

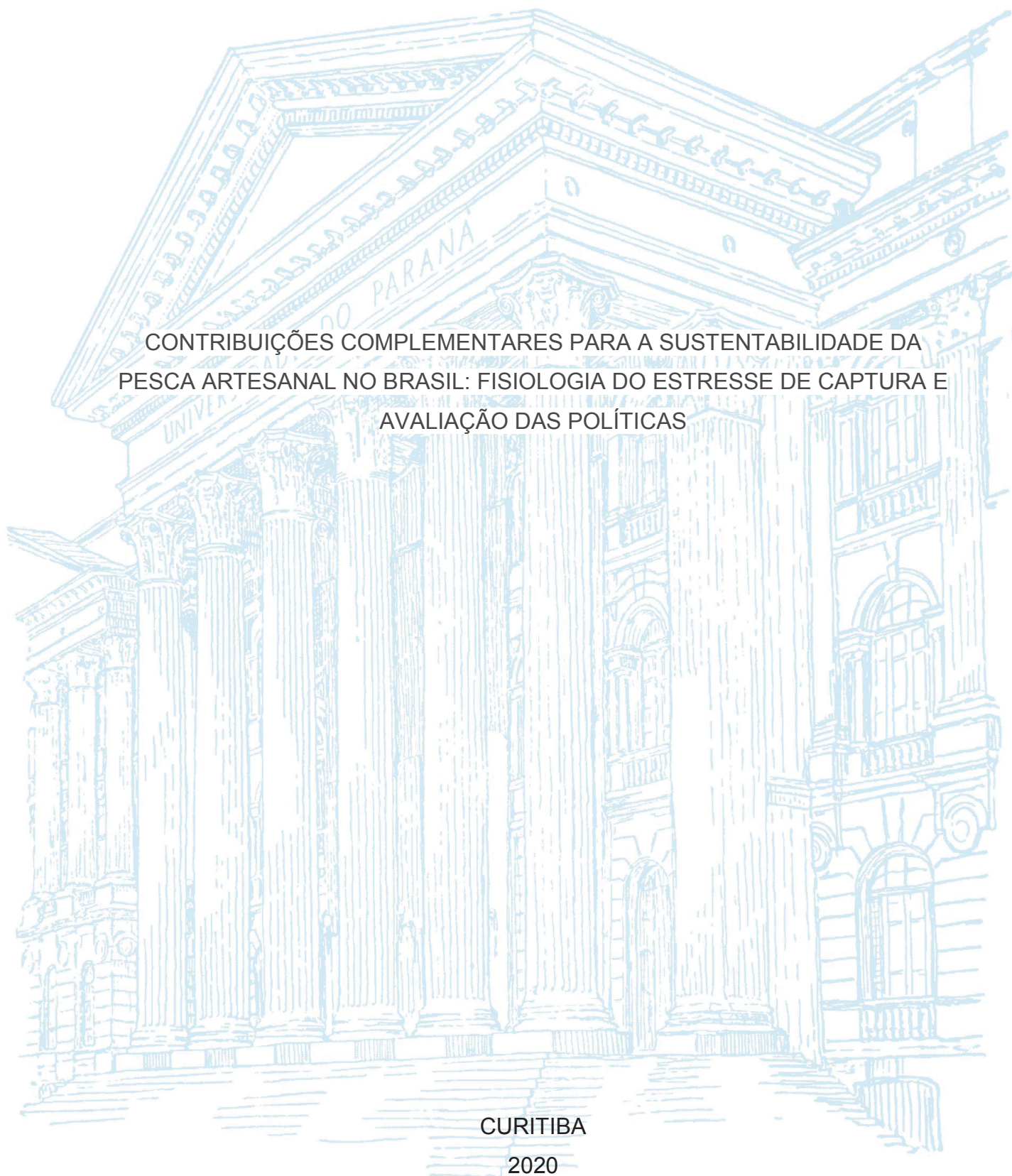
UNIVERSIDADE FEDERAL DO PARANÁ

DALIANA BORDIN

CONTRIBUIÇÕES COMPLEMENTARES PARA A SUSTENTABILIDADE DA  
PESCA ARTESANAL NO BRASIL: FISIOLOGIA DO ESTRESSE DE CAPTURA E  
AVALIAÇÃO DAS POLÍTICAS

CURITIBA

2020



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PESCA ARTESANAL NO BRASIL: FISIOLOGIA DO ESTRESSE DE CAPTURA E  
AVALIAÇÃO DAS POLÍTICAS

Tese apresentada ao curso de Pós-Graduação em  
Zoologia, Setor de Ciências Biológicas,  
Universidade Federal do Paraná, como requisito  
parcial à obtenção do título de Doutor em  
Zoologia.

Orientadora: Profa. Dra. Carolina Arruda de  
Oliveira Freire

Coorientadora: Profa. Dra. Flávia Duarte Ferraz  
Sampaio

CURITIBA

2020

Universidade Federal do Paraná. Sistema de Bibliotecas.  
Biblioteca de Ciências Biológicas.  
(Rosilei Vilas Boas – CRB/9-939).

Bordin, Daliana.

Contribuições complementares para a sustentabilidade da pesca artesanal no Brasil : fisiologia do estresse de captura e avaliação das políticas. / Daliana Bordin. – Curitiba, 2020.  
138 f. : il.

Orientadora: Carolina Arruda de Oliveira Freire.

Coorientadora: Flávia Duarte Ferraz Sampaio.

Tese (Doutorado) – Universidade Federal do Paraná, Setor de Ciências Biológicas. Programa de Pós-Graduação em Zoologia.

1. Pesca - Pesquisa. 2. Pesca artesanal. 3. Pesca de arrastão. 4. Pescaria marinha. 5. Política pública. 6. Peixe – Efeito do estresse. I. Título. II. Freire, Carolina Arruda de Oliveira. III. Sampaio, Flávia Duarte Ferraz. IV. Universidade Federal do Paraná. Setor de Ciências Biológicas. Programa de Pós-Graduação em Zoologia.

CDD (20.ed.) 639.2



MINISTÉRIO DA EDUCAÇÃO  
SETOR DE CIÊNCIAS BIOLÓGICAS  
UNIVERSIDADE FEDERAL DO PARANÁ  
PRÓ-REITORIA DE PESQUISA E PÓS-GRADUAÇÃO  
PROGRAMA DE PÓS-GRADUAÇÃO ZOOLOGIA -  
40001016008P4

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Os membros da Banca Examinadora designada pelo Colegiado do Programa de Pós-Graduação em ZOOLOGIA da Universidade Federal do Paraná foram convocados para realizar a arguição da tese de Doutorado de DALIANA BORDIN intitulada: **CONTRIBUIÇÕES COMPLEMENTARES PARA A SUSTENTABILIDADE DA PÊSCA ARTESANAL NO BRASIL: FISIOLOGIA DO ESTRESSE DE CAPTURA E AVALIAÇÃO DAS POLÍTICAS**, sob orientação da Profa. Dra. CAROLINA ARRUDA DE OLIVEIRA FREIRE, que após terem inquirido a aluna e realizada a avaliação do trabalho, são de parecer pela sua APROVAÇÃO no rito de defesa.

A outorga do título de doutor está sujeita à homologação pelo colegiado, ao atendimento de todas as indicações e correções solicitadas pela banca e ao pleno atendimento das demandas regimentais do Programa de Pós-Graduação.

CURITIBA, 11 de Março de 2020.

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06/04/2020 15:39:36.0

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08/04/2020 08:08:45.0

NATÁLIA TAVARES DE AZEVEDO

Avallador Externo (UNIVERSIDADE FEDERAL DO PARANÁ)

“Dedico esta tese ao meu pai Sérgio Augusto Fernandes Bordin (in memoriam), grande entusiasta das pescarias. Quem me ensinou a pescar com linha, vara, rede, fisga e covo. Quem me ensinou a colocar a isca no anzol e limpar o peixe. Quem despertou a minha paixão por peixes e pesca. Se você estivesse aqui hoje, com toda certeza minha base de dados seria bem maior”!

## AGRADECIMENTOS

Agradeço a Deus por guiar e oportunizar.

Agradeço à minha Mãe, Miriam Seleme Bordin, ao meu irmão Fernando Seleme Bordin, à minha cunhada e amiga Mayara Sakr e ao Seu Adriano Sakr pelo simples fato de serem e de estarem. Obrigada (também) por entenderem a minha ausência, por me “segurar”, me incentivar e me compreender nos momentos caóticos inerentes à minha vida e escolhas conturbadas! Vocês são luz. São a minha essência e minha razão.

À minha orientadora, professora Dr. Carolina Arruda Freire, primeiro por ter sido receptiva ao meu primeiro contato quando nem estava no Brasil. E depois, por ter aceitado o desafio de me orientar no final do primeiro ano. Agradeço pelos intermináveis ensinamentos consequentes desta experiência... Agradeço por ter insistido tantas e tantas vezes em mim, por ter me incentivado a lutar, a buscar, a conhecer e a resolver. Agradeço pelas inúmeras tentativas de projetos e parcerias. Agradeço por compartilhar seus princípios. Agradeço por ter me oportunizado ir ao Chile e à Noruega! (sem palavras...). Tenho muito orgulho de ter passado por sua orientação e compartilhado momentos com Você. Você é, sem dúvidas um exemplo de profissional e de mulher per se. A área científica estaria bem mais “otimista” se todos tivessem a oportunidade de compartilhar de sua experiência. Fico na esperança de mais pessoas como Você nas academias.

À minha Co-Orientadora, professora Dr. Flávia Duarte Ferraz Sampaio, por ser um exemplo de força e superação. Por carregar um entusiasmo que eu não sei descrever, pelas sempre divertidas reuniões e pelos desabafos.

Aos queridos Pescadores Seu Giovani, Seu Hilário, Seu Airton e Dona Maria, Seu Gerson e família (Jaqueline e Andreza) que possibilitaram a realização deste estudo, que compartilharam e compartilharam. Já sinto saudades!

Aos não-pescadores que me ajudaram diretamente no desenrolar das coletas, desde o contato com pescadores (Sr. Secretário da Pesca de SFS; Prof. Dr. Marta Cremer, Fabiano, Giovanna) e, durante as pescarias (Cristiane Collazo), Anelise (por toda a disposição em me ajudar a resolver problemas logísticos em São Chico), Bel Basílio (por me ceder mais eppendorfs!).

À Rita, Neuza e toda a equipe do Hostel da Ilha em São Francisco do Sul, por permitirem que eu fizesse uma pequena extensão do laboratório no hostel e por toda disposição e ajuda.

Aos meus tios Joice Seleme e Casemiro Mota por se orgulharem.

À toda equipe LFCO (Alexssandro, Aline, Deivyson, Ísis, Natasha, Renata, prof. Dr. Viviane Prodocimo), em especial à Nicole, Leo, André e Natália pelos bons momentos e toda ajuda no laboratório.

Ao Marcelo Borges pelos momentos divertidos e por ter me ajudado nas análises multivariadas.

Ao Professor Dr. Emygdio Monteiro por ter sido luz em tempos difíceis. Por, assim como minha orientadora, se preocupar com o aprendizado e formação do aluno. Agradeço também por seu brilho no olho enquanto fala sobre contextos biológicos.

Aos demais professores que contribuíram de formas diferenciadas com o desenvolvimento deste trabalho, Luís Fernando Fávaro, André Padial, Márcio Pie, Fabiano Bendhack, Paulo de Tarso Chaves, Vinicius Abilhôa, Viviane Prodocimo, Rosana Rocha.

Aos professores Dr. Luís Fernando Fávaro, Dr. Natália Tavares de Azevedo, Dr. Renata Guimarães Moreira pelas recomendações de melhora na pré-tese e pelo aceite em participar da banca.

Ao professor Dr. Piero Calosi, pelas inúmeras tentativas e pelos inúmeros documentos preparados a fim de me ajudar a realizar estágio no exterior.

À toda equipe NTNU, em especial as pessoas do departamento de Biologia. Lars Gansel e Vera, Birgitte e família, Stig e família, Ann-Kristin, Anne Stene, Anne Ulla, Cecilie, Ernestine, Grette, Helene, Janna, Kristine, Linda, Max, Ola, Sahar, Tove, Yanhan. Agradeço por todo acolhimento, disposição, hospitalidade e bons momentos.

Ao Henrique Gaspar da NTNU por ser tão amigável, por ter me apresentado a outros brasileiros, por ter me ajudado em aplicações e questões logísticas, e por ter melhorado o desempenho do meu computador em tempos de extrema necessidade.

Ao prof. Dr. José Maria de Souza da Conceição, pelos 5 anos de parceria entre graduação e mestrado e por sempre me considerar em seus variados projetos. Se hoje eu tenho autonomia para fazer as coletas e identificar os peixes é porque você passou horas e horas por dia no laboratório me ensinando como fazer e com toda a paciência do mundo! As contagens de escamas, rastros braquiais, raios de nadadeiras, os padrões de pigmentação, as proporções... Obrigada por acreditar e valorizar o papel das mulheres na ciência!

Aos amigos Ti, Léo, Cris, Drika, Camila, Julian, Laís, Bruna, Larissa, Roger, Jé e Barbs, de contextos diferentes, mas pelo mesmo propósito da amizade.

Aos professores da Phill Young que foram tão gentis e dispostos a me ajudar com a questão do teste de proficiência.

À Dona Iolanda e toda família que me trouxeram um pouco de carinho e acolhida em Curitiba, quando longe dos meus.

Aos funcionários da UFPR, em especial Vanessa, Denise, Tina, Paula e Fabiane.

Ao Jobim e Bob (por terem me escolhido como “humano-tutor”), Kira e Akasha por carregarem a essência da pureza e fidelidade e serem as melhores companhias e os melhores confidentes!

Ao Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq pela concessão da bolsa de doutorado.

Agradeço aos desafios da vida.

“Por que foi que cegamos, Não sei, talvez um dia se chegue a conhecer a razão, Queres que te diga o que penso, Diz, Penso que não cegamos, penso que estamos cegos, Cegos que vêem, Cegos que, vendo, não vêem” (Saramago, 1995 – Ensaio sobre a cegueira).

## RESUMO

Medidas de estresse fisiológico têm o potencial de contribuir na identificação e avaliação de desafios complexos na conservação da vida selvagem e podem informar decisões de manejo e/ou políticas, além de auxiliar na seleção de espécies nativas adequadas para a aquicultura. Nesse sentido, a geração e análise de dados em fisiologia e pesca é útil e urgente, a fim de enriquecer a base de conhecimentos sobre a fisiologia do estresse de espécies selvagens. Assim, este estudo foi dividido em dois capítulos, bastante distintos em sua abordagem, sendo complementares em sua contribuição para a questão da exploração de recursos pesqueiros costeiros no Brasil e sua sustentabilidade. Foi ainda acrescentado um Apêndice, relatório sobre o estágio realizado na Universidade Norueguesa de Ciência e Tecnologia (NTNU), de Novembro de 2019 a Fevereiro de 2020. O primeiro capítulo apresenta, com base em marcadores de estresse fisiológico, a variabilidade na resposta de 35 espécies de peixes marinhos selvagens ao estresse de captura por arrasto, a partir de amostragem aleatória. E o segundo capítulo consiste em uma abordagem teórica das políticas públicas relacionadas à pesca em pequena escala no Brasil, chamada de “pesca artesanal”. No Capítulo 1, foi evidenciada a enorme variabilidade na resposta ao cortisol entre as espécies, sendo possível detectar espécies com respostas altas, intermediárias e baixas após o mesmo estressor, com algumas espécies mostrando notável variação intraespecífica. A variabilidade interespecífica, diante de um mesmo fator estressor, também esteve presente nos demais parâmetros avaliados, glicose plasmática, osmolalidade, íons cloreto e magnésio. O que nos permitiu distinguir diferentes habilidades de resposta ao estresse: (i) espécies que responderam com elevados níveis de cortisol e magnésio; (ii) espécies que responderam com baixos/intermediários níveis de cortisol e mantiveram manutenção do balanço osmoiônico, e (iii) espécies que apresentaram quebra da homeostasia. Desta foram, este capítulo revelou alguns padrões de respostas ao estresse agudo ainda não reportados para espécies de peixes marinhos silvestres coletados no Sul do Brasil. No capítulo 2, descrevemos o histórico do cenário político da pesca em pequena escala no Brasil e fornecemos algumas ferramentas e recomendações baseadas em experiências positivas de outras nações, visando à sustentabilidade desta atividade no país. Essas sugestões buscam contribuir para a recuperação ou conservação de estoques naturais e fornecer políticas mais adequadas para a população humana envolvida na pesca em pequena escala no Brasil e em outros países em desenvolvimento. É assim complementar à abordagem fisiológica da (ainda) enorme diversidade de recursos disponíveis na extensa costa brasileira. O Apêndice ilustra as impressões de um breve convívio e experiência na nação mais desenvolvida no mundo em relação à exploração em escala industrial e de máxima tecnologia de um recurso costeiro: a aquicultura do salmão do Atlântico na Noruega. Esta Tese representa assim uma contribuição para a conservação da diversidade de recursos pesqueiros marinhos costeiros no Brasil, sob duas perspectivas. A primeira aponta para a urgência de se conhecer mais a fisiologia de espécies nativas e disponíveis para eventual exploração em cultivo de pequena ou larga escala no Brasil, e a segunda aponta para a necessidade de maior eficiência jurídica e, em consequência, de gestão dos recursos, para extrativismo e/ou cultivo.

Palavras-chave: Estresse de captura. Peixes marinhos selvagens. Pesca artesanal.

## ABSTRACT

Physiological stress measures have the potential to contribute to the identification and assessment of complex challenges in wildlife conservation and can inform management and / or policy decisions, in addition to assisting in the selection of native species suitable for aquaculture. In this sense, the generation and analysis of data in physiology and fisheries is useful and urgent, in order to enrich the knowledge base on the physiology of stress in wild species. Thus, this study was divided into two chapters, quite distinct in their approach, being complementary in their contribution to the question of the exploitation of coastal fishing resources in Brazil and their sustainability. An Appendix was also added, a report on the internship carried out at the Norwegian University of Science and Technology (NTNU), from November 2019 to February 2020. The first chapter presents, based on markers of physiological stress, the variability in the response of 35 species of wild marine fishes to trawling stress from random sampling. And the second chapter consists of a theoretical approach to public policies related to small scale fishing in Brazil, called "artisanal fishing". In Chapter 1, the enormous variability in the response to cortisol between species was evidenced, being possible to detect species with high, intermediate and low responses after the same stressor, with some species showing remarkable intraspecific variation. Interspecific variability, given the same stressor, was also present in the other parameters evaluated, plasma glucose, osmolality, chloride and magnesium ions. This allowed us to distinguish different stress response skills: (i) species that responded with high levels of cortisol and magnesium; (ii) species that responded with low / intermediate levels of cortisol and maintained maintenance of the osmoionic balance, and (iii) species that presented breakdown of homeostasis. As such, this chapter revealed some patterns of responses to acute stress that have not yet been reported for wild marine fish species collected in southern Brazil. In chapter 2, we describe the history of the political landscape of small-scale fishing in Brazil and provide some tools and recommendations based on positive experiences from other nations, aiming at the sustainability of this activity in the country. These suggestions seek to contribute to the recovery or conservation of natural stocks and to provide more appropriate policies for the human population involved in small-scale fishing in Brazil and other developing countries. It is thus complementary to the physiological approach of the (still) enormous diversity of resources available on the extensive Brazilian coast. The Appendix illustrates the impressions of a brief coexistence and experience in the most developed nation in the world in relation to exploitation on an industrial scale and with the maximum technology of a coastal resource: the aquaculture of Atlantic salmon in Norway. This Thesis thus represents a contribution to the conservation of the diversity of coastal marine fishing resources in Brazil, from two perspectives. The first points to the urgency of knowing more about the physiology of native and available species for possible exploitation in small or large scale cultivation in Brazil, and the second points to the need for greater legal efficiency and, consequently, resource management, for extractivism and/or cultivation.

Keywords: Capture stress. Wild marine fishes. Artisanal fishing

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## LISTA DE ABREVIATURAS OU SIGLAS

ACTH	- Adrenocorticotropic hormone
AVT	- Arginine vasotocin
BSC	- Brain-Sympathetic-Chromaffin Cell
CEPENE	- National Center for Research and Conservation of Marine Biodiversity in the Northeast
CEPERG	- Estuarine and Lagoon Fisheries Research and Management Center
CEPNOR	- Research Center and Management of Fisheries Resources of the North Coast
CEPSUL	- National Center for Research and Conservation of Marine Biodiversity in the Southeast and South
CODEPE	- Fisheries Development Council
CORT	- Cortisol
CRF	- Corticotropin releasing hormone
CTGP	- Technical Commission for Shared Management of Fisheries Resources
DAP	- Department of Fisheries and Aquaculture, linked to the Ministry of Agriculture, Livestock and Supply
DPA	- Department of Fisheries and Aquaculture, linked to MAPA
DPAQ	- Department of Fisheries and Aquaculture, linked to IBAMA
HPI	- Hypothalamc-Pituitary-Interrenal Axis
IBGE	- Brazilian Institute of Geography and Statistics
ICMBio	- Chico Mendes Institute for Biodiversity Conservation
MAPA	- Ministry of Agriculture, Livestock and Supply
MDIC	- Ministry of Industry, Foreign Trade and Services
MMA	- Ministry of the Environment
MPA	- Ministry of Fisheries and Aquaculture
PMP-BS	- Santos Basin Beach Monitoring Project
PREPS	- National Satellite Vessel Tracking Program
PROZEE	- Foundation for Support to Research of Living Resources in the Exclusive Economic Zone
RGP	- General Fisheries Register

- SAP/MAPA - Secretariat of Aquaculture and Fisheries of the Ministry of Agriculture, Livestock and Supply
- SEAP/PR - Special Secretariat of Aquaculture and Fisheries of the Presidency of the Republic
- SEMA - Special Secretariat for the Environment
- SINPESQ - National Fisheries and Aquaculture Information System
- SISRGP - General Fishing Activity Registry System
- SUDEPE - Fisheries Development Superintendence

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## PROLOGUE

### 1. Concerning factors (stressors) that motivated this study

There are several interferences that lead to the reduction of economic performance in marine fishing, such as overfishing, anthropogenic climate change, pollution and habitat degradation (Friedman et al., 2020; Madliger et al., 2017; Cooke et al., 2013; Sumaila et al., 2011; Roessig et al., 2004; Jackson et al., 2001). Although evidence of unsustainability in fisheries is historical and global (Pauly et al., 2002; Jackson et al., 2001), the use of top-down policies is still recurrent in many nations (Worm et al., 2009), including Brazil (Haimovici et al., 2014), in which the increase in fishing-fleet and subsidies by governments to fishers is continuous (Palomares & Pauly, 2019; Schuhbauer et al., 2017; Caddy & Seijo, 2005).

