and ecosystem impacts. Such a response, however, was minimal, as the whole system would remain mostly rooted in the historically important target-stocks (*e.g*., shrimps and sardine). In contrast, fishing authorities launched between 2000 and 2008 an on-going oil subsidy policy, which further supported both managed and unmanaged emerging fishing operations, and sponsored the assessment and development of deep-sea fishing poten-

Figure 1. A traditional pink shrimp trawler operating on the continental shelf off southeastern and southern Brazil (upper photo) and trawling for deep-sea shrimps (lower photo), one of the many new industrial fishing activities developed in the region mostly after 2000.

tialities as an alternative for the overcapitalized coastal fleet (Abdallah & Sumaila, 2007). The latter not only proved unpromising, but also added new components to the "chaotic" scenario of fishing development and management (Haimovici *et al*., 2009; Perez *et al*., 2009). Attempts to change licensing system and prohibit the capture of certain endangered species were implemented after 2011, but these turned out to be highly debated and little effective management actions (Pezzuto & Mastella-Benincá, 2015).

A synthesis of the industrial fishing development in recent years could argue, therefore, that the fishing industry has gradually shown the capacity to adapt and find new paths to achieve economic viability of their operations. Scientists, in turn, have accumulated a long record of biological data of mostly commercial species and a few stock assessments that have generally alerted for limited fishing expansion opportunities and imminent overfishing scenarios (*e.g.,* MMA, 2006). Fishing authorities failed to establish timely reforms to the fisheries management system, but responded to the changing industrial fishing activities with a series of short-term measures, mostly conservation-oriented, which have more often enhanced conflicts than promoted stable (and sustainable) fishing regimes. Added to the country's general political instability, this scenario has allowed no room for predictions about the future of the fishing industry of southeastern and southern Brazil, including new shifts that could point towards globally desired standards of ecological and economic sustainability.

Undoubtedly, such a desired transformation relies largely on political decision-making, particularly on how to manage/restore natural stocks to biological, ecological and economical sustainable states. Nonetheless it has become clear that science should have a supporting role in such a process, by not only providing sound assessments and predictions (Walters & Mantell, 2004), but also developing tools and methods to observe and analyze more efficiently (and less costly) the fishery system and all its components, from the biological, ecological, economic and social perspectives. These were convictions that motivated, in 2009, the conception of a research program named IGEPESCA ("Innovation and Interdisciplinarity applied to Management and Sustainable Development of the Marine Fishing Industry of the Southeastern and Southern Regions of Brazil") with the objectives of updating the current knowledge on industrial fisheries operating off southeastern and southern Brazil, their current resources and ecological impacts, and identifying innovative solutions applicable to fishing development and management. This five-year initiative involved two research institutions of Brazil (Universidade do Vale do Itajaí and Instituto de Pesca de São Paulo) and one from Chile (Escuela de Ciencias del Mar, Pontificia Universidad Católica de Valparaíso), with support of a major industrial fisheries association (Sindicato dos Armadores e das Indústrias de Pesca de Itajaí e Região) and research funds mostly provided by CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Ministry of Education of Brazil - call for proposals in Marine Sciences 09/2009). This volume compiles a series of 20 selected papers that summarize the main results obtained by research activities under IGEPESCA, which point at opportunities regarding the future of the national's most important seafood producing industry.

WHAT WE HAVE LEARNED

As a comprehensive analysis of scientific efforts promoted by IGEPESCA, in this opening paper we highlight five important lessons that emerged from the studies here presented.

I. Observed fishing operations can provide unending opportunities to study commercial stocks, fisheries-related communities and ecosystem processes, and human impacts

In all the developing world, costs of offshore marine research have historically hampered the capacity to produce fisheries-related *in situ* studies, such as direct stock and ecosystem impact assessments. It has also limited the understanding of oceanographic processes and distribution of essential habitats functionally linked to key fishing resources, as well as other components of marine communities. In a perspective of the increasing establishment of ecosystem-based management systems, these may represent important knowledge gaps (Pikitch *et al*., 2004). In Brazil, whereas extremely valuable, offshore surveys have been erratic and determined by the uncertain availability of research vessels and resources to meet their elevated operational costs (see Haimovici, 2007 for review). More importantly, because there has been no permanent government-funded survey program, future assessments are not predictable and constrain the demands for knowledge of the continuously changing marine environments and fishery enterprises.

In 2001, an operational 'observers' program was established in the country and proved a low-cost solution for increasing the capacity to produce data relevant to stocks and fisheries assessments and to test the efficiency of technical management measures. In IGEPESCA we asked what types of information could observers produce during commercial fishing operations, in addition to those related to fishing effort, fishing areas and catches. We further asked how sampling biases introduced by the fishers profit-oriented spatial strategies could be overcome as to make catch and effort data, for example, comparable to those obtained by scientific survey sampling designs.