It is well established that the anthropogenic interference in the abiotic environment affects the physiology of organisms at various levels (Seebacher & Franklin, 2012), which is problematic, given the current level of anthropogenically mediated fast environmental changes (Cooke et al., 2013). Environmental factors that disturb the animal's physiology are also called stressors. And stressors can act synergistically. An environmental factor that does not represent a stressor when experienced alone can become a stressor when experienced in combination with another factor (Pörtner, 2005). This interaction can represent an example of the effects of the so called allostatic load, in which the costs of maintaining a response to a stressor can compromise the body's ability to deal with an additional stressor (Schulte, 2014). An allostatic state is a consequence of regulation of the internal medium, in which there is "stability through change". The internal state departs from the "normal homeostatic state", and, according to the intensity and duration of the stressor, the animal will either achieve and remain in an allostatic state, or else will achieve an allostatic load (see Schulte, 2014, and references). The strongest the allostatic load in intensity and duration, of course, the highest the probability that organismal death will ensue, and in terms of populations and species, extinction risk will be more likely. The physiology of stress is an adequate and timely approach to marine fisheries in general, and coastal marine teleost fisheries, in particular.

Whether the adaptation of fish populations, globally, will be able to keep pace with future changes in environmental conditions is an important open research question. The tolerance and resilience of populations can happen within the scope of

phenotypic plasticity, including changes in behavioral, acclimation and acclimatization mechanisms, and transgenerational and evolutionary adaptations (e.g., Koenigstein et al., 2016). The effects of climate change at the population level can also act synergistically with the impacts of human exploitation, since intense fishing pressure can lead to a reduction in the size of ripening and a greater sensitivity to environmental fluctuations in the exploited stocks (Koenigstein et al., 2016).

Anthropogenic disturbances and climate change are expected to have a global impact on ecosystems, societies and economies, increasing pressure on livelihoods and food supplies, including those in the fisheries and aquaculture sector. Food quality will play a more important role, as food resources will be under greater pressure and the availability and access to fish supplies will become an increasingly critical development problem (Daw et al., 2009).

## 2. Consequence for fish and fishermen

The various negative effects mentioned above, when combined, will have adverse impacts on the already overexploited resource, thus reducing fish biodiversity and production. Depletion of stocks and reduced fish production can threaten the livelihoods of many vulnerable fishing communities and food security globally, especially in developing tropical nations (Mohammed & Uraguchi, 2013). Changes in biodiversity and the carrying capacity of ecosystems, changes in the distribution and abundance of organisms and physiological stress (Beaugrand et al., 2008) are also examples of these effects.

The geographical redistribution of natural resources alters access and, thus, the harvesting (capture) opportunities between countries. Fish resources shared at the international level can be sensitive to changes in the marine environment and this can have a major impact on the economies of countries and regions that depend more on fisheries to provide employment and food supply (Jansen et al., 2016). Responses to these environmental drivers, for example through changes in productivity and spatial distribution, will co-determine the future development of fish and fishery stocks (Perry et al., 2005).

Examples of consequences (positive and negative) in the redistribution of fish species are increasingly evident in the literature, in several places and with several

species, such as *Gadus morhua* in the North Atlantic (Holt & Jørgensen, 2014) and the Barents Sea (Wiedmann et al., 2014), *Scomber scombrus* in the Northeast Atlantic (Jansen et al., 2016), *Isacia conceptionis*, *Paralabrax humeralis*, *Mugil cephalus*, *Sciaena deliciosa*, *Stellifer minor* in Peru (Adams & Flores, 2016); reef fish in Australia's great coral reef (Cheal et al., 2017), and for *Thunnus alalunga* in the Northern Pacific Ocean (Christian & Holmes, 2016). Changes in the distribution and abundance of shallow water fish on the southeastern Brazilian coast were observed in Sepetiba Bay, Rio de Janeiro. These changes were different between fish species, with species with increased populations (*Anchoa lyolepis*, *Anchoa tricolor*, *Harengula clupeola*, and *Sardinella brasiliensis*), Species with decreased populations (*Anchoa marinii*, *Anchoviella brevirostris*, *Anchoviella lepidentostole*, and *Lycengraulis grossidens*), and species that showed changes in distribution patterns (*Achirus lineatus*, *Ctenogobius boleosoma*, *Haemulopsis corvinaeformis*, *Genidens barbatus*, *Platanichthys platana*, *Boridia grossidens*, and *Trachinotus falcatus*) (Araújo et al., 2018).

Maximum capture rates are expected to decrease globally by 7.7% in 2050, compared to the year 2000. And the global fishery revenue is expected to decrease by 10.4%, that is to say, around 35% in relation to the impact on maximum capture rates in high CO<sub>2</sub> emission scenarios (Lam et al., 2016). Knowing the possible changes in the distribution and structure of marine communities is a scientific and economically important concern, because in addition to causing ecological damage, changes in distribution patterns can cause severe changes in fishing activities.

### 3. Stress response

Under these constant environmental and human pressures, animals need to find ways to deal with challenges in order to confront and overcome them, to guarantee their survival. Environmental challenges or anthropogenic disorders can trigger the activation of the vertebrate neuroendocrine axis that generally results in the release of stress hormones, such as catecholamines and corticosteroids. The stress response is often described as the group of adaptive physiological responses to an aversive extrinsic stimulus (a stressor) that helps restore the internal level of homeostasis (or allostasis) after exposure to the aversive stimulus (Dantzer et al., 2014; Sapolsky et al. 2000). When the stressor is generally chronic, the stress

response loses its adaptive significance, with deleterious consequences for fitness of the species (Schoenle et al., 2018).

When the individual perceives the stressor, a series of reactions is initiated, triggering physiological and behavioral processes at primary, secondary and tertiary levels, in response to the activation of the Hypothalamic-Pituitary-Interrenal cascade (Mazeaud et al., 1977). Primary responses are related to the increase in the concentration of corticosteroids and catecholamines and changes in the activity of neurotransmitters. Secondary responses involve metabolic changes, cellular changes, osmoregulatory disorders, changes in hematological factors, and changes in immune function. Tertiary responses involve changes in the animal's performance (such as growth, swimming capacity, resistance to disease and reproduction) and changes in behavioral patterns (such as feeding and aggression) (Barton, 2002). It is possible to assess stress at the three levels mentioned above, from different biomarkers (Figure 1).

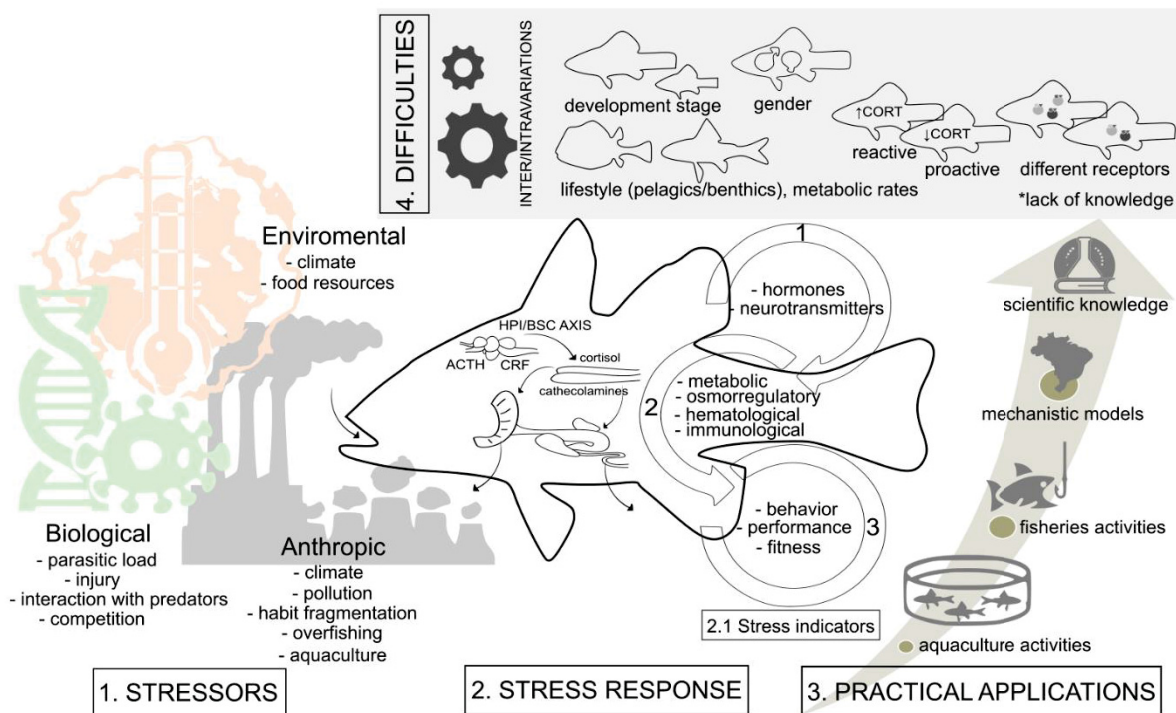


Figure 1. Background of the stress physiology in fish: 1. types of stressors; 2. Mechanisms of response to stress and main indicators of stress (2.1); 3. Examples of practical applications in the use of these tools, and 4. Main difficulties related to the study of physiological stress measures. \*HPI = Hypothalamic-Pituitary-Interrenal Axis, BSC = Brain-Sympathetic-Chromaffin Cell, ACTH = Adrenocorticotrophic hormone, CRF = Corticotropin releasing hormone, CORT = cortisol (Author).

#### 4. Conservation physiology and its applications

Conservation physiology is an integrative scientific discipline, which uses mechanisms, approaches, tools and physiological principles to elucidate conservation problems. This concept is based on how environmental disturbances and threatening processes affect physiological responses and, consequently, ecological function, population resilience and species survival (Seebacher & Franklin, 2012; Cooke et al., 2013; Madliger et al., 2017).

Physiological analyzes, in particular measures of physiological stress, have the potential to contribute in the identification and assessment of complex challenges in wildlife conservation and management (Baker et al., 2013). Physiological research in wild populations provides basic data, allows the monitoring of populations' overtime, enables the rapid evaluation of various natural and anthropogenic pressures, elucidates causal mechanisms and facilitates the assessment of the effectiveness of targeted actions (Baker et al., 2013).

By providing measurable traits, conservation physiology allows limits (i.e. thresholds) to be quantified where conditions may destabilize populations (e.g. through reductions in fitness), species, communities or ecosystems, thus allowing for proactive management within quantitative ranges (Madliger et al., 2017). From an applied perspective, measuring stress is necessary to determine how the health, performance, and welfare of fishes are being influenced by interactions with humans (Sopinka et al., 2016). Linking evolutionary and ecological underpinnings of stress with measures of stress relevant to industry and conservation practitioners can guide management strategies that effectively take into account fish biology, and facets of human livelihood and culture (Sopinka et al., 2015).

There are several examples of applications of stress measures, such as in the fishing and release activities (Schlenker et al., 2016), assesment of the sensitivity of bycatch species (McLean et al., 2016), evaluation of physiological requirements and limitations of species as a potential for aquaculture activities (Froehlich et al., 2016; Barnett & Pankhurst, 1998; Fevolden et al., 1991), determination of which species currently live closer to their upper thermal tolerance limits, which physiological systems establish these limits and how species differ in capacities for acclimatization to modify their thermal tolerances (Somero, 2010), and also incorporation of physiological data in mechanistic models to determine how natural and

anthropogenic stressors can affect organisms (Birnie-Gauvin et al., 2017; McKenzie et al., 2016), to name a few examples (Figure 2).

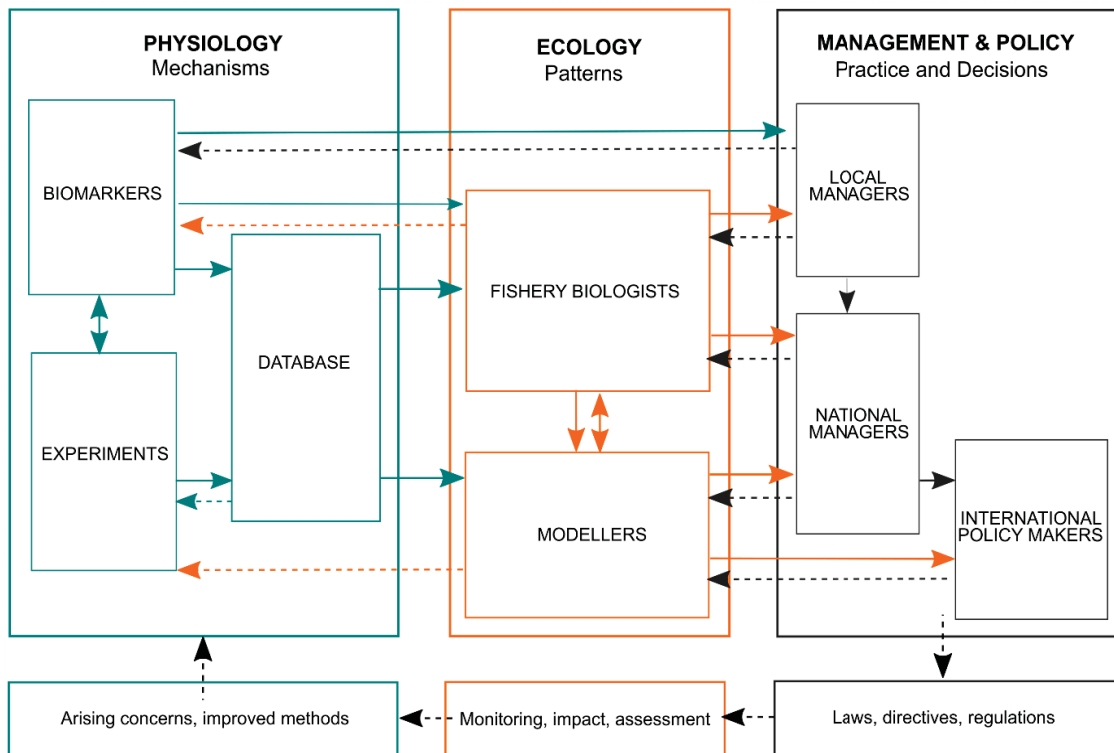


Figure 2. Flow diagram of how physiological information can inform management and/or policy decisions (continuous lines) for marine fishes, and how analysis of the information can be feedback to develop targeted research activities (dotted lines). Biomarker information can be used directly for local management (in particular, early warning and evaluation of ecological status). Physiological information can also influence national and international management/policy indirectly, by interactions with ecologists; for example, biomarkers of bycatch survival to inform fishery biologists, or physiological databases for use in modelling of population dynamics or effects of global change. The number of dotted lines feeding back to physiology reveal the many contributions that physiological research could make to adaptive management programmes, including large-scale and long-term research in response to, for example, EU or Intergovernmental Panel on Climate Change recommendations (Taken from McKenzie et al., 2016, modified).

## 5. Main challenges in implementing these measures

Ecological, biological, and methodological factors must be considered when selecting, measuring, and interpreting stress indicators. Inter- and intraspecific, gender, life stage, different coping styles and other differences in physiological responses to stressors can confuse confirmation of a stressed state (Madliger et al., 2018; Sopinka et al., 2016; Busch & Hayward, 2009). In addition, although there are >30,000 species of fish, knowledge about marine fish is confined to dozens of species, which occur in countries with research communities developed in the field of fish ecophysiology, with a focus on species that are economically or ecologically important and/or are relatively easy to obtain and keep in captivity (McKenzie et al.,

2016; Pankhurst, 2011). It is recognized that studies on captive or laboratory fish, due to domestication and acclimation processes, may mask overall variation in the vertebrate neuroendocrine response (Raulo & Dantzer, 2018; Balasch & Tort, 2019).

The assess to the vertebrate's population health in conservation studies increased considerably from 1993 to 2013 and has been done through assess the physiological response of animals to environmental disruptions from various biomarkers, immunity markers (64%), glucocorticoids (31%), and markers of oxidative status (5%) (Beaulieu & Constantini, 2014). Stress physiology corresponds to 45% of studies published in 'Conservation Physiology' between 2013–2018, and the fish group taxonomic corresponds only to 11% of the total number of studies on this topic (Madliger et al. 2018) (Figure 3).

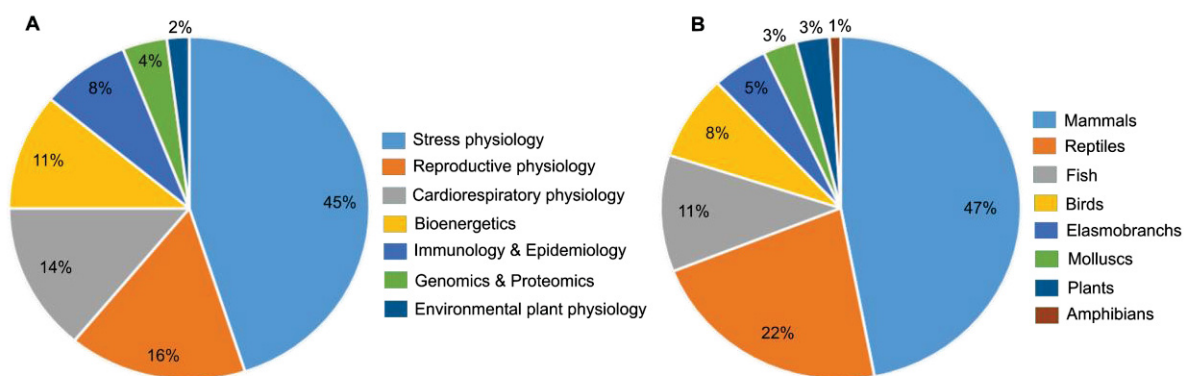


Figure 3. Subject area of the 73 papers published in 'Conservation Physiology' in the past 5 years (2013–18) based on: (A) physiological sub-discipline and (B) taxonomic group. Note: Fish includes all bony and cartilaginous fish aside from those that are elasmobranchs, which are featured as a separate category (the figures were taken from Madliger et al. 2018, modified).

In a quick search for studies published in journal in Latin America, from Scielo database (<https://www.scielo.org/>), the theme "cortisol in fish" is present in 61 articles between the years 2001-2019, of which only 8% refer to studies with wild species. In addition, although the data below corresponds only to a cut of the total number of available publications, almost all of the studies refer to the development of knowledge to improve aquaculture activities (Figure 4A), as in the use of various anesthetic substances to reduce transport stress, for example, with an emphasis on freshwater species (Figure 4B), mainly the Nile tilapia.

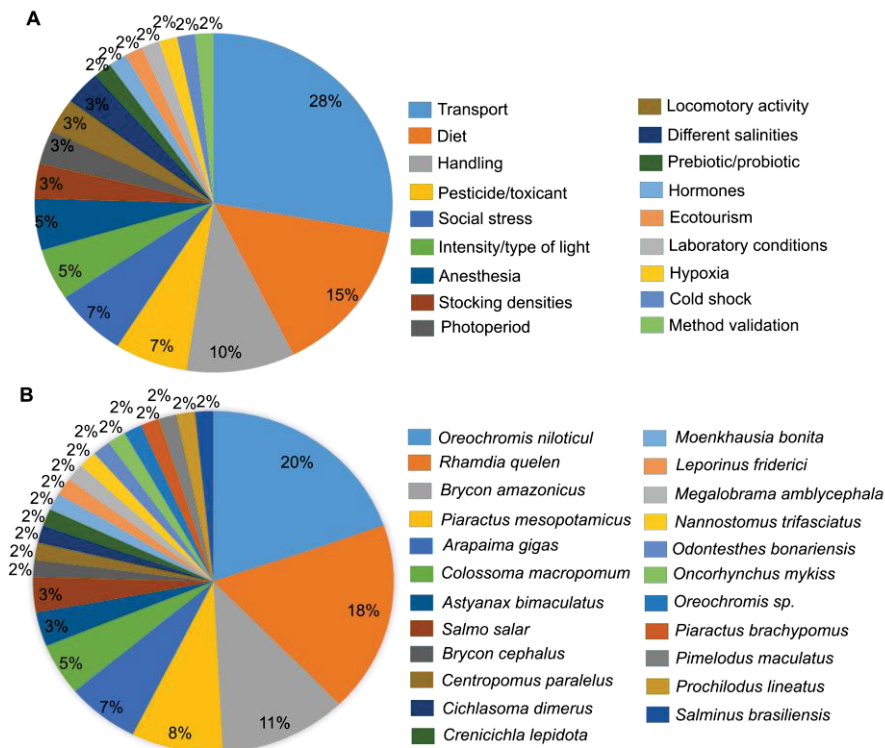


Figure 4. Focus of 61 papers found in Scielo database in the past 18 years (2001-19), on fishes. The research was done in February 2020 by using and entering the following keywords: (i) “cortisol” (ii) “fish”. (A) physiological sub-discipline and (B) species.

In this sense, the generation and analysis of data both in ecophysiology and fisheries is useful and urgent in order to enrich the knowledge base on the stress physiology of wild species. A more complete evaluation of the stress response to fishing, contemplating natural biodiversity in coastal marine teleosts, contributes both to the development of more reasonable fisheries policies and the selection of adequate native species for aquaculture. Thus, this study was divided into two chapters, and an appendix. The chapters were written in the form of a scientific article and with the format referring to the journals in which they will be submitted. The appendix is presented as a result of the internship held at the Norwegian University of Science and Technology (NTNU) in Norway, between November/2019 and February/2020.

**Chapter 1:** The first chapter presents, based on markers of physiological stress, the variability in the response of wild marine fish to the capture stress through trawling, from random sampling.

**Chapter 2:** The second chapter consists of a theoretical approach to public policies related to small scale fishing in Brazil. In this chapter, some historical and current aspects related to small-scale fishing (production data by extractive fishing, status of fishing statistics, historical changes in management entities and/or fishing related) will be reviewed in order to propose measures to improve these gaps.

**Appendix:** This final section presents the internship report from my stay at the Norwegian University of Science and Technology - NTNU (Campus Ålesund), between the period of 21 November 2019 and 18 February 2020. It illustrates the valuable experience of visiting an aquaculture facility of the leading nation on large scale aquaculture technology and production.

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**CHAPTER 1: VARIABILITY IN THE ACUTE STRESS RESPONSE TO CAPTURE THROUGH TRAWLING IN SUBTROPICAL SOUTHERN COASTAL MARINE TELEOSTS<sup>1</sup>**

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<sup>1</sup> Chapter formatted according to Marine Biology journal standards.

# **<sup>1</sup> VARIABILITY IN THE ACUTE STRESS RESPONSE TO CAPTURE THROUGH TRAWLING IN SUBTROPICAL SOUTHERN COASTAL MARINE TELEOSTS**

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**Running Head:** Variable cortisol response in coastal marine teleosts

## **Abstract**

The relevance of the plasma cortisol response as primary stress marker in teleosts is established. However, the concept that very low levels of cortisol are associated to the absence of a stressful conditions needs to be revisited. Moreover, most data refer to a handful of species. In order to improve the data base of the cortisol response in wild coastal marine teleosts, this study aimed at evaluating the response - survival and plasma cortisol, glucose, osmolality and plasma ions - of marine teleosts to the capture stress of trawling. Fish sampled were divided into 3 groups: dead after trawling (DT), alive after trawling (LT), and live fish that were kept for ~ 12h in a tank after trawling (OT). Blood samples (224) from 35 species out of 19 fish families have been assayed. A large variability in the cortisol response between species, within the 3 groups, was found, with high (>1000 ng/mL), low (nearly zero) and intermediate (10-1000 ng/mL) responses to cortisol being detected, and some species showing remarkable intraspecific variation. Inter-specific variability was also present in plasma glucose, osmolality and ions. This study revealed that one should not expect uniformity in the teleost stress response; the HPI axis regulatory strategies of coastal marine fish species is remarkably variable, when equally challenged through beach trawling.