The development of portable sampling technology readily deployed/ operated from fishing vessels proved a promising solution to collect large volumes of environmental data during fishing operations. A Towed Oceanographic Vehicle (VOR) was developed in the early phases of IGEPESCA (Faccin *et al*., 2014) and subsequently improved to act as a "continuous plankton recorder" at the same time it records physical and chemical data of the pelagic system (Tamanaha *et al*., 2016; Cunha & Resgalla Jr., 2016). Similarly a steel tube-like 'bottom sediment sampler' attached to the ground rope of bottom trawls was shown to produce sediment and benthic community samples during commercial trawls for demersal stocks (Almeida *et al*., 2016). In both cases, samples of pelagic and benthic communities a) were quantitative and comparable to those obtained by samplers commonly used during scientific surveys and b) represented, along with geological, chemical and physical data, environmental settings directly related to fish production. Their regular use in commercial fishing operations could significantly increase the country's capacity to produce oceanographic data and fill in important gaps regarding the understanding of fishery-related ecosystem processes, as previously noted.

Improvement of such understanding, however, derives from a subsequent analysis of the data obtained at sea, which can be biased due to the spatial and temporal distribution of samples, as driven by fishermen strategies to access areas of fish concentration. Sant´Ana and Perez (2016) addressed this problem exploring density records, as obtained by commercial trawl operations, to estimate total biomass of three slope fish stocks: blackfin goosefish (*Lophius gastrophysus*), hake (*Merluccius hubbsi*) and the codling (*Urophycis mystacea*). By using geostatistical models to expand mean densities to the stocks' distribution area, they defined important conditions to obtain robust abundance estimates at low cost and on a potentially regular basis.

Finally, the performance/effectiveness of management measures can also be tested in observed commercial fishing operations, as demonstrated by the study of Schroeder *et al*. (2016) addressing the long implemented but little complied use of a 'turtle excluding device' (TED) during shrimp trawling operations.

II. Fishing fleets change their foraging behavior and catch technology, adjust to changing ecological, market-oriented and legal scenarios and accumulate ecosystem impacts in space and time

One of the overarching goals of IGEPESCA was to document, characterize and understand both causes and consequences of the patterns of change of the industrial fisheries off southeastern and southern Brazil. In part, addressing this goal would allow the redefinition of realistic 'fisheries' (or fishing métiers) that in turn could help to delimit more effective 'management units'. It would also allow predictions about future responses of fishing fleets to changes on stocks availability and management measures, including their impacts on marine ecosystems.

The identification of fishing métiers were the primary focus of three studies that analyzed the dynamics of bottom trawl and gillnet fisheries on the shelf and slope off southeastern and southern Brazil (Corrêa & Ávila-da-Silva, 2016; Dias & Perez, 2016;

Pio *et al*., 2016a). Together, they provided a valuable empirical basis to disentangle complex multifleet arrangements formed to explore multiple demersal resources at variable areas and seasons, and to build a realistic view of "who-where-when-how many" actually explore different fish and shellfish stocks. In their study, Dias & Perez (2016) also differentiated "generalist" from "specialist" slope trawlers and discussed a mechanism whereby the latter can be formed and affected by the former. Trawlers (double-rig) were further described with regards to their physical characteristics and, most importantly, to the structure and operating patterns of the used nets (Queirolo *et al*., 2016a). A similar study was conducted on gillnetters (Queirolo *et al.*, 2016b), but in this one selectivity patterns of the whitemouth croaker (*Micropogonias furnieri*) were differentiated among specific nets employed. Combined, these five studies demonstrated a) how Brazilian fishers have gradually adjusted their foraging behavior to either access greater diversity of targets or optimize catches of a preferred one, and b) the extent to which such a process has been accompanied by structural modifications on the fishing gear.

What drives fishers to change towards a specific new fishing pattern and how these choices become economically viable are critical questions that need to be addressed to improve general understanding of fishing dynamics and responses to different management strategies. In that sense, Martinez-Musoles *et al*. (2016) proposed that value, as determined by the chemical composition of different species' edible flesh, has actually driven the development of specialized slope trawl fishing off Brazil. Rolim & Ávila-da-Silva (2016) have shown that industrial trawlers experienced income reductions and changed their fishing behavior and targets in response to spatial management measures (*i.e*., regulations associated to a Marine Protected Area). Additionally, Pio *et al.* (2016b) demons-trated that three gillnet fisheries (*i.e*., directed at whitemouth croaker, blackfin goosefish and codling, respectively) have been operating in a fragile economic and financial performance, which could only margi-nally improve if submitted to management actions involving reductions on the length of the fishing sets. These are all exciting examples of how much understanding on fisheries is gained by studying fishers behavior, constraints and preferences, that may improve the capacity to make predictions about future trends and impact of management regimes.

Changes in fishing behavior also tend to produce changes in the spatial patterns of accumulated ecosystem impacts. That message developed from two studies that analyzed both pelagic and demersal fisheries (Imoto *et al*., 2016) and specifically bottom trawlers (Port *et al*., 2016a). Whereas a clear dimension of such impacts in the communities and habitats is still a major knowledge gap, both studies highlighted areas more/ less intensely used throughout the year. The first highlighted the concentration of fishing effort in shallow waters and its importance to generate jobs. The latter provided estimates of spatial footprints historically established by trawlers and an index of 'area swept' that may become useful as a proxy for benthic habitat disturbance. Early in IGEPESCA development, this approach was also used to estimate regional levels of oil consumption and greenhouse gas emissions of the trawling fleet (Port *et al*., 2016b).