**Keywords:** allostasis, glucocorticoids, physiological plasticity, stress physiology

## **1. Introduction**

The stress response is considered to be an adaptive mechanism that allows fish to deal with real or perceived stressors, in order to assure the preservation of their homeostatic

state (Barton 2002). In the short term, this response is considered adaptive because it initiates a set of physiological and behavioral responses that promote the survival of the individual (Wingfield et al. 1998; Sapolsky et al. 2000). Hormones play key roles in the stress response. The adrenocortical response to acute stress results in the release of glucocorticoids by the activation of the hypothalamic-pituitary-interrenal axis – HPI, in what generally constitutes the primary stress response (Mommsen et al. 1999), a pivotal hormonal axis that regulates daily metabolic needs as well as behavioral responses to environmental disturbances (Wingfield 2013). This way, the stress response with the activation of the HPI axis may naturally influence the fitness of a species (Schoenle et al. 2018). Activation of the HPI axis means elevated plasma cortisol, increase in plasma glucose by increased glycogenolysis, and osmoregulatory disturbances, these latter being in general related to the secondary stress response (Mommsen et al. 1999). Upon prolonged activation of the stress response, the so called tertiary responses ensue, with reproductive and immunological consequences, and thus, reduced fitness (Busch and Hayward 2009).

The evaluation of glucocorticoid levels raised great interest between the 1960s and 1970s (Bouck 1966; Donaldson and Dye 1975; Fryer 1975; Mazeaud et al. 1977). Years of study led to the production of a vast literature, recognizing an undisputed role of cortisol as a marker of stressful conditions for teleost fishes (e.g., see Mommsen et al. 1999). However, interpretations of circulating levels of glucocorticoids/cortisol in marine teleosts still remain complex (Busch and Hayward 2009; Beaulieu and Constantini 2014; Kalamarz-Kubiak 2018). Recent wildlife investigations have revealed patterns of hormonal responses to environmental, physical, and social changes, which could not have been predicted from laboratory experiments (Ajó et al. 2018; Currylow et al. 2018; Wingfield 2018). Simple 'linear' stress paradigms explored in laboratory contexts are unable to contemplate the inherent variability of the much more complex social (Goymann and Wingfield 2004) physiological and physical interactions that occur in the natural environment (Pankhurst 2011).

New insights into the use of glucocorticoids in wildlife understanding have been proposed (Sopinka et al. 2015; Madliger et al. 2018), contrary to previous paradigms that the stress response could not really be contemplated in nature, due to influences from biotic and abiotic traits inherent to the species, and the additional difficulty in obtaining "non-stressed" individuals. After much debate on how to apply an experimental "stressor" in the field, it was concluded that the animals response to capture, management and containment could be applied equally to all species and would properly reflect the individual's ability to respond to an acute stressor (Wingfield 2018). A consensus was reached that, if a blood sample is collected as soon as possible after capture (~3 min), then the plasma cortisol concentration in this sample at least approximately represents the baseline levels. Subsequent samples, after 5, 10, 30 and 60 minutes, for example, would properly represent the rate of increase

and the maximum levels of cortisol obtained after acute stress (Wingfield 2018). Given that the way an animal responds to a short-term stressor may reflect its long-term ability to adapt to a changing environment in the face of diseases, anthropic disturbances, and increasingly scarce resources (Currylow et al. 2018), it is essential to improve our knowledge about the response to stress in wild fish.

Knowledge on marine fishes is confined to tens of species, which occur in countries with developed fish ecophysiology research communities. Within these countries, there is a focus on species that are economically or ecologically important and/or are relatively easy to obtain and maintain in captivity. These include temperate species, such as Atlantic cod (*Gadus morhua*), Atlantic salmon (*Salmo salar*), Dover sole (*Solea solea*), European sea bass (*Dicentrarchus labrax*), Pacific salmonids of the genus *Oncorhynchus* or turbot (*Scophthalmus maximus*), plus various tropical species from the Great Barrier Reef (Mackenzie et al. 2016).

In this context, the objectives of the study were: (i) to evaluate the response of coastal marine fishes of several different families to capture stress, through the evaluation of cortisol, glucose, osmolality, and plasma ions; and (ii) to compare the level of the adrenocorticotrophic response between fish that died from the trawling stress, fish that were recovered alive from the trawling net, and a third group, fish that were alive after trawling and were kept for ~12 h in a seawater tank.

## **2. Material and methods**

### **(a) Fish trawling and blood sampling**

Fishes were obtained on the shallow platform coast of Paraná (25° 35'20.96 "S and 48° 21'53.20" O) and Santa Catarina States (26° 18'38 "S and 48° 52'76" W), in Southern Brazil, between April 2017 and July 2018. In these places, two types of trawling were carried out - sandy beach trawling in the morning (500 m long and 4 cm mesh size), and - outrigger trawling (10 m long and 3 cm of mesh size in the codend) in the night. Trawl times were similar between the fishing gears (30-45min), with the longest times being related to the greater amount of fish in the beach trawl, mainly to the mullet catching seasons. Immediately after sandy beach capture, fish were grouped into: dead fish after trawling (DT) or live fish after trawling (LT), and blood samples were collected by caudal puncture using heparinized syringes. Fish that were alive after trawling meant fish that were still showing opercular and caudal contractions when removed from the net. The third group, comprising a different treatment of the fishes (named OT - fish kept overnight in tank), consisted of bycatch individuals collected from a small shrimp trawler (outrigger trawler) and kept overnight, in a

confinement fisherman tank, under constant flow of marine water. Fish chosen for this distinct treatment were fish that were alive after the shrimp trawling and were in good condition. The addition of this treatment was done to check if it is possible for the fish to recover pre-stress levels after this period of time. After ~12h, fish were anesthetized in benzocaine (60 mg/L) until showing loss of balance (2-3 min), and blood samples were collected by caudal puncture with heparinized syringes. After blood collection, samples were centrifuged in a microcentrifuge (2,100 rpm for 5 min). Plasma was pipetted out and frozen at -20 °C for later analysis in the Laboratory of Comparative Physiology of Osmoregulation, Federal University of Paraná in Curitiba, Paraná. At the time of blood withdrawal, all fishes were identified at the lowest taxonomic level and the total length (cm) measured. Weight estimates (g) were obtained at the [www.fishbase.org](http://www.fishbase.org) site from the measured lengths for each individual. This experimental protocol was in agreement with the Animal and Federal Experimentation Ethics Committee University of Paraná, on the use of benzocaine and blood withdrawal from teleosts (certificate n° 1056/2017).

#### **(b) Assessment of the acute stress response to trawling**

The responses to acute stress were evaluated from the main primary stress marker in bonefish (plasma cortisol) and from well established secondary stress parameters: plasma glucose, osmolality, chloride and magnesium. Plasma cortisol was determined by a solid-phase immunoabsorbent enzyme assay (ELISA) based on the competitive binding principle (commercial kit DRG Cortisol Elisa; Ref EIA-1887). Glucose was measured directly using blood obtained from the caudal vein through the Accu-Chek® digital device (Roche - Performa Nano model). Osmolality was determined by reading samples without dilution in a vapour pressure micro osmometer (Wescor® 5520 VAPRO). Chloride and magnesium concentrations were determined by spectrophotometry (Ultrospec 2100 PRO Amersham Pharmacia biotech, Sweden) using colorimetric kits (Labtest, Brazil), and reading absorbance, respectively, at 470 nm and 505 nm. Fish plasma samples were diluted 1: 2 for the determination of Cl<sup>-</sup> ions and 1: 4 for the determination of Mg<sup>+2</sup> ions.

#### **(c) Validation of the elisa for cortisol**

Recovery and linearity tests of 4 samples of marine-estuarine fish were performed for the validation of the cortisol ELISA. Samples from *Sphoeroides testudineus* (sample 1), *Mugil liza* (sample 2), *Menticirrhus americanus* (sample 3) and *Genyatremus luteus* (sample 4) were selected and 54/96 wells were used from an ELISA plate. The recovery test was performed from 1:1 dilution between the selected samples and the 50, 100 and 200 ng.ml<sup>-1</sup> standards. For the linearity test, serial dilutions (1/2, 1/4, 1/8 and 1/16) were made from

standard 0 and the four selected samples. All tests were performed in duplicates. The precision and reproducibility of the assay (intra-assay) were verified by calculating the coefficient of variation (CV) of repeated measures of samples within the same assay. Inter-assay precision and reproducibility was determined by assaying the same samples in three separate assays, again though its CV.

The standard curve showed a high correlation coefficient between Logit OD and log concentration of standard solutions for all plates used in the dosages ( $R^2 = 0.9821$  - plate 1; 0.934 - plate 2; 0.9804 - plate 3; 0.9721 - plate 4; 0.9705 - plate 5; e 0.9628 - plate 6). The precision and reproducibility of the assay was good, as CVs <10%, as was the CV for duplicates of all samples (see Supplementary Material 1).

#### **(d) Data analysis**

Correlations between cortisol, glucose, osmolality, chloride, and magnesium were evaluated through Spearman's correlation analysis (see Supplementary Material 2). As the intra and interspecific variation of the primary and secondary stress markers was very clear within each treatment, graphs were prepared as scatter plots displaying individual values. To verify which components (cortisol, glucose, osmolality, chloride, magnesium, length, weight, and season) best explained the variation in stress response between individuals in each group, the Principal Component Analysis (PCA) was performed and the groupings classified by the k-means algorithm. In order to evaluate the similarity of the stress response among individuals and groups, the Permutational Multivariate Variance Analysis (PERMANOVA) was performed. Data analysis was performed using SigmaPlot® software version 11.0 and "R" version 3.6.1 and the significance level adopted was 0.05 for all the results.

### **3. Results**

#### **(a) General characteristics of samples**

A total of 224 samples were collected, representing 35 species from 19 families of wild subtropical marine teleosts. Fifty-nine samples were assigned to the DT group (dead after trawling), 93 to the LT group (alive after trawling), and 72 to the OT group (alive, kept overnight in a tank by the local fisherman, see Supplementary Material 3 for the list of species sampled, and length/weight data of the individuals).

#### **(b) Variability of the stress response**

The variability of the response among individuals and species was remarkable, within each of the 3 groups. For cortisol (Figure 1), there were basically three types of responses to

acute capture stress: i. species with high response; ii. Species which presented both high and low responses, and iii. Species which presented only a low response. For example, the Atherinopsidae - brazilian silverside *Atherinella brasiliensis* presented extremely high values both as DT (89.6 to 2115.2 ng/mL) and as LT (2228.83 to 7890.62 ng/mL). Centropomidae - sea bass (*Centropomus undecimalis*), Paralichthyidae – bay whiff (*Citharichthys spilopterus*), Haemulidae - stonefish (*Genyatremus luteus*), and Mugilidae – grey mullet (*Mugil liza*) showed both low (107, 44, 14, 5 ng/mL, respectively) and high values (532, 448, 294, 595 ng/mL, respectively) for cortisol, in DT and LT groups. In contrast, some individuals, mainly representatives of the family Sciaenidae – smallscale weakfish, king weakfish, and southern kingcroaker (*Cynoscion microlepidotus*; *Macrodon ancylodon*, *Menticirrhus americanus*), always had a low stress response both as DT as LT (average 14, 11, 25 ng/mL, respectively), while some individuals showed high values of cortisol only in the OT group, of ~297-408 ng/mL.

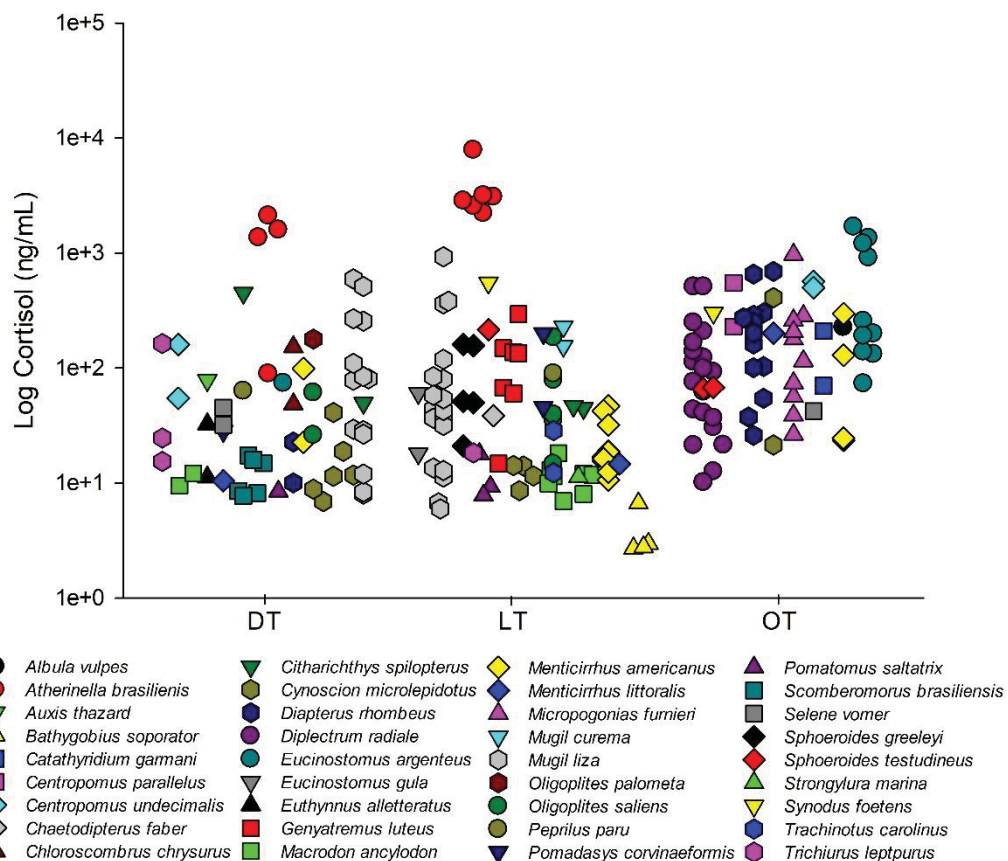


Figure 1. Plasma cortisol (ng/mL) of the trawled fished individuals in each group (DT = dead fish after trawling; LT = live fish after trawling; OT = live fish kept overnight in tank). Symbols with the same colors and shapes represent individuals of the same species.

Glucose was shown also to be highly variable among groups, species and individuals. The minimum values (12 mg/dL) were presented by Sciaenidae - whitemouth croaker

*Micropogonias furnieri* in OT and maximum (534 mg/dL) for Serranidae – pond perch *Diplectrum radiale* in the same treatment. However, a few species showed less variability of this marker within a same group. For example, *Cynoscion microlepidotus* (20 - 68 mg/dL) and Scombridae – Spanish mackerel *Scomberomorus brasiliensis* (72 - 132 mg/dL) in the DT. Tetraodontidae – green puffer *Sphoeroides greeleyi* (32 - 67 mg/dL) in LT, and Gerreidae – silver mojarra *Eucinostomus argenteus* in OT (25 - 89 mg/dL), with the exception of one individual of this species who showed a glycemia of 439 mg/dL in this treatment (Figure 2).

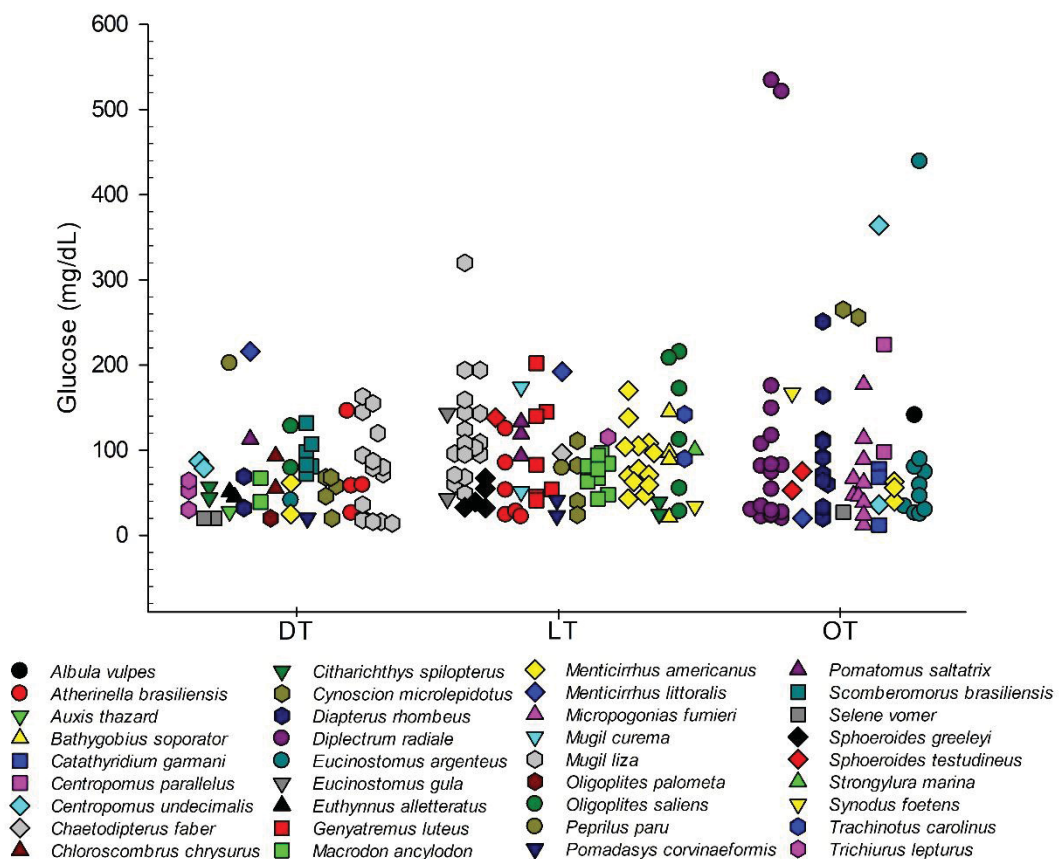


Figure 2. Blood glucose (mg/dL) of the trawled fished individuals in each group (DT = dead fish after trawling; LT = live fish after trawling; OT = live fish kept overnight in tank). Symbols with the same colors and shapes represent individuals of the same species.

Most values of plasma osmolality were of ~400 mOsm/kg H<sub>2</sub>O. However, there was some dispersion around that value, with some very high values (around 600-947 mOsm/kg H<sub>2</sub>O), and a few very low ones (85-243 mOsm/kg H<sub>2</sub>O). Very high values among these treatments were recorded for Scombridae - frigate tuna *Auxis thazard* (803 mOsm/kg H<sub>2</sub>O), Carangidae - lookdown *Selene vomer* (784 mOsm/kg H<sub>2</sub>O) and Haemulidae - roughneck grunt *Pomadasys corvinaeformis* (816 mOsm/kg H<sub>2</sub>O) in DT. And for Gobiidae – frillfin goby *Bathygobius soporator* (906 mOsm/kg H<sub>2</sub>O), *Pomadasys corvinaeformis* (663 mOsm/kg H<sub>2</sub>O)

and *Menticirrhus americanus* (682 mOsm/kg H<sub>2</sub>O) in LT. Relatively low values of osmolality were also found in these treatments (DT and LT), being frequent in *Cynoscion microlepidotus* (e.g. 85 and 166 mOsm/kg H<sub>2</sub>O) and *Macrodon ancylodon* (e.g. 107 and 129 mOsm/kg H<sub>2</sub>O). OT species presented higher variability in the osmolality values, with individuals of the same species presenting a wide range of values, within this same treatment, as especially observed for Gerreidae – caitipa mojarra *Diapterus rhombeus* (278 – 947 mOsm/kg H<sub>2</sub>O) (Figure 3).

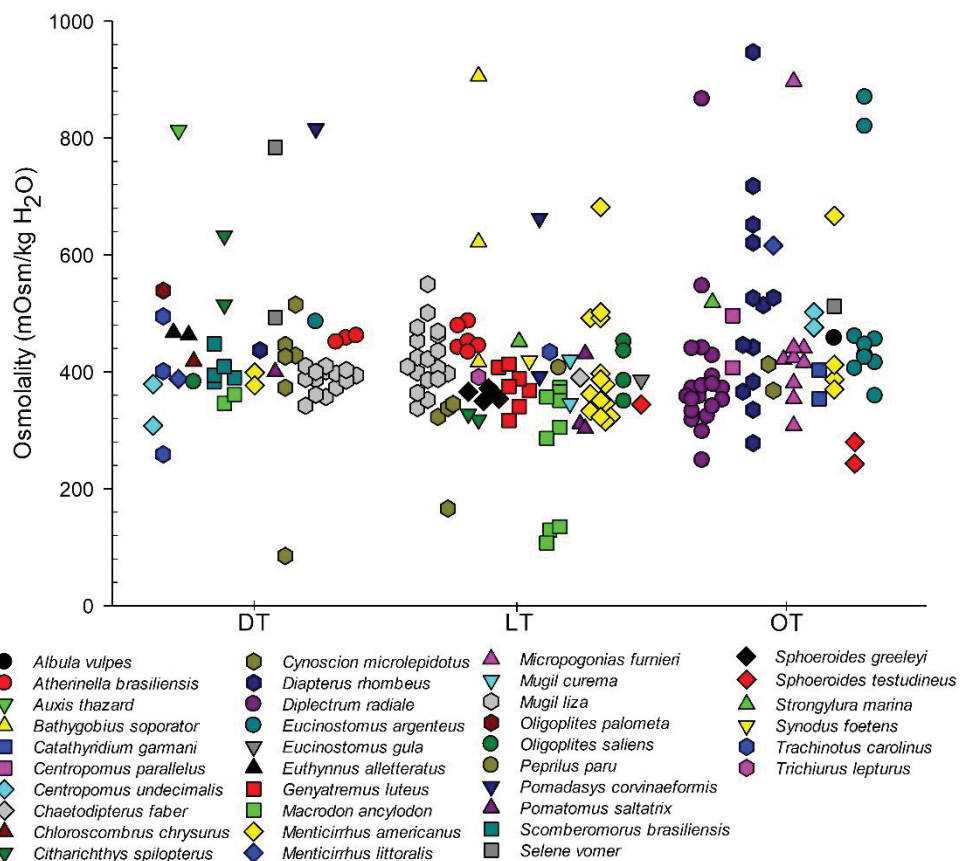


Figure 3. Plasma osmolality (mOsm/kgH<sub>2</sub>O) of the trawled fished individuals in each group (DT = dead fish after trawling; LT = live fish after trawling; OT = live fish kept overnight in tank). Symbols with the same colors and shapes represent individuals of the same species.

Accordingly, plasma chloride concentrations were also quite varied in OT individuals, mainly for *Diplectrum radiale* (range 82 - 401 mM) and *Diapterus rhombeus* (109 - 333 mM). *Pomadasys corvinaeformis* showed high Cl<sup>-</sup> values in both DT (357 mM) and LT (192-310). Some individuals showed little variation, being able to highlight Carangidae – castin leatherjacket *Oligoplites saliens* (120-127 mM in DT, and 120-132 mM in LT), *Mugil liza* (72 - 161 mM in DT, and 121-185 mM in LT), *Atherinella brasiliensis* (143-161 mM in DT, and 173-208 mM in LT), and *Macrodon ancylodon* (124-128 mM in DT, and 130-236 mM in LT). Extremely low values of Cl<sup>-</sup> were presented for *Bathygobius soporator* (33 mM) in LT, and

Scombridae – little tunny *Euthynnus alletteratus* (34 mM), and Trichiuridae – largehead hairtail *Trichiurus lepturus* (40 mM) in DT groups (Figure 4).

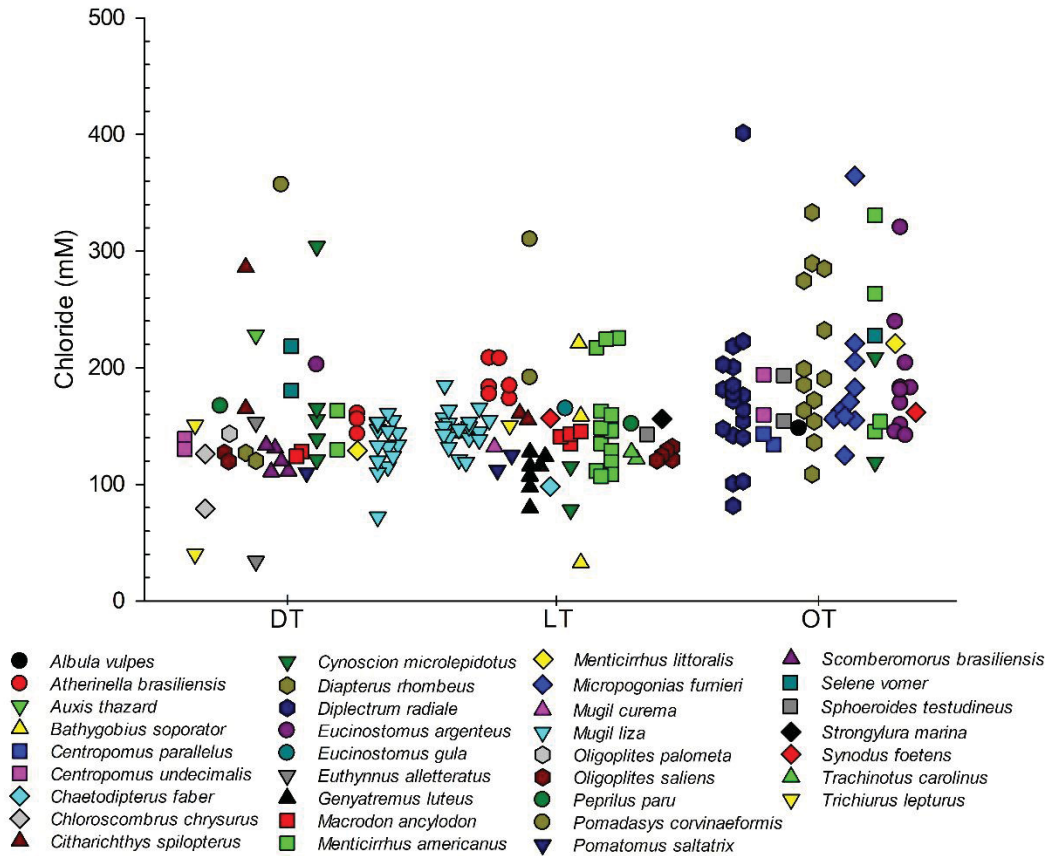


Figure 4. Plasma chloride (mM) of the trawled fished individuals in each group (DT = dead fish after trawling; LT = live fish after trawling; OT = live fish kept overnight in tank). Symbols with the same colors and shapes represent individuals of the same species.

Following the Cl<sup>-</sup> pattern, plasma Mg<sup>2+</sup> exhibited great variability among OT individuals of a same species. All species sampled in this group – OT - showed a large amplitude of this ion, with the greatest differences found in *Diapterus rhombeus* (1.4 – 9.7 mM), *Micropogonias furnieri* (1.8 – 10.3 mM), and *Eucinostomus argenteus* (1.9 – 8.9 mM). Also highlighting the great variability in magnesium concentration between *Cynoscion microlepidotus* in DT (0.02 – 11 mM). Considerably lower and less variable values were found in individuals of the species *Mugil liza* in DT (0.6 – 2.4 mM), and LT (0.2 – 2.0 mM) groups, and *Scomberomorus brasiliensis* (1.7 – 2.1 mM), and *Sphoeroides greeleyi* (1.7 – 1.9 mM) in DT group. *Atherinella brasiliensis* presented higher concentrations of this ion among the sampled species in DT (6.7 – 12 mM) and also high concentrations in LT (5.3 – 9.5 mM) (Figure 5).

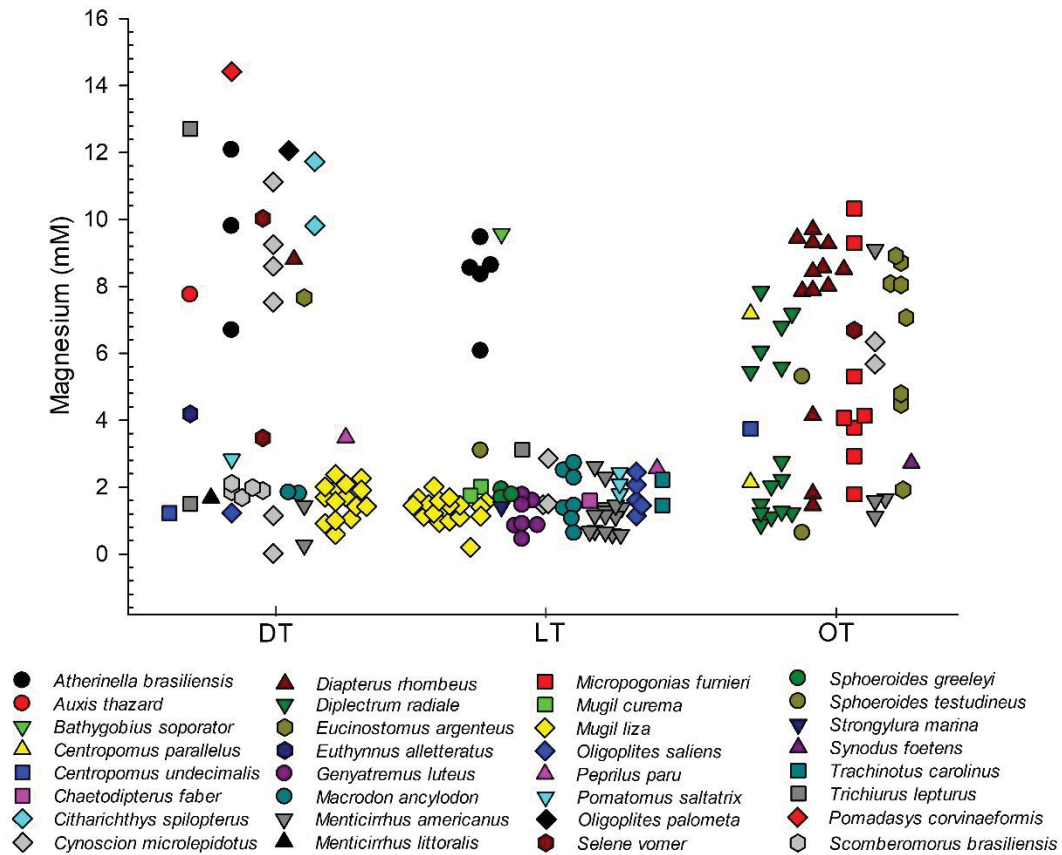


Figure 5. Plasma magnesium (mM) of the trawled fished individuals in each group (DT = dead fish after trawling; LT = live fish after trawling; OT = live fish kept overnight in tank). Symbols with the same colors and shapes represent individuals of the same species.

### (c) Different ability for acute stress response between individuals and/or species

According to results of the PCA analysis, performed to group individuals based on the similarity of the stress response and determine which physiological components could explain this variation, plasma cortisol (Comp.1) and osmolality (Comp.2) components together explained more than 67% of the variance found within each group (Figs. 6 A, B, and C), as expected. From these results we can suggest the formation of four clusters – black, red, blue, and green circles. The first cluster (black circles) referred to individuals which presented distinctly high levels of cortisol and magnesium after stress, represented only by *A. brasiliensis* (both in DT and LT treatment). The second grouping reflected the individuals who presented high osmolality and low glucose values (red circles). The third (blue circles) and fourth (green circles) groupings included individuals who had low-intermediate levels of cortisol with slight variations in secondary stress responses.

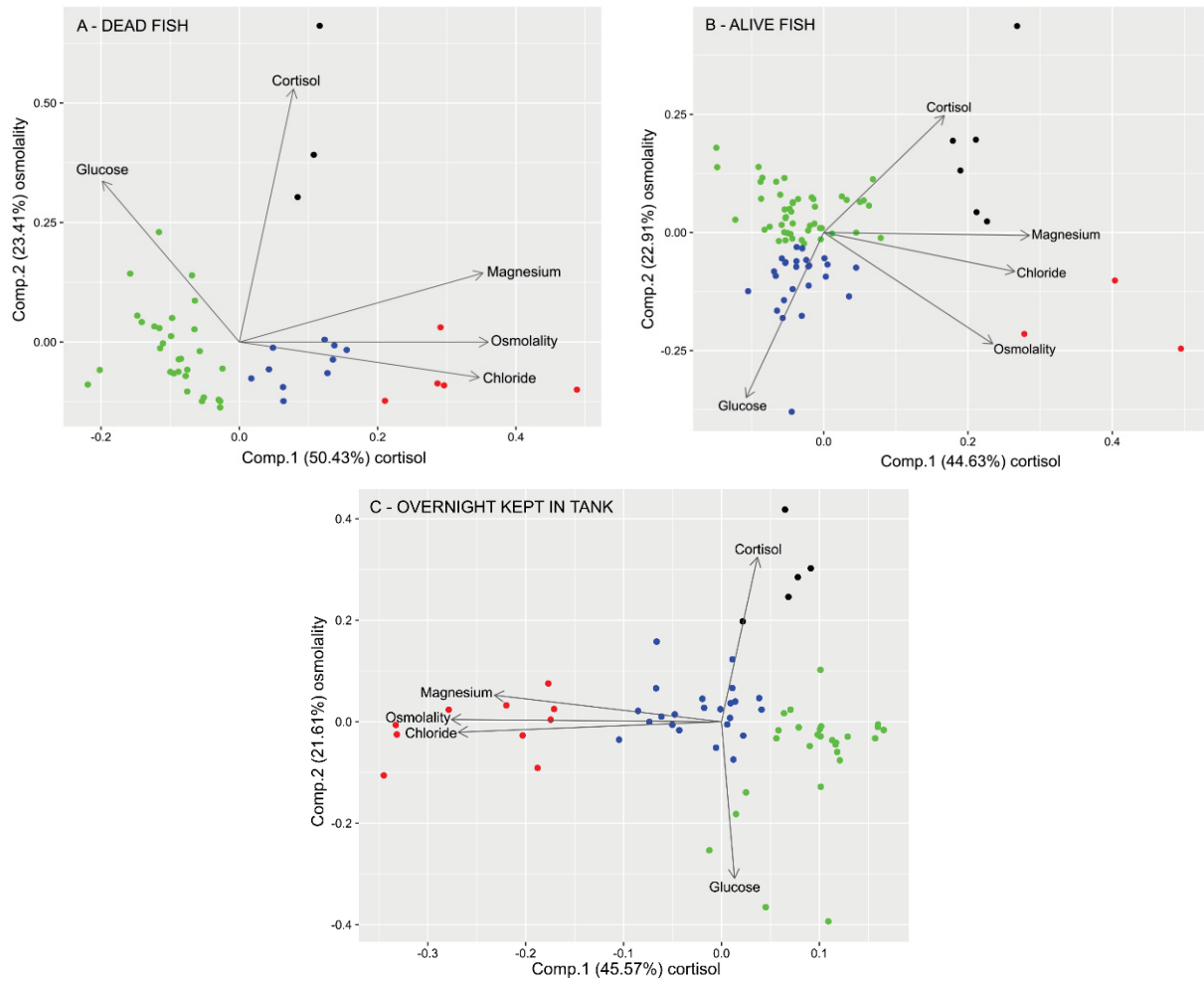


Figure 6. Scatterplot of Principal component analysis (PCA) applied to physiological parameters cortisol, osmolality, glucose, chloride, and magnesium measured in DT (A), LT (B), and OT (C). The first two components (Comp.1 = cortisol; Comp.2 = osmolality) accounted for 73.8%, 67.5%, and 67.2% of the variability of data in groupings DT, LT, and OT, respectively. These results showed four different ways of coping with stress in each group based on the similarity between the stress markers and the individuals sampled. Besides a positive linear correlation between the cortisol, osmolality, chloride and magnesium components; and negative correlation (exception DT) between the cortisol and glucose components. The length, weight and season components together explained less than 10% of the data variation and were therefore excluded from the analysis.

The PERMANOVA results (performed to verify the influence of the proposed groups on data variability) showed that data variation was better explained by the inherent characteristics of the individuals (different stress response abilities) than by the association to any of the 3 groups (Table 1, Figure 7).

Table 1. Permutational multivariate analysis of variance (PERMANOVA) table for stress response between individuals and groupings

Source of variation	df	Sum of Squares	Mean of Squares	F.Model	R <sup>2</sup>	Pr(>F)
Individuals	35	5.87	0.16	4.42	0.43	0.001
Groupings	2	0.45	0.22	5.93	0.03	0.001
Residuals	186	7.06	0.03		0.52	
Total	223	13.38				

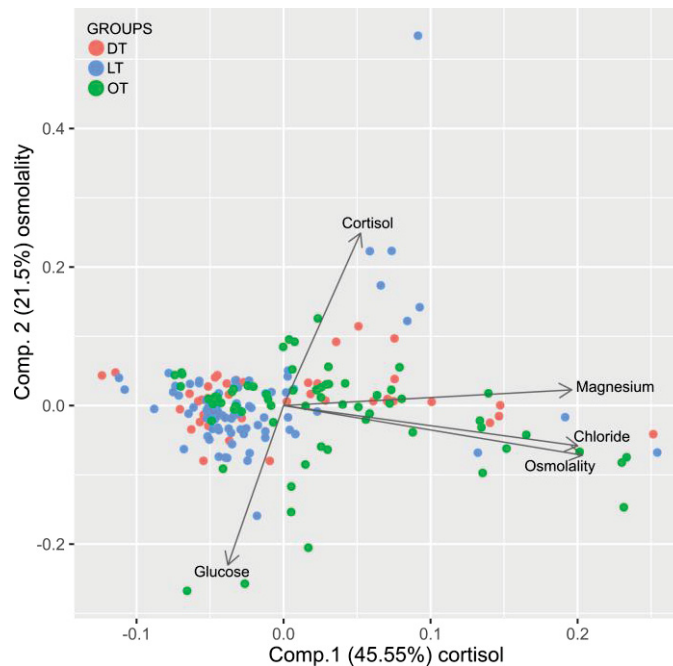


Figure 7. Permutational multivariate analysis of variance (PERMANOVA) results applied to physiological parameters measured in the 3 groups (DT, LT, and OT), with all individuals (n=224). These results showed that the differences found in the response to the capture stress were not related to the different groupings proposed, being the variability of the response to stress (way of coping with stress) specific to each individual and/or species. Besides a positive linear correlation between the cortisol, osmolality, chloride and magnesium components; and negative correlation between the cortisol and glucose components. The analysis was performed using the “vegan” package, being the Euclidean distance measure and 999 permutations were applied.

## 4. Discussion

### (a) General characteristics of samples

Despite the already recognized variation in the HPI axis stress response between individuals and species (Schreck et al. 2001; Barton 2002; Schoenle et al. 2018), the stress-related levels of one or a few species are in general misleadingly extrapolated to all teleosts (Balasch and Tort 2019). Despite the use of numerous types of biomarkers of stress, our understanding of how absolute levels of biomarkers relate to stressor severity and recovery remains limited to date.

It is important to note that the individuals collected here referred to small scale fishing resources in subtropical regions of Brazil, so the results reflected the seasonality (April 2017 - July 2018) and selectivity of the fishing gear in terms of the collected species, through random sampling. In addition, we must indicate here that we did not make directional predictions for basal glucocorticoids, but rather an exploratory analysis to investigate patterns that might represent different types of ways of coping with acute stress from subtropical wild fishing resources. As the samples were commercial resources of the fishermen, it was not possible to remove the gonads to determine the gender and maturation stage. Thus, the gender factor was not investigated in this study, could not be correlated with the stress markers assayed here.

### **(b) Variability in the stress response between individuals and species: cortisol release**

Glucocorticoid release is the end result of the Hypothalamic-Pituitary-Interrenal cascade, activated upon exposure to a stressor. The situation of stress stimulates production of corticotropin-releasing factor (CRF), resulting in release of adrenocorticotrophic hormone (ACTH) from the anterior pituitary gland. The ACTH binds to receptors on interrenal cell stimulating production of glucocorticoids (Mommsen et al. 1999).

Stress responses must be compensatory and adaptive (eustress) to allow the animal to overcome the threat. However, stress responses may lose their adaptive meaning (distress) under chronic or intense stressors, and may result in adverse effects on growth and reproduction (Samaras et al. 2018) and in dysregulation or suppression of immune function (Tort 2011). In fact, the “fight-or-flight” response is probably not regulated the same way in all species (Romero and Gormally 2019). In response to a stressor, animals exhibit physiological and behavioral changes (i.e., allostasis; McEwen and Wingfield 2003; Romero et al. 2009) that are part of a set of characteristics that are consistently different between individuals (as personality type), but are stable within an individual (glucocorticoid release rates may be conserved in proactive and reactive stress coping styles among diverse species), contexts (as foraging), and time (daily variation) (Wong et al. 2019). The combined actions of cortisol between glucocorticoid and mineralocorticoid receptors are among allostasis mediators (see reviews in Wendelaar-Bonga 1997; Reid et al. 1998; McEwen 2000; Korte et al. 2005; McEwen and Wingfield 2010; Pankhurst 2011), regulating hydromineral balance and energy metabolism in an adaptive way. The release of cortisol during stress can cause osmoregulatory perturbations (Wendelaar-Bonga 1997) due to changes in branchial permeability to water and electrolytes: cortisol has a recognized role in stimulating salt secretion (hypoosmoregulatory capacity) in fish (Mommsen et al. 1999; McCormick 2001).

The early waves of endocrine stress responses and physiological consequences involve modulating and preparative actions. Modulating actions (permissive, suppressive, and stimulating glucocorticoid actions), which alter an organism's response to the stressor; and preparative actions, which alter the organism's response to a subsequent stressor or aid in adapting to a chronic stressor (mediating or suppressive) (Sapolsky et al. 2000). The assessment of the capture stress response from the three groups was valid to comprise a time course of physiological changes induced by stress in living individuals immediately after capture (LT) and in individuals who have recently died (DT) and observe the possible recovery from capture stress or failure to maintain homeostasis in individuals who have been maintained overnight in a seawater tank (OT). This type of assessment (post-capture stress) in fish has been useful to know for how long the target species of commercial, recreational fisheries or bycatch individuals are able to be exposed to the air without showing failure to maintain equilibrium, evidenced by changes levels of physiological markers, and locomotor impairment (Brownscome et al. 2013, Cook et al. 2015). From these observations it is possible to identify species more or less sensitive to capture stress for the development of fisheries management voluntary "best practice" regulations and guidelines, improving post-release survival (Brownscome et al. 2013, Cook et al. 2015; McLean et al. 2016; Cook et al. 2018). Thus, repeatable responses were demonstrated by some species between DT and LT, and OT treatment represented a good positive control to evaluate the maximum stress response rates for both cortisol and secondary parameters.

Fish capture by trawling, followed by transfer and maintenance of the subjects for ~12h in the tank (OT treatment), did not allow individuals to recover their pre-stress glucocorticoid levels. Other factors that possibly favored the development of stress in this treatment were the confinement regime (hierarchically distinct species in a limited space), the removal of the fish from the tank (Ellis et al. 2004) and the use of benzocaine prior to blood collection (Wosnick et al. 2018). Crowding explains high cortisol values and great variability in secondary plasma parameters in others studies with fish, compared to not crowded groups. In crowded and confined sea bass *Dicentrarchus labrax* (Perciformes, Moronidae) serum Cl<sup>-</sup> increased concentrations by approximately 8%, and there were no differences in osmolality and ion concentration between groups of brief-handling fish (Marino et al. 2008). *Salmo salar* (Salmoniformes, Salmonidae) showed a 10% increase in the monovalent Cl<sup>-</sup> ion, and glucose concentration increased 76% in the crowded group (Gatica et al. 2010). When a wild animal is kept in captivity for the first time, symptoms of chronic stress can occur even though the animal's physical needs are attended, and the captivity stress response in wild animals is highly species-specific (Fischer & Romero, 2018).

Besides that, our results evidenced the existence of species-specific responses in magnitude and amplitude of the cortisol release/response after severe acute stress. Some

species had always high levels of cortisol, others showed frequently low levels of cortisol, while and others showed as high as low levels in response to the same stressor. *Atherinella brasiliensis* (Atheriniformes, Atherinopsidae) presented extremely high values of cortisol in this study, a feature that was repeated for all individuals of this species, even those sampled in different months and, either individuals that were dead after trawling (DT) or alive (LT). Very high values of plasma cortisol, although not as high as some of the values we found here, for this species have been previously reported in the literature: ~564–650 ng/mL of plasma cortisol in *A. brasiliensis* caught in Paranaguá Bay 7 months after the Vicuña oil spill (Souza-Bastos and Freire 2011). Values as high as for those assayed in *A. brasiliensis* have been reported for a chub, *Squalius cephalus* (Cypriniformes, Cyprinidae) (highest individual level of 1927 ng/mL, and mean levels of 1500 ng/mL) after severe handling acute stress (Pottinger et al. 2000). The potentially adverse effects of supposedly high circulating levels of cortisol found both at rest (50-100 ng/mL) and under conditions of stress in *S. cephalus* were proposed to be offset by the lower affinity of the cortisol receptor, rather than the low abundance of target-tissue receptor sites (Pottinger et al. 2000). Recurrent high cortisol values after stress are found for sea bass *D. labrax* (~800 ng/mL) in the literature (Rotllant et al. 2003, Fanouraki et al. 2011, Samaras et al. 2018) and may be explained by either increased activity of the interrenal cells (Rotllant et al. 2003).

In the present study, most species of benthic habits, such as the Perciformes, Sciaenidae (*C. microlepidotus*, *M. ancyllodon*), and Gobiiformes, Gobiidae (*Bathygobius soporator*); displayed very low levels of plasma cortisol after the trawling. It is possible that plasma cortisol in these fishes would later increase. In fact, a delayed cortisol response was reported for the Scorpaeniformes, Hemitripterae - sea raven *Hemitripterus americanus* (Vijayan and Moon 1993): this fish showed a slow response to post-stress cortisol levels, taking up to 4 hours to reach its maximum level after acute stress. A delayed cortisol production may be a feature conserved in some families of fish due to changes in neuroendocrine mechanisms, particularly corticotropin-releasing factor and ACTH release (Vijayan and Moon 1993). This altered stress response may represent an adaptation to avoid over-mobilization of energy in a species with inactive lifestyle and low metabolic activity (Vijayan and Moon 1993). Significantly reduced responses (both baseline and after stress) were also found after chronic stress in birds (*Sturnus vulgaris*). Under chronic stress, the hypothalamus regulates arginine vasotocin (AVT) release, which most likely results in less adrenocorticotrophic hormone (ACTH) leading to lower concentrations of stress-induced corticosterone (Rich & Romero, 2005).