III. Addressing key unknown population processes can disentangle old management constraints

Research efforts in support of industrial fisheries have long concentrated in describing life-history patterns and population processes of targeted fish and shellfish species (*e.g.*, MMA, 2006). These efforts have provided empirical data for some of the most persistent management strategies, *i.e.*, fishing closures and size limits. Yet for some economically important species, key biological aspects have remained unknown, hampering the improvement of management measures.

That is the case of the whitemouth croaker, which has been the single most productive demersal resource in the region and shared by several fleets (Valentini & Pezzuto, 2006). The species is exploited in northern Argentina, Uruguay and along the entire southeastern and southern coast of Brazil where, despite the availability of pressing scientific evidences, no stock structure-derived management units has been formally adopted or influenced management in the region. Haimovici *et al*. (2016) synthetized results obtained during a bottom trawl survey and proposed three geographical management units in the shared waters of Argentinian and Uruguayan waters, southern Brazil and southeastern Brazil, respectively.

Similarly, management of Brazil's most abundant pelagic stock, the Brazilian sardine, has been based on a long-standing fishing closure regime (Dias-Neto & Dias, 2015). During the closed seasons, however, the numerous purse seine fleet produces significant catches of at least three unmanaged small pelagic fish species (*Opisthonema oglinum*, C*hloroscombrus chrysurus* and *Scomber japonicus*). Petermann & Schwingel (2016) analyzed both individual and population patterns of sexual maturation of these species, revealing the extent to which they could biologically benefit from the same management measures to which the Brazilian sardine is submitted annually, in support of an eventual multispecies management regime.

IV. Fish waste is valuable and can represent alternatives to improve fishing profit and reduce the environmental cost of fishing

Profit opportunities (*i.e.*, when total incomes exceed the costs of fishing operations) ultimately drive the development of commercial fisheries (Sethi *et al*., 2010). Increased abundance of target stocks may increase profits because elevated catches (*i.e*., income) can be obtained with less effort (*i.e.*, costs). Economic subsidies to fishers attenuate costs and produce a similar economic impact because profits tend to increase even if catches do not. In overfishing scenarios, when abundance is generally low, only the latter seems possible, although with catastrophic consequences to already fragile natural stocks (UNEP, 2004). In such circumstances, aggregating value to catches emerge as one alternative solution to maintain or increase total fishing income while harvesting less fish.

One way of raising the value of the catch is by developing technological products from a number of body parts that are seldom used for human consumption and normally comprise the fishing industry waste. As part of IGEPESCA work plan, Amorim *et al*. (2016) and Wosniak *et al*. (2016) extracted protein hydrolysates from viscera, heads and carcasses of the most important fishing resources of Brazil, the Brazilian sardine and the whitemouth croaker. These were not only shown to be of acceptable quality but in fact, Wosniak *et al*. (2016) demonstrated that they could be successfully used as food in catfish farms of southern Brazil. While preliminary in nature, these studies represent innovative solutions to the fishing industry crisis of southeastern and southern Brazil, where fish waste can reach sizeable proportions.

V. Existent descriptive data of fisheries dynamics and modern data processing tools may pave the path to remodeling Brazil´s fishing management system

IGEPESCA has contributed to an improved diagnosis of the current state of industrial fisheries off south-eastern and southern Brazil. Yet results have only reinforced the notion that current management regimes no longer support the extreme levels of complexity, as revealed by the diversity of species shared by multiple fleets in overlapping areas and seasons. Because, in such a scenario, species and/or fisheries tend to have a poor performance as ‘management units’, spatial management (Gilliland & Laffoley, 2008; Crowder & Norse, 2008) emerge as a promising concept to sustain a desired reform of the country’s management system.

The study by Rosso & Pezzuto (2016) close the series of IGEPESCA collected papers by providing an example of how diverse geo-referenced data of fishing dynamics, combined with habitat descriptors, can be used to discriminate ecologically- and economically-sound areas which could act as spatial management units. This is a pilot study that requires improvement in spatial coverage and detail. Yet it provides a new framework for restructuring the industrial fishing management in Brazil harmonized with other national’s marine spatial planning initiatives.

THE WAY AHEAD

IGEPESCA clarified current complexities of the fishing industry and proved concepts that demonstrate the importance of the interdisciplinary approach to study fisheries comprehensively. Particularly meaningful concepts involved:

a) amplifying the use of technology to observe fisheries and the marine environment on board fishing vessels,

b) understanding human processes that either maintain fishing patterns or force their changes,

c) developing fish products and uses that increase earnings with less fishing mortality, and

d) combining interdisciplinary data to delimit spatial management units.

These concepts are not new to fishery science but definitely less commonly addressed by national scientists who have largely focused in fisheries biological aspects. Studies under IGEPESCA evidence that expanding our knowledge on the human and ecosystem aspects related to fishing activity is possible and worthwhile. It can improve understanding and may represent a promising pathway for science to help building a new, and hopefully sustainable, phase of the Brazilian fishing industry.

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