Besides this notable inter-species variability, some species showed marked intra-specific variability in post-trawling plasma cortisol levels, with some individuals showing very high values, while others showed low values. This happened with the Pleuronectiformes

flounders Achiridae, *Catathyridium garmani* and Paralichthyidae, *C. spilopterus*, Mugiliformes, Mugilidae *M. liza*, and Perciformes, Gerreidae *E. argenteus* and *D. rhombeus*, for example, as already demonstrated in other studies for other species. For example, the (European sea bass, Perciformes, Moronidae) *Dicentrarchus labrax* with so called low- (LR) and high- (HR) responses to cortisol were identified in relation to the intensity and consistency of their response after exposure to acute stressors. The hepatic transcription profiles of the LR and HR fish indicated differential liver regulation among these divergent phenotypes, with no differences observed in plasma ACTH concentrations between these two phenotypes (Samaras and Pavlidis 2018). These hepatic transcriptional differences were related to several proteins related to metabolic and immunological processes, with 169 transcripts being exclusively of LR fish and 161 exclusively of HR fish (Samaras et al. 2016). Different LR and HR responders, were also reported to *Gadus morhua* to handling and thermal stress (Hori et al. 2012), and to *Sparus aurata* to handling and confinement for a period of 3h (Tort et al. 2001).

There is consistent evidence that stress response profiles are correlated with behavioral characteristics, which are called “coping styles” (Koolhaas et al. 1999). Individuals with low responses are characterized as proactive and typically exhibit high sympathetic reactivity and release of catecholamines; while reactive individuals have been shown to display low sympathetic activity and low release of catecholamines, but high levels of cortisol or plasma corticosterone (Koolhaas et al. 2011). In this sense, plasma cortisol levels also differ in subordinate and dominant individuals of fish (Winberg et al. 2016), with dominant individuals returning to their baseline levels within hours and subordinate individuals taking days or weeks to have baseline plasma cortisol levels after establishment of the internal hierarchy (Balasch and Tort 2019). However, it is not clear whether these differences in the physiological characteristics of the stress response between subordinate and dominant individuals are causes or consequences of social classification (Schoenle et al. 2018).

**(c) Integrating the several parameters evaluated: the multivariate analyses (pca and permanova)**

The multivariate analyses corroborated the idea that the species use different physiological mechanisms to deal with acute stress, as explained by cortisol and osmolality components. These analyses also showed that weight and length (intrinsic factors) and season (extrinsic) did not interfere significantly on the results.

Intrinsic factors such as life stage, life history or reproductive stage, and sex, as well as extrinsic factors such as climate, competition, food resources, habitat quality, social structure, parasitic load and injury, human disturbances, interaction with predators, and handling are exhaustively cited as influencers in the response of glucocorticoids to a specific

stress, in a variety of vertebrates (Iwama et al. 2004; Busch and Hayward 2009; Madliger et al. 2015; Birnie-Gauvin et al. 2017, Madliger et al. 2018). Thus, a cause-and-effect relationship is not always very clearly described (Mommensen et al. 1999; Romero et al. 2009).

Marine teleosts regulate their internal salt concentrations and osmotic pressure at levels well below seawater 370–480 mOsmol/kg H<sub>2</sub>O x 1000 mOsmol/kg H<sub>2</sub>O (Freire and Prodocimo 2007). Consequently, they tend to osmotically lose water over the entire permeable surface area of the gills. To compensate for osmotic water loss and prevent dehydration, must eliminate divalent ions as Mg<sup>2+</sup>, and SO<sub>4</sub><sup>2-</sup> mainly by the kidneys and the monovalent salts, Cl<sup>-</sup> and Na<sup>+</sup>, by the gills (Takei and McCormick 2012). Cortisol release promotes monovalent ion extrusion by the gills in marine species and, consequently, a lower osmolality value in the high-cortisol responders could be expected. High osmolality responders would correspond to low-cortisol responders and vice versa (Tort et al. 2001). Besides that, cortisol has a substantial physiological impact on ion uptake in many teleosts, but this function has not been fully elucidated due to the emphasis on the role of cortisol in salt secretion (Takei and McCormick 2012).

The tightness of the specific responses patterns found in the present study are reflected by the reproducibility of the responses between individuals of *A. brasiliensis* (black circles), *M. liza*, *S. brasiliensis*, *G. luteus*, the cyanides (*M. ancylodon*, *M. americanus*, *C. microlepidotus*), and some carangids (*T. carolinus*, *O. saliens*), even when either dead or alive after trawling (green and blue circles).

The type of response to stress presented in individuals of *A. brasiliensis* (black circles) was quite peculiar, with high levels of cortisol and magnesium and no marked variation in chloride and osmolality values. Increased magnesium concentrations after exposure to a stressful load have already been observed in other studies with other fish species. For example, after 4 and 24 hours of transport at three densities tested for juveniles of *Oreochromis niloticus* (Cichliformes, Cichlidae) (Moreira et al. 2015). And for *Salmo salar* immediately after transport and transfer to sea, both experimental groups showed an increase in plasma Mg<sup>+</sup> compared with pre-stress levels. In this same study, it was found that sedated salmon returned to pre-stress levels in 72 hours, with non-sedated individuals showing no recovery even one week after transport (Iversen et al. 2009). Zaprudnova (2018) revealed the dependency of magnesium concentration in red blood cells of fish on intensity of stressor loads of different types: level of erythrocytic magnesium increased under the effect of insignificant and average stressors (at physiological stress) and decreased – under effect of significant loads (at pathological stress).

The individuals belonging to the cluster of blue and green circles apparently showed great capacity to maintain osmoregulatory balance, both in individuals with low response and in individuals with high response to cortisol. *M. liza*, *S. brasiliensis*, *G. luteus*, *T. carolinus*,

and *O. saliens* are examples of species that maintained osmoregulatory maintenance after stress in both individuals with high or low response to cortisol. And *M. ancylodon*, *M. americanus*, and *C. microlepidotus* are examples of species that also showed maintenance of osmoionic balance, however, with low responses to cortisol. Plasma cortisol concentration is probably not a direct determinant of osmoregulatory mechanisms after acute stress in Sciaenidae, and it is necessary to investigate the other mechanisms that support this type of response.

The individuals represented by the red circles were not able to cope with this type of stressor. *A. thazard*, *P. corvinaeformis*, and *B. saporator*, for example, presented osmoregulatory rupture after the capture stress, evidenced by the difficulty in remaining hyposmotic, possibly as a consequence of the low cortisol and glucose values. However, it should be investigated whether low post-stress glucose levels were due to intense mobilization of energy reserves or whether low cortisol levels did not allow glucose mobilization.

Increased plasma glucose levels after stress are widely recognized, however plasma glucose and hepatic glycogen concentrations vary substantially depending on the species, stage of gonadal maturation (Wendelaar-Bonga 1997) and metabolic status of the animal (Mommsen et al. 1999). In addition, it should also be considered that both cholinergic and adrenergic pathways are involved in the production and/or re-availability of glucose (Martínez-Porchas et al. 2009). Evidence of a sexually dimorphic response between glucose levels has been evidenced in some studies, being greater in females than in chub males (Pottinger et al. 2000) or greater in males than zebrafish females (Wong et al. 2019). The use of glucose as a stress marker shows better results in studies with cultivated species, usually showing a significant correlation with cortisol levels (Pottinger et al. 2000, Trenzado et al. 2003), what is expected, due to the fact that fish receive the same treatments and diet. The different glucose concentrations in fish may also reflect the disparity in glucose mobilization between fish with divergent low (LR) and high (HR) adrenocorticotrophic responses to stressors, perhaps linked to differential activation of glycogenolytic pathways (Trenzado et al. 2003). The variations found in ionic and glucose concentrations can be attributed to several factors not yet fully explored for the species studied (and not only driven by stress), such as differences in lifestyle, sex, corticotropin-releasing factor and ACTH release, and cortisol receptor affinity.

## 5. Conclusion

From this study, it was possible to evidence species-specific cortisol responses after acute stress, demonstrating that not all species respond with high levels of cortisol after

stress. In addition, it was possible to indicate distinct abilities among wild fish species in coping with the same stressor: (i) species that have high cortisol, and magnesium response; (ii) species that have low/intermediate cortisol response and maintained the osmoionic balance, and (iii) species that presented osmoregulatory disruption in the response to capture stress. The repeatability of the stress response under different conditions (treatments, season, collection site, etc.) shows that HPI axis regulation is indeed an intraspecific factor. The variation in response between individuals of the same species may be related to different coping styles (LR and HR).

The use of primary and secondary markers was adequate to contemplate the variability of responses between species. For future studies it is suggested to determine the basis of this variability, identifying the neuroendocrine and molecular functions that regulate the different responses between species.

### **Acknowledgements**

The authors acknowledge the financial support from CNPq (PhD fellowship to DB - 141074/2016-7) and fishermen's logistical support during fieldwork. We sincerely thank researcher Marcelo Borges for his great help in performing the multivariate analysis.

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### Supplementary Material 1 - Validation of the cortisol ELISA assay

Validation of the cortisol ELISA was performed by plotting a standard curve (mean absorbance values of standard solutions 20, 50, 100, 400 and 800 ng/mL<sup>-1</sup>) and calculating the cortisol concentration for each of the 4 selected plasma samples. The curve was plotted with the log concentration of each standard solution against the logit optical density. Optical density (OD) was calculated as the absorbance of each standard solution over the absorbance of the zero-standard, with logit OD calculated by the Logit equation OD:  $\log(OD/(100-OD))$ . The percent recovery was calculated by multiplying the ratio between the measurements and the expected values by 100. To verify the parallelism (linearity test) between the standard curve and diluted plasma samples, a plot of the relative log of serial dilutions against the logit OD of these diluted samples was plotted and compared to the trend of the standard curve.

The absorbance values for all standard solutions showed a coefficient of variation lower than 7% (Table 1). The standard curve showed a high correlation coefficient between Logit OD and the log of the concentration of standard solutions ( $r^2 = 0.9628$ ) (Figure 1a).

Table 1. Optical density (OD) and logit OD of standard solutions values of plasma cortisol assay

Standard solutions (ng/mL-1)	Absorbance (nm)*	OD	Logit OD
0	1.1495 (1,52)	—	—
20	0.894 (1,01)	0.777729448	-2.105780618
50	0.765 (5,88)	0.665506742	-2.173947621
100	0.535 (6,73)	0.465419748	-2.330129183
200	0.3645 (1,23)	0.317094389	-2.497432132
400	0.231 (4,76)	0.200956938	-2.696023373
800	0.1415 (2,47)	0.123096999	-2.909217603

\*The values are expressed as mean. The coefficient of variance is show in parenthesis.

The cortisol values for the four samples used for the validation tests showed low coefficients of variation, being 0.17%; 4.83%; 2.44% and 0.78% for samples 1, 2, 3 and 4, respectively. The final cortisol concentration and recovery percentage is shown in Table 2.

Table 2. Recovery Test

Sample	Added concentration (1:1) (ng mL <sup>-1</sup> )	Measured cortisol (ng mL <sup>-1</sup> )	Expected cortisol (ng mL <sup>-1</sup> )	Recovery (%)
1	x	83.15114579	83.15114579	—
	50	61.70104548	66.57557289	93
	100	63.82727383	91.57557289	70
	200	126.6124007	141.5755729	89
2	x	43.63288982	43.63288982	—
	50	38.61882084	46.81644491	82
	100	59.77402869	71.81644491	83
	200	78.12528021	121.8164449	64
3	x	63.72353023	63.72353023	—
	50	141.814602	56.86176512	249
	100	75.78280647	81.86176512	93
	200	119.8724284	131.8617651	91
4	x	202.7850548	202.7850548	—
	50	87.16539311	126.3925274	69
	100	111.2155423	151.3925274	73
	200	157.7698402	201.3925274	78

Serial dilutions of the 4 samples (Table 3) exhibited displacement parallel to that of the standard curve and all dilutions fell within the linear portion of the standard curve (Figure 1b).

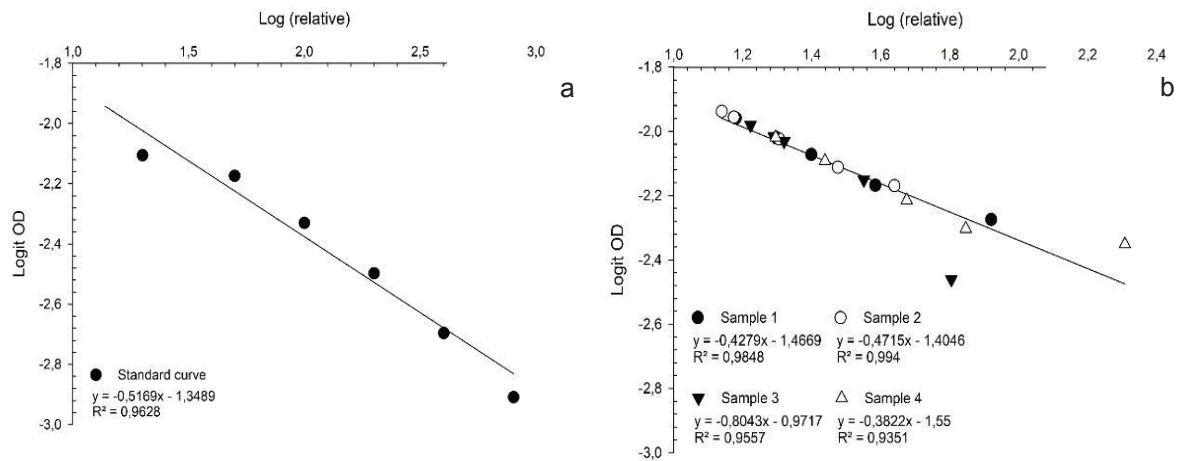


Figure 1. Standard curve and equation for determination of cortisol (a). Curves of the 4 samples selected for the validation test (b).

Table 3. Linearity Test

Sample	Dilution	Measured [cortisol] (ng ml <sup>-1</sup> )	Expected [cortisol] (ng ml <sup>-1</sup> )	Recovery (%)
1	0	83.15114579	—	—
	1/2	38.37686048	41.57557289	92
	1/4	25.04141493	20.78778645	120
	1/8	19.85331656	10.39389322	191
	1/16	15.13618233	5.196946612	291
2	0	43.63288982	—	—
	1/2	29.90277115	21.81644491	137
	1/4	20.17801716	10.90822245	185
	1/8	13.78901364	5.454111227	253
	1/16	14.94848386	2.727055614	548
3	0	63.72353023	—	—
	1/2	35.55740515	31.86176512	112
	1/4	16.69177447	15.93088256	105
	1/8	19.50168815	7.965441279	245
	1/16	20.89033017	3.98272064	525
4	0	202.7850548	—	—
	1/2	70.19060969	101.3925274	69
	1/4	47.29981261	50.6962637	93
	1/8	27.42531638	25.34813185	108
	1/16	19.74683132	12.67406592	156

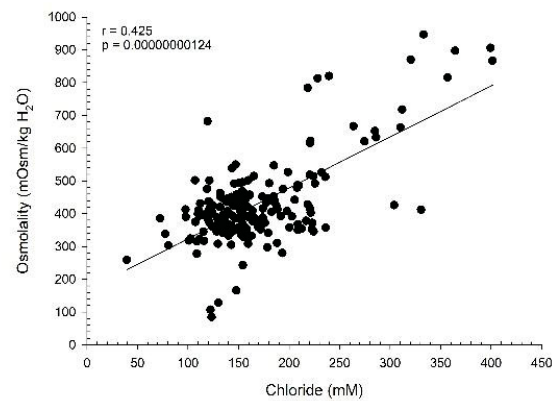
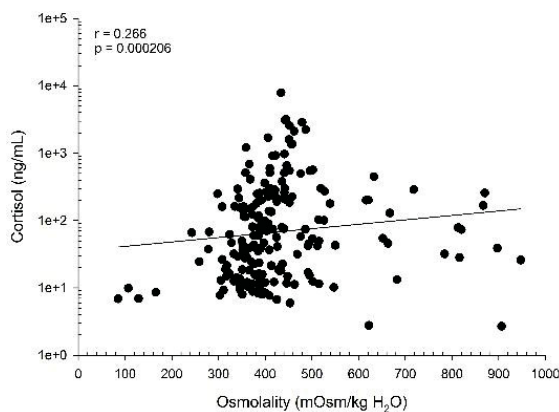
## Supplementary Material 2 – Spearman's correlation

The results of Spearman's correlation between all stress markers assessed in the three groups (DT, LT, and OT) are shown in Table 1.

Table 1. Spearman correlation analysis results between stress markers: cortisol, glucose, osmolality, chloride and magnesium. The table shows the Spearman's  $R_s$  values (bold) and the respective p values ( $p < 0.05$ ) described below

	Glucose (mg/dL)	Osmolality (mOsm/kg H <sub>2</sub> O)	Chloride (mM)	Magnesium (mM)
<b>Cortisol (ng/mL)</b>	-0,0733	<b>0,266</b>	<b>0,329</b>	<b>0,341</b>
	0,313	0,000206	0,000039	0,0000159
<b>Glucose (mg/dL)</b>	—	-0,0447	<b>-0,164</b>	<b>-0,179</b>
	—	0,539	0,0236	0,0131
<b>Osmolality (mOsm/kg H<sub>2</sub>O)</b>	—	—	<b>0,425</b>	<b>0,542</b>
	—	—	0,000000012	0,0000002
<b>Chloride (mM)</b>	—	—	—	<b>0,494</b>
	—	—	—	0,0000002
<b>Magnesium (mM)</b>	—	—	—	—
	—	—	—	—

Weak positive correlations were found between cortisol x osmolality, cortisol x chloride, and cortisol x magnesium; and moderate between osmolality x chloride, osmolality x magnesium, and chloride x magnesium. Weak negative correlations were observed between glucose x chloride and glucose x magnesium (Figure 1).



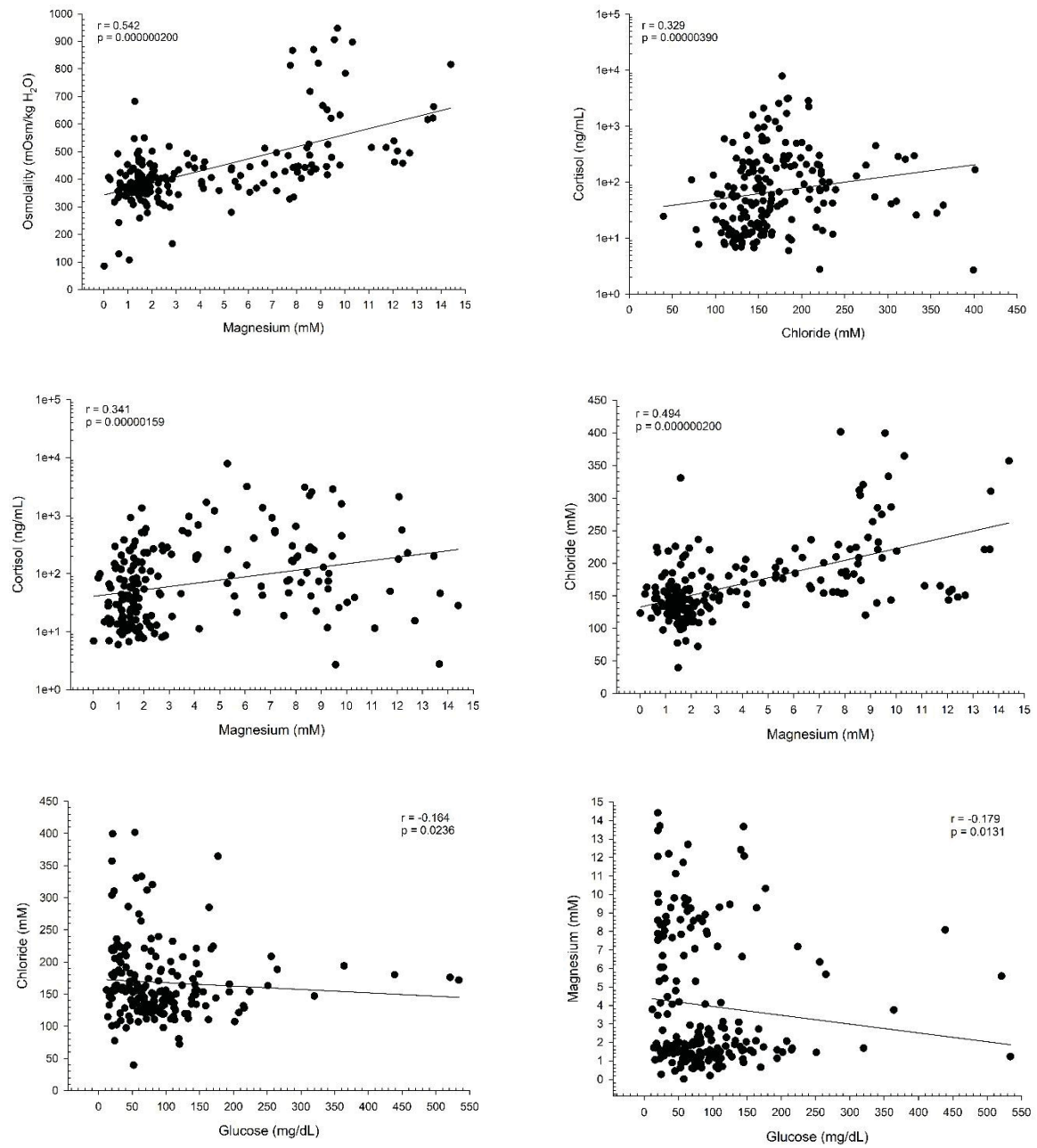


Figure 1. Spearman correlation analysis results between stress markers (cortisol, glucose, osmolality, chloride and magnesium).

## Supplementary Material 3 - List of individuals collected

Family	Specie	Group	Length (cm)	Weight (g)
Achiridae	<i>Catathyridium garmani</i>	OT	15	—
	<i>Catathyridium garmani</i>	OT	19	—
	<i>Catathyridium garmani</i>	OT	15	—
Albulidae	<i>Albula vulpes</i>	OT	17.5	75.87
Atherinopsidae	<i>Atherinella brasiliensis</i>	DT	14	18.58
	<i>Atherinella brasiliensis</i>	DT	14.4	20.27
	<i>Atherinella brasiliensis</i>	DT	14.4	20.27
	<i>Atherinella brasiliensis</i>	DT	10	6.55
	<i>Atherinella brasiliensis</i>	LT	11	8.8
	<i>Atherinella brasiliensis</i>	LT	11	8.8
	<i>Atherinella brasiliensis</i>	LT	11	8.8
	<i>Atherinella brasiliensis</i>	LT	10	6.55
	<i>Atherinella brasiliensis</i>	LT	11	8.8
	<i>Atherinella brasiliensis</i>	LT	12	11.52
Belonidae	<i>Strongylura marina</i>	LT	75	603.43
Carangidae	<i>Chloroscombrus chrysurus</i>	DT	19.3	63.32
	<i>Chloroscombrus chrysurus</i>	DT	34	303.91
	<i>Oligoplites palometa</i>	DT	21	—
	<i>Oligoplites saliens</i>	DT	42	—
	<i>Oligoplites saliens</i>	DT	23	—
	<i>Oligoplites saliens</i>	LT	23.5	—
	<i>Oligoplites saliens</i>	LT	22	—
	<i>Oligoplites saliens</i>	LT	22.5	—
	<i>Oligoplites saliens</i>	LT	22	—
	<i>Oligoplites saliens</i>	LT	20	—
	<i>Oligoplites saliens</i>	LT	23	—
	<i>Selene vomer</i>	DT	16.5	51.8
	<i>Selene vomer</i>	DT	14.5	35.98
	<i>Selene vomer</i>	OT	18	66.21
	<i>Trachinotus carolinus</i>	LT	20.5	66.14
<i>Trachinotus carolinus</i>	LT	18	47.17	
Centropomidae	<i>Centropomus undecimalis</i>	DT	49.3	881.97
	<i>Centropomus undecimalis</i>	DT	30	204.75
	<i>Centropomus undecimalis</i>	OT	20.5	66.84
	<i>Centropomus undecimalis</i>	OT	23	93.75
	<i>Centropomus parallelus</i>	OT	28	215.91
	<i>Centropomus parallelus</i>	OT	27	193.38
Ephippidae	<i>Chaetodipterus faber</i>	LT	35	1078.7
Gerreidae	<i>Diapterus rhombeus</i>	DT	28	399.99
	<i>Diapterus rhombeus</i>	DT	18	102.12
	<i>Diapterus rhombeus</i>	OT	15.5	64.34
	<i>Diapterus rhombeus</i>	OT	16	70.97
	<i>Diapterus rhombeus</i>	OT	17.5	93.61

Family	Specie	Group	Length (cm)	Weight (g)
	<i>Diapterus rhombeus</i>	OT	16	70.97
	<i>Diapterus rhombeus</i>	OT	12	29.17
	<i>Diapterus rhombeus</i>	OT	12	29.17
	<i>Diapterus rhombeus</i>	OT	11	22.3
	<i>Diapterus rhombeus</i>	OT	35	797.08
	<i>Diapterus rhombeus</i>	OT	13	37.36
	<i>Diapterus rhombeus</i>	OT	19.5	130.78
	<i>Diapterus rhombeus</i>	OT	17	85.59
	<i>Diapterus rhombeus</i>	OT	15	58.14
	<i>Diapterus rhombeus</i>	OT	14.5	52.36
	<i>Eucinostomus argenteus</i>	DT	15	55.13
	<i>Eucinostomus argenteus</i>	OT	18.5	86.46
	<i>Eucinostomus argenteus</i>	OT	20	110.1
	<i>Eucinostomus argenteus</i>	OT	19	93.92
	<i>Eucinostomus argenteus</i>	OT	16	55.13
	<i>Eucinostomus argenteus</i>	OT	16	55.13
	<i>Eucinostomus argenteus</i>	OT	10.5	14.94
	<i>Eucinostomus argenteus</i>	OT	12	22.6
	<i>Eucinostomus argenteus</i>	OT	15	45.13
	<i>Eucinostomus argenteus</i>	OT	13	28.96
	<i>Eucinostomus argenteus</i>	OT	14	36.44
	<i>Eucinostomus gula</i>	LT	8	8.24
	<i>Eucinostomus gula</i>	LT	10	16.27
Gobiidae	<i>Bathygobius soporator</i>	LT	12.5	24.02
	<i>Bathygobius soporator</i>	LT	11	16.37
	<i>Bathygobius soporator</i>	LT	10.3	13.44
	<i>Bathygobius soporator</i>	LT	10.3	13.44
Haemulidae	<i>Genyatremus luteus</i>	LT	30	558.68
	<i>Genyatremus luteus</i>	LT	24	285.41
	<i>Genyatremus luteus</i>	LT	28.5	478.75
	<i>Genyatremus luteus</i>	LT	28	453.92
	<i>Genyatremus luteus</i>	LT	25	322.72
	<i>Genyatremus luteus</i>	LT	22.5	235.02
	<i>Genyatremus luteus</i>	LT	25	322.72
	<i>Pomadasys corvinaeformis</i>	DT	8	6.84
	<i>Pomadasys corvinaeformis</i>	LT	8	6.84
	<i>Pomadasys corvinaeformis</i>	LT	8	6.84
Mugilidae	<i>Mugil curema</i>	LT	32	403.17
	<i>Mugil curema</i>	LT	30	334.35
	<i>Mugil liza</i>	DT	57.4	2050.76
	<i>Mugil liza</i>	DT	59.4	2274.23
	<i>Mugil liza</i>	DT	63.8	2822.01
	<i>Mugil liza</i>	DT	55	1802.58
	<i>Mugil liza</i>	DT	70	3734.19

Family	Specie	Group	Length (cm)	Weight (g)
	<i>Mugil liza</i>	DT	60	2344.32
	<i>Mugil liza</i>	DT	61	2464.31
	<i>Mugil liza</i>	DT	59.2	2251.19
	<i>Mugil liza</i>	DT	56	1903.39
	<i>Mugil liza</i>	DT	61.4	2513.44
	<i>Mugil liza</i>	DT	60	2344.32
	<i>Mugil liza</i>	DT	60	2344.32
	<i>Mugil liza</i>	DT	53	1611.81
	<i>Mugil liza</i>	DT	44	918.81
	<i>Mugil liza</i>	DT	75	2985.37
	<i>Mugil liza</i>	LT	55	983.34
	<i>Mugil liza</i>	LT	65	2985.37
	<i>Mugil liza</i>	LT	61	2464.31
	<i>Mugil liza</i>	LT	62	2588.35
	<i>Mugil liza</i>	LT	71	3897.63
	<i>Mugil liza</i>	LT	75	4599.23
	<i>Mugil liza</i>	LT	73	4238.72
	<i>Mugil liza</i>	LT	62	2588.35
	<i>Mugil liza</i>	LT	63	2716.49
	<i>Mugil liza</i>	LT	72	4065.78
	<i>Mugil liza</i>	LT	71	3897.63
	<i>Mugil liza</i>	LT	73	4238.72
	<i>Mugil liza</i>	LT	65	2985.37
	<i>Mugil liza</i>	LT	66	3126.24
	<i>Mugil liza</i>	LT	76	4786.93
	<i>Mugil liza</i>	LT	74	4416.52
	<i>Mugil liza</i>	LT	51	1435.03
	<i>Mugil liza</i>	LT	36	351.2
Paralichthyidae	<i>Citharichthys spilopterus</i>	DT	17	43.76
	<i>Citharichthys spilopterus</i>	DT	16	36.3
	<i>Citharichthys spilopterus</i>	LT	12	14.97
	<i>Citharichthys spilopterus</i>	LT	11	11.45
Pomatomidae	<i>Pomatomus saltatrix</i>	DT	29	248.55
	<i>Pomatomus saltatrix</i>	LT	28	224.27
	<i>Pomatomus saltatrix</i>	LT	29.5	261.32
	<i>Pomatomus saltatrix</i>	LT	33	362.94
Sciaenidae	<i>Cynoscion microlepidotus</i>	DT	35	409.07
	<i>Cynoscion microlepidotus</i>	DT	42	725.15
	<i>Cynoscion microlepidotus</i>	DT	22	95.2
	<i>Cynoscion microlepidotus</i>	DT	21	82.26
	<i>Cynoscion microlepidotus</i>	DT	22	95.2
	<i>Cynoscion microlepidotus</i>	DT	19.4	64.14
	<i>Cynoscion microlepidotus</i>	LT	26	160.86
	<i>Cynoscion microlepidotus</i>	LT	20	70.58

Family	Specie	Group	Length (cm)	Weight (g)
	<i>Cynoscion microlepidotus</i>	LT	41	672.31
	<i>Cynoscion microlepidotus</i>	LT	32	308.74
	<i>Cynoscion microlepidotus</i>	OT	22	95.2
	<i>Cynoscion microlepidotus</i>	OT	31	279.45
	<i>Macrodon ancylodon</i>	DT	38.5	517.44
	<i>Macrodon ancylodon</i>	DT	35	382.15
	<i>Macrodon ancylodon</i>	LT	37	456.02
	<i>Macrodon ancylodon</i>	LT	38	496.37
	<i>Macrodon ancylodon</i>	LT	32.5	301.92
	<i>Macrodon ancylodon</i>	LT	34	348.5
	<i>Macrodon ancylodon</i>	LT	30.5	246.7
	<i>Macrodon ancylodon</i>	LT	34.5	246.7
	<i>Macrodon ancylodon</i>	LT	36	417.96
	<i>Macrodon ancylodon</i>	LT	32.5	301.92
	<i>Macrodon ancylodon</i>	LT	33	316.94
	<i>Menticirrhus americanus</i>	DT	29.5	251.65
	<i>Menticirrhus americanus</i>	DT	32	325.14
	<i>Menticirrhus americanus</i>	LT	27	190.39
	<i>Menticirrhus americanus</i>	LT	32	325.14
	<i>Menticirrhus americanus</i>	LT	38	558.69
	<i>Menticirrhus americanus</i>	LT	36	471.2
	<i>Menticirrhus americanus</i>	LT	32	325.14
	<i>Menticirrhus americanus</i>	LT	31	294.2
	<i>Menticirrhus americanus</i>	LT	33	358.24
	<i>Menticirrhus americanus</i>	LT	29	238.45
	<i>Menticirrhus americanus</i>	LT	28	213.5
	<i>Menticirrhus americanus</i>	LT	40	358.24
	<i>Menticirrhus americanus</i>	LT	38	558.69
	<i>Menticirrhus americanus</i>	LT	40	656.66
	<i>Menticirrhus americanus</i>	LT	33	358.24
	<i>Menticirrhus americanus</i>	LT	35	431.19
	<i>Menticirrhus americanus</i>	OT	29	238.45
	<i>Menticirrhus americanus</i>	OT	28.5	225.74
	<i>Menticirrhus americanus</i>	OT	34	393.56
	<i>Menticirrhus americanus</i>	OT	30	265.33
	<i>Menticirrhus littoralis</i>	DT	34	—
	<i>Menticirrhus littoralis</i>	LT	32	—
	<i>Menticirrhus littoralis</i>	OT	15.4	—
	<i>Micropogonias furnieri</i>	OT	19	76.39
	<i>Micropogonias furnieri</i>	OT	24	154.68
	<i>Micropogonias furnieri</i>	OT	21.5	110.96
	<i>Micropogonias furnieri</i>	OT	23.5	145.15
	<i>Micropogonias furnieri</i>	OT	23	136.02
	<i>Micropogonias furnieri</i>	OT	15	37.41
	<i>Micropogonias furnieri</i>	OT	19.5	82.62

Family	Specie	Group	Length (cm)	Weight (g)
	<i>Micropogonias furnieri</i>	OT	21	103.35
	<i>Micropogonias furnieri</i>	OT	20	89.19
	<i>Micropogonias furnieri</i>	OT	23	136.02
	<i>Auxis thazard</i>	DT	58	3472.14
	<i>Euthynnus alletteratus</i>	DT	48	1740.58
	<i>Euthynnus alletteratus</i>	DT	62	3703.3
Scombridae	<i>Scomberomorus brasiliensis</i>	DT	42.5	633.15
	<i>Scomberomorus brasiliensis</i>	DT	38	457.67
	<i>Scomberomorus brasiliensis</i>	DT	32	278.05
	<i>Scomberomorus brasiliensis</i>	DT	32	278.05
	<i>Scomberomorus brasiliensis</i>	DT	32	278.05
	<i>Scomberomorus brasiliensis</i>	DT	32	278.05
	<i>Scomberomorus brasiliensis</i>	DT	31.5	265.63
	<i>Diplectrum radiale</i>	OT	17.5	64.39
	<i>Diplectrum radiale</i>	OT	18.5	76.75
	<i>Diplectrum radiale</i>	OT	15.5	43.88
	<i>Diplectrum radiale</i>	OT	15.5	43.88
	<i>Diplectrum radiale</i>	OT	15	39.56
	<i>Diplectrum radiale</i>	OT	17	58.75
	<i>Diplectrum radiale</i>	OT	16.5	53.46
	<i>Diplectrum radiale</i>	OT	19	83.5
	<i>Diplectrum radiale</i>	OT	18.5	76.75
Serranidae	<i>Diplectrum radiale</i>	OT	16	48.51
	<i>Diplectrum radiale</i>	OT	21	114.56
	<i>Diplectrum radiale</i>	OT	18	70.38
	<i>Diplectrum radiale</i>	OT	18	70.38
	<i>Diplectrum radiale</i>	OT	18	70.38
	<i>Diplectrum radiale</i>	OT	19.5	90.64
	<i>Diplectrum radiale</i>	OT	17	58.75
	<i>Diplectrum radiale</i>	OT	17.5	64.39
	<i>Diplectrum radiale</i>	OT	17.5	64.39
	<i>Diplectrum radiale</i>	OT	18	70.38
	<i>Diplectrum radiale</i>	OT	18	70.38
	<i>Diplectrum radiale</i>	OT	20	98.19
	Stromateidae	<i>Peprilus paru</i>	DT	26
<i>Peprilus paru</i>		LT	27	322.95
Synodontidae	<i>Synodus foetens</i>	LT	13	13.6
	<i>Synodus foetens</i>	OT	27	138.93
	<i>Sphoeroides greeleyi</i>	LT	15	74.93
	<i>Sphoeroides greeleyi</i>	LT	10.2	22.76
	<i>Sphoeroides greeleyi</i>	LT	11	28.74
Tetraodontidae	<i>Sphoeroides greeleyi</i>	LT	9.5	18.27
	<i>Sphoeroides greeleyi</i>	LT	10	21.41
	<i>Sphoeroides testudineus</i>	LT	10	23.46
	<i>Sphoeroides testudineus</i>	OT	18	130.51
	<i>Sphoeroides testudineus</i>	OT	22	234.49

<b>Family</b>	<b>Specie</b>	<b>Group</b>	<b>Length (cm)</b>	<b>Weight (g)</b>
Trichiuridae	<i>Trichiurus lepturus</i>	DT	73.1	356.18
	<i>Trichiurus lepturus</i>	DT	71.5	332.27
	<i>Trichiurus lepturus</i>	DT	73.5	362.34
	<i>Trichiurus lepturus</i>	LT	96	838.11

**CHAPTER 2: SMALL-SCALE FISHING POLICIES IN BRAZIL: WHAT WE CAN  
PROPOSE FOR FISH AND FISHERMEN<sup>2</sup>**

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<sup>2</sup>Chapter formatted according to Marine Policy journal standards.

## Small-scale fishing policies in Brazil: what we can propose for fish and fishermen

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**Abstract:** Small-scale fishermen face difficulties due to adequate public policy gaps. Many nations have already gone through or are undergoing fisheries reform, in order to readjust their historic development policies for a more sustainable vision. Brazilian historical and current public policies are created from data that do not portray the reality of fishing and personal resources in these activities. In addition, the constant changes in the rules, secretariats and systems for recording fishing activities create an unsustainable scenario for their dependents. Thus, in the present study we detect some deficiencies covering the scenario of small scale fishing in Brazil, and provide some tools and recommendations, based on positive experiences from other nations. These suggestions are aimed at contributing to the recovery or preservation of natural stocks, and providing more adequate policies for the human population involved in small scale fishing in Brazil and other developing nations.

**Key-words:** Data, subsidies, fisheries management, ecophysiology

### 1. Introduction

The global fishing crisis began to be highlighted more than three decades ago (Pauly, 2011; FAO, 2009; Alisson, 2001). The causes of this crisis are complex and due to a variety of reasons. These include the challenge of setting an equilibrium between ecological sustainability and social and economic needs and priorities with resulting severe habitat degradation on many places, poor goal setting by governments and institutions related to the rights of access of all actors and stakeholders into participation in management actions, of course allied to intense and chaotic and wasteful fisheries practices all over the globe (Salas et al., 2019; Longo et al., 2015; Greenberg, 2010; Worm et al., 2006; Caddy & Seijo, 2005; Cochrane, 2000).

Almost half of the world's total fish production comes from small-scale fisheries (FAO, 2015), in contrast to about ½ million large-scale fishermen and about 12 million small-scale fishermen (Palomares & Pauly, 2019; Gasalla & Ykuta, 2015). Thus, a lot of people directly threatened by the global crisis on this sector. Globally, government subsidies for large-scale fishing were around 25-30 billion of USD, while for small-scale fishing, only 5-7 billion of USD was applied (Palomares & Pauly, 2019). Therefore, it is essential to recognize the different types of economic incentives aimed at different fisheries sectors, as well as to assess the impacts of these incentives on the sustainability of resources (Schuhbauer et al., 2017; Costello et al., 2008; Vasconcellos et al., 2006) and fishermen.

Furthermore, there is still no global consensus on how to define the “small-scale fishing” and “artisanal fishing” sectors (Rousseau et al., 2019), making comparative studies and international

agreements difficult. The interchangeability of terms normally associated with small-scale fishing - 'artisanal', 'local', 'coastal', 'traditional', 'small', 'subsistence', 'non-industrial', 'low-tech', 'poor'- is indicative of the many values and characteristics underlying its definition (Natale et al., 2015). Proper definition of the type of fishing is relevant for comparing different small-scale fisheries (FAO, 2017) and for planning public policy actions (Ruffino, 2018). Small-scale fishing represents a diverse and dynamic subsector, often characterized by seasonal migration. The precise characteristics of this subsector vary by location and tend to be strongly anchored in local communities, reflecting often historical links to fisheries adjacent to resources, traditions and values, and support social cohesion (FAO, 2015; Silva, 2014). Public management of fishing activity in Brazil has been insufficient to reverse the process of environmental and social degradation in fishing (Haimovici et al., 2014; Dias-Neto, 2010). Balancing fisheries policies and sustainability is a challenge not only for developing countries, such as Brazil, but also for developed countries with a long history of fisheries legislation such as Canada (Bailey et al., 2016).

For many decades, fisheries management focused on achieving maximum sustainable yield through top-down management. These top-down policies were often prescribed without consideration of local social or political contexts, often resulting in unsustainable fisheries. Considerable contemporary fisheries literature is focused on documenting how equilibrium-based policies caused widespread changes to marine ecosystems and the coastal societies that depend on them (Cinner et al., 2013). Conventional management tools used for industrial fisheries are generally unenforceable in small-scale fisheries when implemented in a top-down manner (Worm et al., 2009). For many nations, the development of national rules and regulations is increasing. Initially, development referred mainly to the sustainable harvesting of individual fish stocks, but then also increasingly around general rules of responsible behavior regarding resource use, such as bycatch, as well as damage to the benthic ecosystem caused by certain fishing techniques (Stefansson et al., 2019).

This type of approaches initially appeared in developed countries, as Australia, Canada, European Union Countries (Leal, 2010; OECD, 2006), but later some attempts at change was adopted in developing countries, as Mexico, Africa, and Bangladesh, for example (Branch & Clark, 2006; Sultana & Thompson, 2007). While there are numerous difficulties in implementing bottom-up approaches to small-scale fisheries, as high costs (Mangin et al., 2018), long-term recovery of fish stocks (OECD, 2006) and long-term social dynamics of fishing (Boonstra & Dand, 2010), successful initiatives of such changes are found in many locations and ecosystems (Donda, 2016; SEDAR, 2016; Agar et al., 2014). Lake Chiuta in Malawi is a successful example of a change in small-scale fisheries policies, which excluded some types of overfishing, reduced incentives and promoted co-management, for example, thus allowing the sustainability of local fishing (Donda, 2016). Immediate

management reforms lead to annual improvement in aggregate biomass, harvest and profit over time, such as reported for Mangin et al. (2018) for 28 Mexican fisheries. However, postponing the reform results in substantial costs. A delay of just five years in implementing a comprehensive fisheries reform could lead to a 51 million of USD loss in average annual profits, while a 10-year delay results in a 96 million of USD loss, in addition to affecting the timing of fishery recovery, as predicted upon the analysis of Mexican fisheries (Mangin et al., 2018).

Mainstreaming policy and scientific needs should create opportunities for advancing key measures for small-scale fisheries in a collaborative and multidisciplinary manner. In this context, it is necessary to integrate the different biological, social and economic approaches, with the active participation of stakeholders (government, researchers, fishermen, dealers, companies) to better assess and manage small-scale fishing and the challenges that fishing actors face (Lloret et al., 2018; FAO, 2003). Thus, precise analyses of historical data and current conditions are mandatory for the indication of necessary changes and improvements in this relevant activity, not only in developing nations, but also in developed nations of stronger participation of large-scale fisheries.

The objective of this study was to make an analysis of the Brazilian public policy aimed at small-scale fishermen over the last decades until the present (1962 - 2020). From this analysis, we propose improvements aiming at the sustainability of fishing resources at the coast of Brazil and offshore, conserving resources locally and globally for the future of fishermen and societies.

## **2. Material and Methods**

In order to identify the main challenges related to the resilience of species and small-scale fishers in Brazil, it was necessary to understand the main political transformations that occurred over time, according to the different fisheries management institutions. To this end, a Brazilian fisheries background was constructed (Figure 1), divided into four periods of fisheries management (State 1934 – 1962; SUDEPE 1962 – 1989; IBAMA 1989 – 1998, and Ministries 1998 - Current). From this scenario, it was evaluated: a) competence of fishing statistics; b) small-scale fishery data; c) concept of small-scale fishing and its situation in Brazil; d) subsidies provision for fishing in Brazil. The Brazilian fishing background was created from the assessment of existing relevant legislation (Table 1 - Appendix), and information on total catch reconstruction data accessed in Freire et al. (2015). Items “a”, “b” and “c” were developed from the historical series of official (1945-2012) and unofficial/remaining agreements (Santos Basin Fisheries Activity Monitoring Project, reports 2015-2018, for the States of RJ, SP, PR, and SC) and (agreement between FURG-MPA, reports 2015-2016, for the State of RS). Item “d” was developed by consulting the main benefits and subsidies generated

over the management periods. As a final result of the evaluation of these topics, options were identified to improve the problems faced in this sector in Brazil (Table 2).

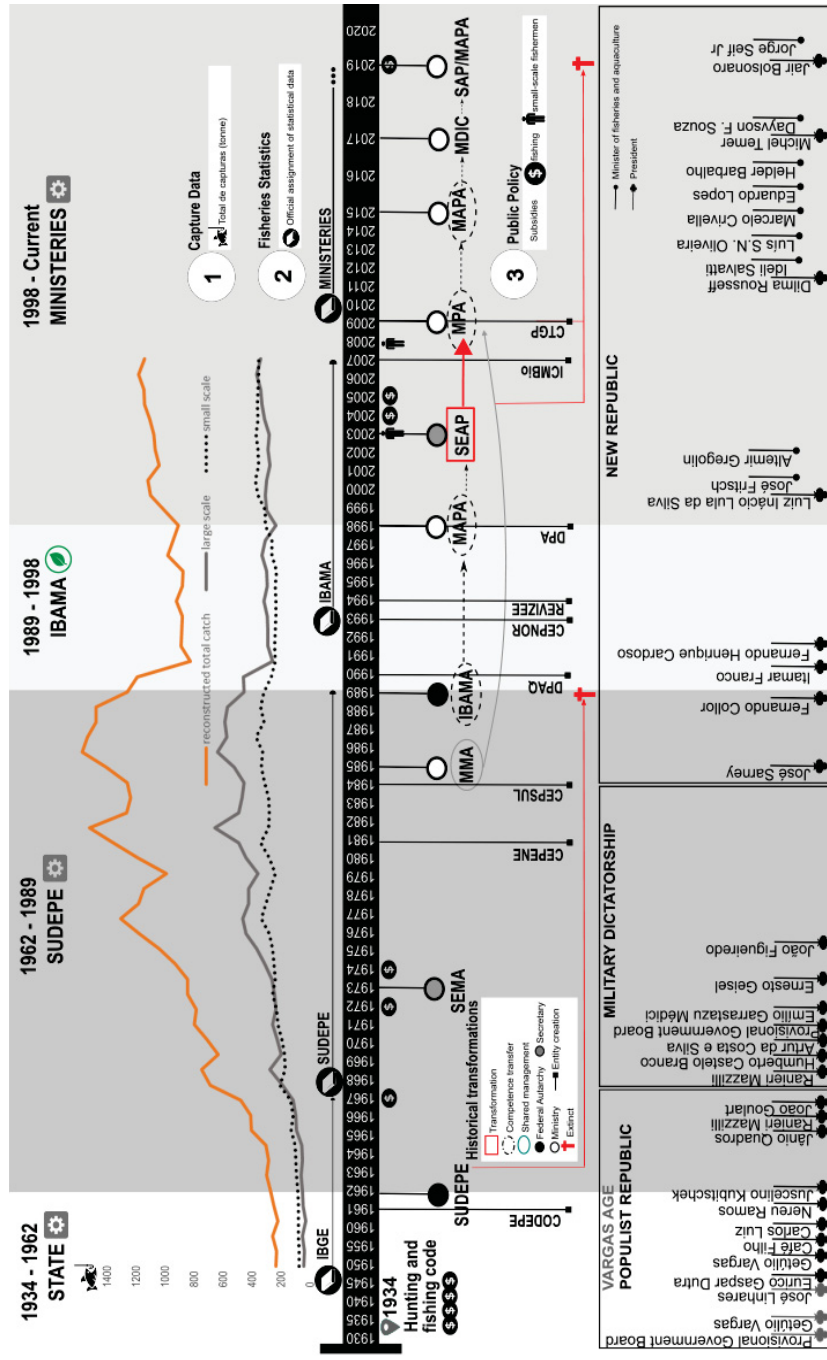


Figure 1. Brazilian fisheries background, divided by management periods: State (1934-1962), SUDEPE (1962-1989), IBAMA (1989-1998) and Ministries (1998 - Current).

### 3. Results and discussion

#### 3.1 Small-scale fishing concept and the situation in Brazil

The distinction between the type of fishing (in Brazilian fishing statistics) was made by various terms (business, colonial/non-colonial, artisanal, industrial) throughout the different periods of fisheries management (Figure 2). As business fishing in which some degree of modernization and greater structuring was supposed, and colonial or non-colonial fishing when carried out by artisanal fishermen (affiliated or not with colonies), as a rule with more rudimentary characteristics (IBGE, 1990).

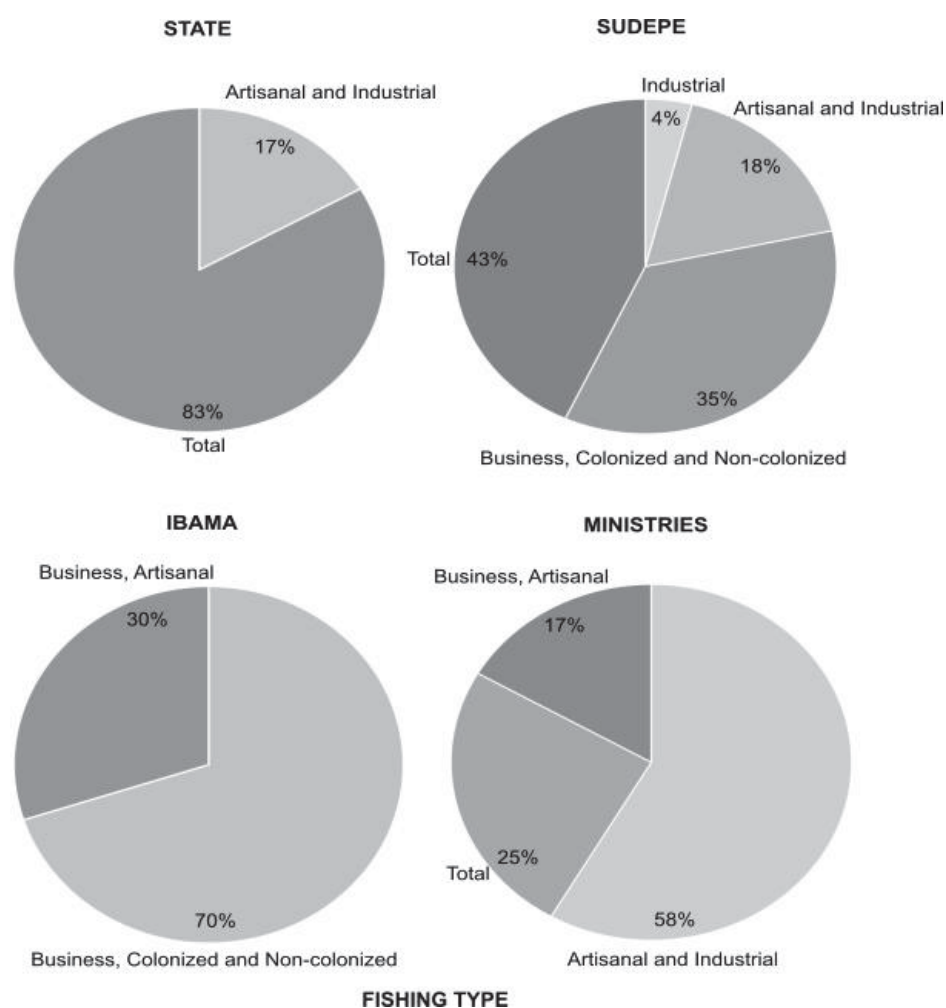


Figure 2. Denominations used for fishing types employed in Brazil in official reports (1945-2012) at different management periods.

Currently, since the creation of the fisheries law, the terms industrial and artisanal are used to differentiate the types of fishing. However, there is no degree of detail that defines small-scale fishing under Brazilian law (Rousseau et al., 2019), being coastal, artisanal (professional), recreational or subsistence fisheries often used as synonyms for small-scale fishing.

Artisanal fishing is defined in Brazil by the National Policy for Sustainable Development of Aquaculture and Fisheries (Law 11.959/2009) (Brazil, 2009) and comprises part of commercial fishing “when practiced directly by professional fishermen, either autonomously or in family economy regime, with its own means of production or by means of a partnership contract, landed, and may use small vessels”. According to Interministerial Normative Instruction 10/2011 (Brazil, 2011), vessels must have a Gross Tonnage (GT) of less than or equal to 20. Also considering the artisanal fishing activities, for the purposes of the Fishing Law, the work of confection and repairs to gear and fishing gear, repairs to small boats and processing of artisanal fishery products.

In several contexts, the term “artisanal fishing” has a definition consistent with the technology (vessel and fishing) used for the development of the activity, and the term “small-scale fishing”, having a definition consistent with its extent (Rousseau et al., 2019). However, these criteria may not be sufficient or appropriate. A broader definition of small-scale fishing would need to include, in addition to vessel size and length attributes, variables related to its local operational range and social role in coastal communities and economies (Natale et al., 2015) and a number of post-harvest sector considerations (FAO, 2017).

According to the Information System on Small-Scale Fisheries (ISS), 62% of studies published in Latin America between 1987 and 2014 use the term “artisanal”, and the remaining 38% of publications use “small-scale fishing” ([issf.toobigtoignore.net](http://issf.toobigtoignore.net)). Small-scale fishing uses smaller (or no) fishing vessels and relatively low-technology fishing methods, and tend to be more labor intensive. Small-scale fisheries are often seen as an activity of low productivity, with low yield rates and low-value products directed mainly to local consumption. However, modern small-scale fisheries can be economically efficient and produce high-value products for international markets. Technological developments particularly motorization, modern navigation, and communication equipment; globalization; and food safety requirements have changed the way many small-scale fisheries operate (FAO, 2012).

If we look at the most recent continuous catch data (unofficial, without considering the Northern and Northeast states) by type of fishing in some southern and southeastern states of Brazil, only the state of Rio Grande do Sul is relatively represented by the industrial fleet. The other states show great contribution by artisanal fishing fleet. Of particular note is the state of Paraná, which is practically dominated by small-scale fisheries (Figure 3).

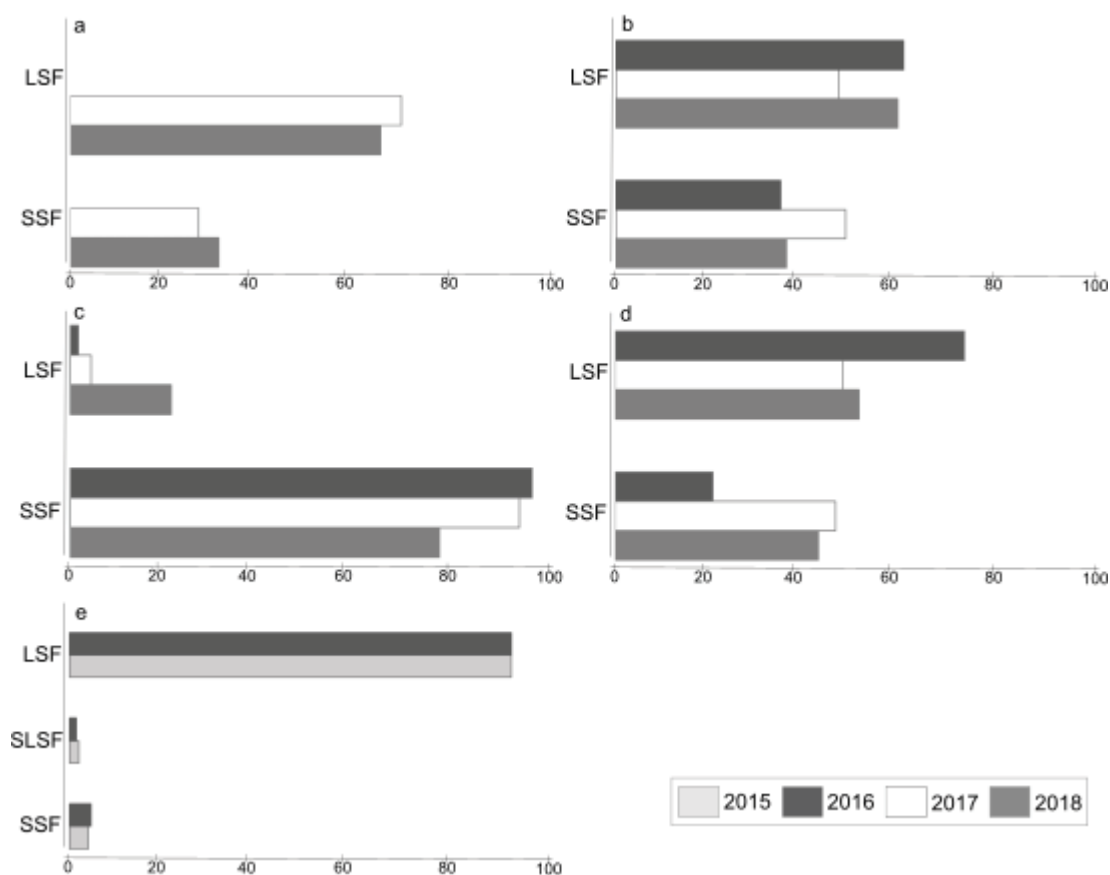


Figure 3. Frequency of total landed marine fish by type of fishing (large-scale: LSF; semi-large-scale: SLSF; small-scale: SSF) in the states of Rio de Janeiro (a), São Paulo (b), Paraná (c), Santa Catarina (d), and Rio Grande do Sul (e).

The artisanal fleet of the State of Rio de Janeiro includes boats known as rowing, canoes, caicos or boats with or without motor, more mobile boats, speedboats, even vessels that can exceed 15m in length, but are still considered small size ( $\leq 20$  AB). These vessels are more mobile and operate on the continental shelf and beyond the slope (PMP-BS, 2018).

In the state of São Paulo, all fishing activities not considered as industrial by exclusion are considered as artisanal. Artisanal fishing can be defined as marine resource extraction activity carried out without a vessel, with a vessel  $< 8$ m (devoid of hold) and with a vessel  $< 20$  AB (provided hold). In general, it is characterized by the use of hand-held or lower fishing gear and operates in coastal and estuarine areas, and is generally linked to traditional fishing communities with their own cultural elements, generating locally or regionally consumed products (PMP-BS, 2017).

The fishing fleet of Paraná is considered mainly artisanal, having only two vessels with AB  $> 20$  in the whole state. Noteworthy is the artisanal fishing fleet of the municipality of Guaratuba, which has the highest catching power of the State, due to the presence of hold, casarias and engine of greater power in the boats (PMP-BS, 2019).

Artisanal fishing is defined in Santa Catarina as an extractive activity of marine resources which, in general is carried out without vessels or with small vessels (i.e. <20 AB), with small displacement power and autonomy per trip, and without hold for storage; uses manual or less fishing power equipment operating in coastal, estuarine and/or lagoon areas; is linked to traditional communities with cultural components, generating locally or regionally consumed products (PMP-BS, 2018).

The fishing activity of Rio Grande do Sul is classified according to the length of the vessel. Fishing is considered “Artisanal” when the vessel has a length less than or equal to 12 meters and with fishing predominantly in the estuary; “Semi-industrial” when the vessel is 12-16 meters long with fishing in the adjacent coastal zone. And “Industrial” when the vessel is 16 meters or more in length with fishing in the adjacent coastal and oceanic region (FURG/MPA, 2018).

### 3.2 Who produces the fishing statistics in Brazil (historical account)?

Brazilian fishery statistics (published in official reports) show the constant changes in internal policies by fisheries management institutions, mainly reflected by the different interests of the institutions responsible (and/or agreed) for the generation and processing of fishery data and by the different information collection systems. Conflicts between government institutions and segregation of responsibilities prevent the development of a unified policy for monitoring and statistics (Silva, 2014).

The first fishing statistics were produced by the Production Statistics Office of the Ministry of Agriculture (Decree-Law 1633/1939) and by IBGE until 1967. In subsequent years, until 1989, the production responsibility for fisheries statistics was attributed to the SUDEPE. It was replaced in 1990 by the creation of IBAMA, which (due to the transitions between SEAP-PR to MPA) led the process of making capture data available until 2008. In 2009, MPA assumed responsibility for producing the reports. Currently (since January 2019), the coordination, systematization, consolidation and publication of national fishery and aquaculture statistics has become the responsibility of the General Coordination for Monitoring Aquaculture and Fisheries, of Secretariat of Aquaculture and Fisheries, of the Ministry of Agriculture, Livestock and Supply (CGMAP/SAP-MAPA) (<http://www.agricultura.gov.br/assuntos/aquicultura-e-pesca>).

Most of the reports analyzed during the management period of SUDEPE were generated due to the Brazilian Fisheries Research and Development Program, in agreement with FAO (Decree 60.401/67), which was initially implemented in the state of Santa Catarina and later extended to other Brazilian states, such as ES, RJ, PR and RS. The reports generated through this agreement presented a greater level of detail of information than previous reports, including data on catches used and scientific names of target species, but focusing efforts on industrial fleet species.

From 1995, IBAMA promoted the improvement of the national fishing statistics consolidation system with the creation of the ESTATPESCA project, developed by CEPENE in all Northeastern States and the State of Pará, by CEPNOR. Being the Fisheries Statistics System of the industrial and artisanal fleet, executed by CEPSUL, CEPERG, Fisheries Institute of São Paulo State and Special Secretariat of Aquaculture and Fishery of the Presidency of the Republic-SEAP/University of Vale do Itajaí - UNIVALI, in the Regions Southeast and South. The reports generated by IBAMA counted on the effective participation of ICMBio's Specialized Centers for Fisheries Management (ICMBio Ordinance 16/2005): CEPNOR, CEPENE, CEPSUL, CEPERG and SEAP/PR, through the agreement SEAP/IBAMA/PROZEE (Monitoring of fishing activity off the coast of Brazil) and were complemented with data and information provided by various institutions across the country (IBAMA, 2007).

In 2007, SEAP/PR informally created a working group to develop and deploy SINPESQ (created by Decree 1.694/95, under IBGE assignment), a system that was shared with the MPA in 2009 due to the Technical Cooperation Agreement between these two agencies (IBGE/MPA). With the insertion of MPA in the attribution of the consolidation of national fishery statistics, the ESTATPESCA Program was gradually replaced by a new monitoring methodology based on the SINPESQ model (MPA, 2012).

Currently, fisheries data are still being generated in some regions of Brazil through remaining agreements between MPA (FURG-MPA, for example), ICMBio (National Research Centers) and Universities. FURG published its latest artisanal fishing newsletter in 2016, continuing only the industrial fishing landing statistics (FURG-MPA, 2018).

In addition to these initiatives, we highlight the São Paulo State Marine and Estuarine Fishing Activity Monitoring Program - PMP (linked to the Paulista Agribusiness Technology Agency of the Secretariat of Agriculture and Supply), which has had a fishing data collection system since 1944, through the ProPesqWeb System (<http://www.propesq.pesca.sp.gov.br/>).

As a control measure to subsidize the environmental licensing processes of PETROBRAS Exploration and Production projects in the Santos Basin, the monitoring of fishing activities (landing data and socioeconomic variables) has been developed since 2008 by the Activity Monitoring Fishing Project (PMP) in the states of SP and RJ (Paraty and Angra dos Reis). Being expanded in 2014 through the project Socioeconomic Characterization of Fisheries and Aquaculture along the coast of the states of Santa Catarina and Rio de Janeiro. And since the second half of 2016, the Santos Basin Fisheries Activity Monitoring Project (PMP-BS) has been running in the state of Rio de Janeiro, São Paulo, Paraná and Santa Catarina by the executing institutions FIPERJ, Fishing Institute, Fundepag and Univali, respectively. The storage of monitoring data is also performed by the ProPesqWeb Information System.

However, the generation of artisanal fisheries data remains challenging, either due to budgetary contingencies (FURG/MPA, 2018) and/or the difficulties in contemplating most fishing

locations and the wide diversity of these types of fishing (PMP-SC, <http://pmap-sc.acad.univali.br/projeto.html>). In addition, there is no body to centralize and analyze the data and to continue the survey. Unfortunately, fishing statistics in Brazil vary according to the government's objective.

### 3.3 Small-scale fishing catch data

As a consequence of the constant changes (creation, alteration and extinction) of the entities responsible for preparing the data in official reports (Figure 1), the catch data reported in official reports (1945-2011) do not represent the reality of targeted stocks of small-scale fishing in Brazil. Data correction should be done through catch reconstruction, including previously unreported and/or omitted (most artisanal catches, subsistence catches, catches by fleets operating illegally, and discarded fish) (Palomares & Pauly, 2019; Zeller & Pauly, 2018). For example, Mozambique's fishing data officially reported in 2004 provided an 800% increase in small-scale catches compared to the previous year, clearly the result of improvements in sampling and reporting systems rather than actual changes in fishing catches from one year to the next (Zeller & Pauly, 2018). Adding estimates of these neglected catches added about 50% to the global marine catch (Pauly & Zeller, 2016), most of it to coastal fisheries (Palomares & Pauly, 2019). For Brazil, the total catch for can be almost twice the baseline reported in the official reports (Freire et al., 2015).

The different methodologies employed, the different data collection investment periods and the different interests in the generation of knowledge about species and fishing activities have generated a quite uneven historical scenario over the periods of fisheries management, which makes it difficult to compare data and the assessment of fish stocks. Several gaps in data collection and publication of fishery statistics can be observed over the years due to political and institutional transitions. From 1990, due to financial and operational problems, the process of disclosure of data was interrupted. Thus, projections of landing data for the period 1990-1994 were made by IBAMA. These projections were made by calculating the arithmetic averages of the data presented by IBGE between 1986-1989, with the addition of production data of the main species of fish accompanied by the Permanent Groups of IBAMA Studies (IBAMA, 1997). This disruption has resulted in a deep gap in official fisheries information, undermining the entire decision-making process concerning the planning, conservation and development of the fisheries management process (IBAMA, 2007). Another discontinuity in the collection of fishing landing data occurred in 2008 and 2009, due to the transition periods between IBAMA, DAP and MPA (MPA, 2010). According to the latest Food and Agriculture Organization of the United Nations report (FAO, 2018) on the state of world fisheries, Brazil has not reported official catch data since 2014, so the data contained in these reports are estimates. However, the last official report was for the year 2011 and published in 2012. Legitimate

information, in addition to supporting planning and decision-making, enhances the chances of success in the formulation and implementation of effective and sustainable public policies aimed at the fishing sector (IBGE, 2012; MPA, 2011). Although the catch data needs to be used with care (Pauly, 2013) they can be used to infer the status of fisheries, especially considering that for developing countries data collection is limited.

In general, fishing data contained in official reports constitute annual production or landing information by regions and federation units. The first reports on the landing of fish mostly addressed the total resources obtained from total extractive fishing in Brazil, with further reports in the state of São Paulo. Under the management of SUDEPE, individual reports were produced for some Brazilian states with greater level of detail, such as information on the gear and effort employed in catching target species from industrial fishing, such as sardines, shrimp, etc.

Reports published under IBAMA and Ministries management periods included information on freshwater and marine species production, extractive fishing and aquaculture. The information on gear contained in the latest reports refers only to artifacts used by the industrial fleet, vessels registered in PREPS (IN SEAP/MMA/MD 02/2006). Through the analysis of the reports, the focus on the industrial fleet and the loss of detail on the components of artisanal fishing are evident. The increase in information in the reports over the years refers to aquaculture and export data.

With respect to capturing data from unofficial reports, small-scale fishing in the South and Southeast regions refers to varied resources, and most activities, in addition to fish catches, aim to obtain miscellaneous shrimps, uçá crab, clams and oysters, for example. Regarding the catching of fish, it is observed that most landings consist of sciaenids (mainly whitemouth croaker), grey mullets and engraulids/clupeids (RJ). The categories “other” and “mixture” are quite representative in some fisheries (Figure 4). These categories represent fish of various species that are accidentally caught, mainly by shrimp trawling. Considering that the annual bycatch by Brazilian fisheries is of the order of 55 thousand tons (Silva-Júnior et al., 2015) and that sciaenids are resources captured by small and large-scale fishing along the Brazilian coast, both as target species and as bycatch (Chaves & Silva, 2019, Passarone et al., 2019; Queirolo et al., 2016; Schroeder et al., 2014), which much of the bycatch refers to juvenile individuals (Silva-Júnior et al., 2015; FAO, 2011), and that this fish family has resources of great commercial value, there is an urgent need to manage these resources. Sciaenids constitute about 20% of total marine fish landings and 9% of freshwater landings in Brazil. And both freshwater and marine sciaenid resources are considered vulnerable to overfishing; coastal habitat degradation from urbanization and aquaculture; oil exploration and dam construction (Chao et al., 2015). Although the Brazilian Sciaenid fishery production has been relatively stable over the past decade, the level of production has likely been maintained by increased fishing effort and expansion of fishing grounds (Chao et al., 2015).

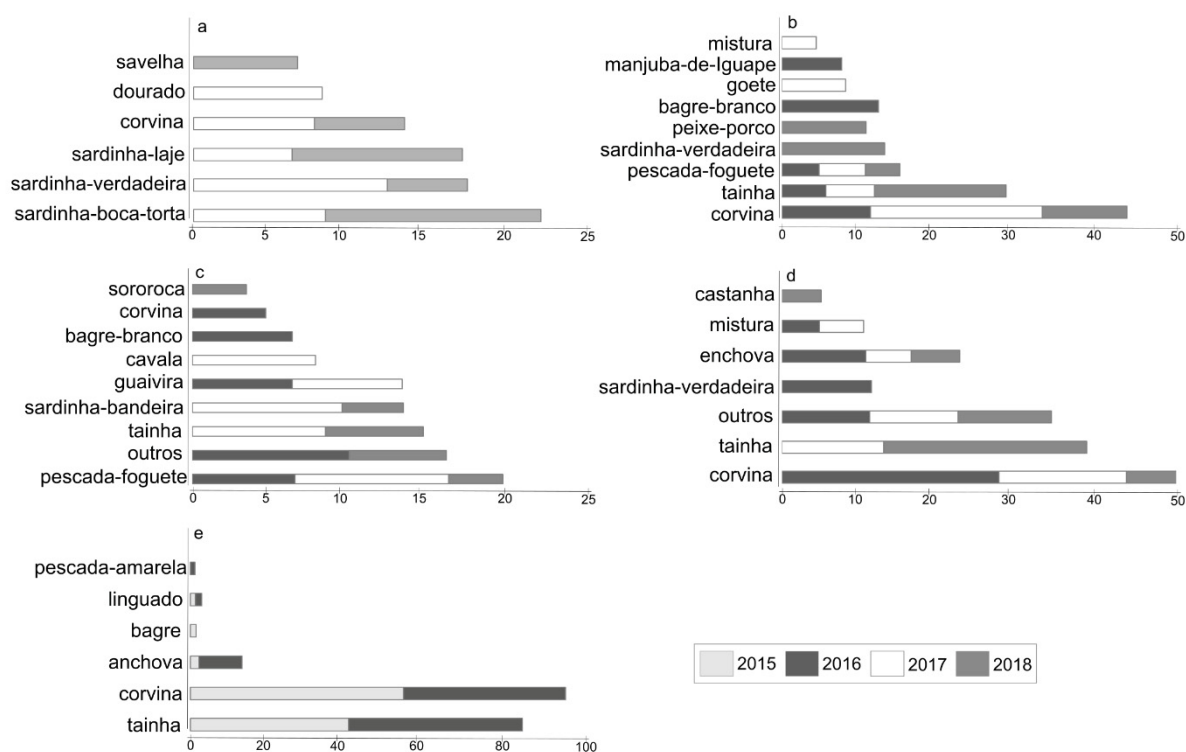


Figure 4. Frequency of the five main species landed annually by artisanal fishing in the states of Rio de Janeiro (a), São Paulo (b), Paraná (c), Santa Catarina (d), and Rio Grande do Sul (e).

The most representative small-scale fishing gears were mostly gillnets for the Santos Basin monitoring target states, except for the state of Rio de Janeiro, which had its largest catches from purse-seine. Other arts often used by artisanal fishers are double-trawl, miscellaneous lines and manual collection (Paraná) (Figure 5). However, more than twenty fishing gears are known to be used by small-scale fishermen in these regions (PMP-BS, 2019, 2018, 2017).

Although we selected only a cut from the most recent fishing data presented for the states of RJ, SP, PR, SC and RS, it is evident that there is great variability in fishing characteristics between regions and years. Artisanal fisheries in these states present a great diversity of fishing strategies as well as of caught resources. It can operate in open water, estuarine and lagoon areas, and use (or not) both low mobility boats, with low power oars or engines, even medium and large vessels with characteristics of the industrial fleet (PMP-BS, 2019).

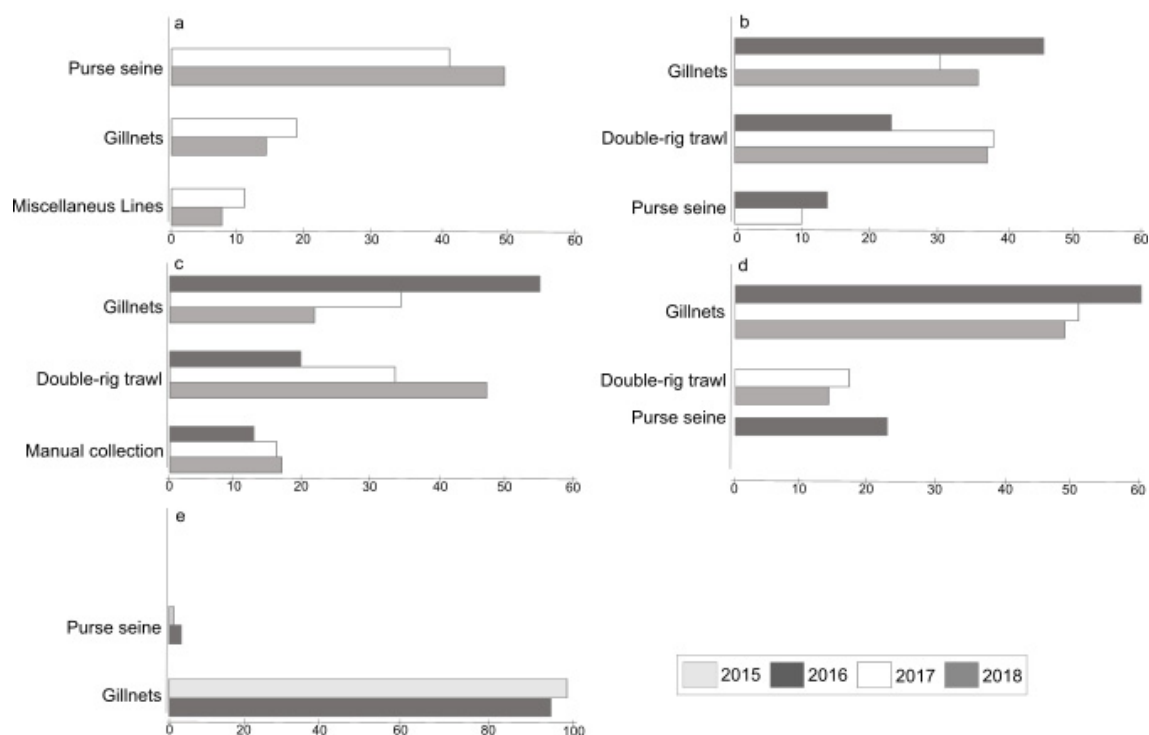


Figure 5. Frequency of the main artisanal fisheries gears used per year in the states of Rio de Janeiro (a), São Paulo (b), Paraná (c), Santa Catarina (d), and Rio Grande do Sul (e).

The inherent characteristic of artisanal fishing is its complexity, due to the diversity of the equipment used to catch fish from multispecific stocks, the dispersion of landing points and the participation in various production chains (Silva, 2014; Soares et al., 2009). Information about the number of small-scale fishers and their catches reveals the social and economic importance of this sector (Chuenpagdee et al., 2006). The lack of reliable information on the artisanal fishers contingent, their fishing practices and livelihoods can be considered as one of the main limiting factors for the success of current artisanal fisheries management and development measures (Haimovici et al., 2014).

An important feature of small-scale fisheries is that they do not fluctuate as strongly as industrial fisheries, for two basic reasons: (1) the fishing power of artisanal fisheries is rarely sufficient to annihilate marine fish stocks, something which industrial fisheries are not only capable of, but also frequently do and (2) when a species targeted by a small-scale fishery declines, other species are exploited, so that overall catches are maintained (Palomares & Pauly, 2019).

### 3.4 Public policies for small-scale fishing in Brazil

Public policies affect many aspects of life in society and interest in studying them has been growing (Rodrigues, 2011). In order to evaluate Brazilian legislation related to small-scale fishing, we use the concept of public policy proposed by Secchi (2014): a public policy is a policymaker's

guideline to the activity or passivity of a policytaker and also the set of actions or inactions derived from it. State policies should be long-term, focused on the general interest of the population and independent of electoral cycles (Secchi, 2014). The Federal Constitution of Brazil adopted the principle of sustainable development (Brasil, 1988), but this principle is not yet present in many public policies in the country. The Brazilian constitution is recent (1988) and Brazil still has a weak democratic regime. In accordance with the principle of sustainable development, the environmental, economic and social dimensions must be present for the management of activities.

Throughout the history of Brazilian fisheries, since before the promulgation of the federal constitution, it is possible to identify a series of tax benefits and incentives that marked periods of fomenting fishing activities (State, SUDEPE, and Ministries) (Figure 6) and a phase of resource conservation (IBAMA), without generating subsidies to foster activities.

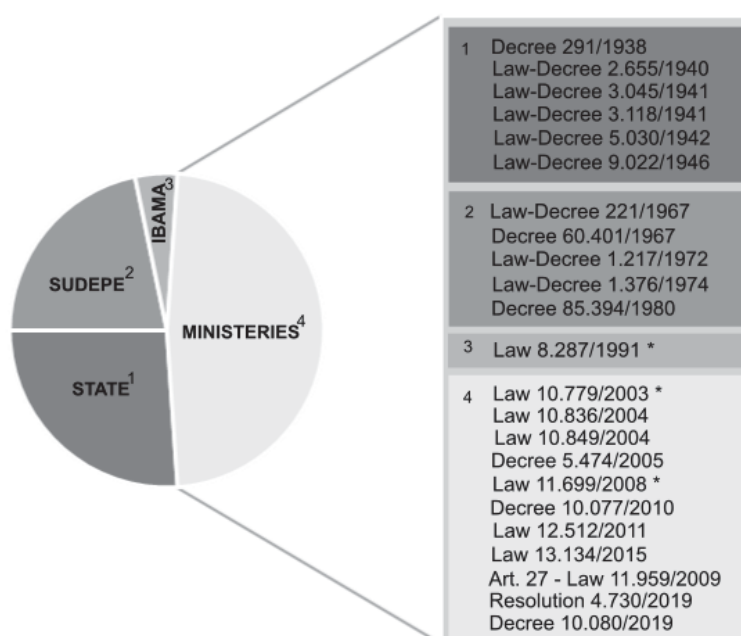


Figure 6. Subsidies and incentives for Brazilian fishing activity at different management periods. Highlighted laws (\*) refer to small-scale fishing.

Initially, in the 1950s, fishing incentives for fisheries in Brazil are focused on industrial fishing. This historic moment is related to the Brazilian military regime that prioritized industrial development at the expense of the exploitation of natural resources (Dias, 1998). In the 2000s, there was a greater concern about the social issues of artisanal fishermen and the strengthening of the production chain (Hellebrandt et al., 2012). Regarding subsidies directed to the artisanal fisherman, “*Seguro Defeso*” (a kind of unemployment benefit) (created by Law 8287/1991) stands out, which has as its environmental and socioeconomic objectives and is one of the fishing planning instruments of the current Fisheries Law. However, although this subsidy has been an advance in terms of

considering the artisanal fisherman in Brazilian law, it does not represent an effective benefit for improving the fisherman's quality of life and ensuring the resilience of the species. The social dimension is less researched and receives less political attention when compared to the environmental and economic dimensions (Gollan, 2019). Therefore, understanding the role of *Seguro Defeso* is important to know if it meets the principle of sustainable development in the context of small-scale fishermen's policy.

Some problems with the implementation of this benefit can be highlighted since the registration phase of the fisherman in the system. The initial requirement for granting the artisanal fisherman's *Seguro Defeso* (Unemployment income during time of reproduction of the target species - Law 10.779/2003) is to register with the General Fisheries Register - RGP (Law No. 11.959/2009) to apply for the Professional Fisherman's License (IN MPA No. 06/2009). However, since 2014, the Fisheries and Vessel Licenses Registration and Issuance System - SISRGP, has presented recurring operational problems. The new Aquaculture and Fisheries Secretariat is currently implementing a new registration system, SISRGP 4.0, and this system is in the process of re-registering and training collaborating entities (<http://www.agricultura.gov.br/>).

Fisheries monitoring reports in the Santos Basin show a downward trend in the number of fishermen with the RGP (from 2014 to 2018) in all monitoring target states. There is a tendency to reduce fishermen's access to *Seguro Defeso* and reduce the number of beneficiaries of other public policies, such as oil and ice subsidies, Pronaf and Profrota. In addition, an important part of the artisanal fishermen who are active are in irregular condition with the managing authorities. As this reduction reflects the changes in public policies related to the sector, which has not yet been able to implement a way to register fishermen and since 2015 has been presenting great difficulties in advancing this issue (PMBS, 2018; 2017; 2016). This way, there is no control over who is actually receiving the benefit and preventing the registration of new beneficiaries. There are discrepancies in all Brazilian states regarding the number of artisanal fishermen and the number of beneficiaries of *Seguro Defeso* (Figure 7). These discrepancies are related to the fact that the program targets groups that apparently are not from artisanal fishermen, or even fishermen (Campos & Chaves, 2014).

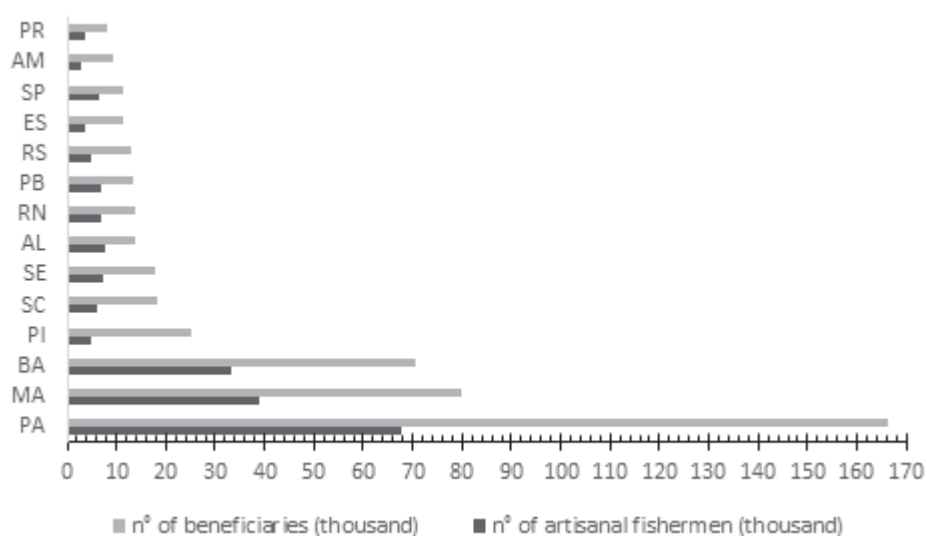


Figure 7. Number of artisanal fishers and beneficiaries (in thousand) of the Safe Defeso program (Law 10.779/2003) by Brazilian coastal state in 2010. Taken from Campos & Chaves (2014), modified.

In addition, a number of other issues can be listed, such as the difficulty in overseeing fishing activities during the off-season, the management of beneficiary information, the lack of coordination between the actors involved, the lack of a policy steering committee and lack of data (SECAP, 2019). Artisanal fishing over the different management periods has been the subject of virtually no action by governments, which have focused on either the industrial development of the sector or the conservation and preservation of resources. And subsidies for large-scale fishing are harmful to small fishers (Schuhbauer, et al, 2017). In this way, the social condition of artisanal fishermen, their economic and food production contribution, and the diversity of their cultural life forms were fundamentally beyond governmental concerns. More than that, the result of developmental and conservationist policies, coupled with the void of substantive artisanal fishing policies, has meant that most artisanal fishers and their communities are left in very precarious living conditions. As such, they were the main victims of the fisheries crisis without being primarily responsible for causing it, being condemned to impoverishment and to face unequal competition with industrial fishing and business aquaculture and related conflicts (Azevedo & Pierri, 2014).

Policies for the fisheries sector, from 1960s to the mid-1980s, led to a great increase in fisheries harvest, without appropriate consideration for the long-term sustainability of the marine resource. The main consequence of this policy was the decline in fish catch in the following years, simultaneously with a decline in the output of the post-harvest sector. In the face of declining fish harvest over time, the present government (2019) instigated an incentive program to increase catches, without formulating management plans with regard to the species that were to be caught. Besides the need for scientific management of fisheries resources, there is an economic need to add

value to the raw resource. This would entail the improvement of the processing of fish and the utilization of some of the parts of the resource presently being discarded. Finally, if the economic logic does not consider the biological logic of renewable natural resources, the result will be the extinction of the natural capital, resulting in terrible consequences on the nutritional requirement of generations of Brazilians to come (Abdallah & Sumaila, 2007).

Currently, the current government continues to implement *Seguro Defeso* and to generate new options for promoting fishing activities through rural credit (Resolution No 4.730/2019), with no apparent benefit programs for the artisanal fishermen and overfished fishery resources. In addition, ongoing management objectives are the strengthening and expansion of aquaculture and exports (<http://www.agricultura.gov.br/>). In addition to the growing incentive to aquaculture and industrial fishing, small-scale fishermen need to deal with legislation that creates protected areas further limiting their activity (Pérez & Gómez, 2014). Additionally, SAP/MAPA has excluded all direct, municipal and foundational federal public administration colleges (Decree 9.759/2019 and Decree 9.812/2019) (<http://www.agricultura.gov.br/>). These colleges included the permanent management committees, forums and other groups related to fisheries planning based on shared management. Democratic governance of marine resources requires democratic accountability to the people, and therefore steering instruments in fisheries should consider the public's interest and allow participation of all stakeholders and especially those most affected by the management of the resource (Harring & Ronnerstrand, 2016).

What is possible to conclude the set of legislation associated with small-scale fishermen in Brazil is that welfare assistance prevails instead of rules that help the social, economic and environmental development of the activity. There is no clear guiding rule for new laws to be created. Each government decides how to deal with the issue of small-scale fishing. Thus, the principle of sustainable development is not included in the legislation on small-scale fishing and fish and fishermen are devoid of a policy that complies with the Brazilian federal constitution.

#### 4. What is needed to improve highlighted issues?

According to the scenario analyzed, there is no effective evidence (except individual and/or regional initiatives) of developing current measures that favor the landscape of small-scale fishing in Brazil, both in reference to fishery resources and fishermen. On the contrary, the new management period is pointing to flaws in several segments that form part of the Fisheries Act itself (Law 11.959/2009). Failures that were already being committed in other fisheries management periods (Dias-Neto, 2010; Abdallah & Sumaila, 2007).

According to Article 7 of the Law in force, the sustainable development of the fishing activity will occur through:

- I – management of access and use of fishery resources;
- II – determining specially protected areas;
- III – social participation;
- IV – training of the fishing sector workforce;
- V – environmental education;
- VI – the construction and modernization of the port infrastructure of port terminals, as well as the improvement of port services;
- VII – the research of the resources, techniques and methods pertinent to the fishing activity;
- VIII – the fishing activity information system;
- IX – control and inspection of fishing activity;
- X – credit to promote the fishing sector.

From the analysis of the competence on the fishing statistics, it was evident the difficulty of only one institution in collecting and producing relevant information for the proper contemplation of the complexity of the small scale fishing that compose the different Brazilian regions. Catch data are out of date and, in fact, information on artisanal fishing activities are secondary objectives in these reports. In addition, there are several issues regarding the benefits and tax incentives for artisanal fishers, which start from the basic register of fishermen in the activity registration system, to the correct inspection and distribution of subsidies. These deficiencies, coupled with the current condition of fishing resources (Brasil, 2006), make it difficult for small-scale fishing activities to resilience in Brazil. Conventional management tools used for industrial fisheries (such as current fisheries law) are generally not applicable to small-scale fisheries when implemented in a top-down way (Worm et al., 2009). The lack of information makes it impossible to construct indicators to monitor the policy, such as catch per unit effort (CPUE), for example, that can also be used as a proxy for the size measurement of the fish stock (SECAP, 2019).

Thus, below are some measures based on other studies that may contribute to the improvement of the highlighted problems (Table 1).

Table 1. Proposed measures to contribute to the improvement of the problems highlighted for small-scale fishing in Brazil

Highlighted issues	Improvement proposal	Source
a) Lack of Data	Participatory information acquisition	Canty et al. (2019); Begossi et al. (2016); Silva (2014); FAO (1998)
	Unified database	Mcdonalds et al. (2018); Chuenpagdee et al. (2017); FAO (2015)
	Ecophysiology data	Cook et al. (2018); Birnie-Gauvin et al. (2017); Mckenzie et al. (2016); Dantzer et al. (2014); Cochrane (2000)
b) Small-scale fishing concept	Disaggregated information	<sup>34</sup> FAO (2012)
	Index for small-scale fisheries characterization	<sup>14</sup> FAO (2017)
c) Public politics	Ecosystem management	Benson & Stefenson (2018); Schumacher et al. (2018); FAO (2015a); FAO (2013); Serafini et al. (2014), Fletcher et al. (2010);
	Collaborative management	Seixas e Kalikoski (2009); FAO (2003); Garcia et al. (2003); Cochrane (2000)
	associative structures for small-scale fishermen proposals contained in “a” and “b”	Haimovici et al. (2014); FAO (2013)

#### 4.1 Improvement of the reliability of data generated on SSF

Data generation and knowledge production of the various aspects related to artisanal fishing activities should be the first steps in any decision making regarding the use of resources and policies of artisanal fishing. Continuous monitoring of fishing landings is essential to develop, encourage or slow the exploitation of a resource and to support the definition of fisheries planning measures, the establishment of a closed period, and knowledge of trends and variations in national production of the fishery.

Fisheries monitoring reports in the Santos Basin, although existing as a result of a licensing process, provided information that had not been continuously collected for a long time and should serve as examples as fisheries monitoring in other Brazilian states.

As an example, the information contained in these reports was used to guide public policies related to fisheries and fishery resources, such as fishing permits in Marine PARNA of Currais

(Commitment Term, 2017 and Statement of Commitment, 2018), as well as Marine Catfish Recovery Plan (Inter-Ministerial Ordinance MMA/SGPR n°39/2018) (PMBS, 2019).

Like many other scientific, economic and policy endeavours, fisheries science uses time-series data as part of investigations and analyses, and derives both scientific conclusions and policy recommendations from such data (Zeller & Pauly, 2018). In addition, other forms of knowledge could be incorporated into management plans and public policies, such as the traditional knowledge (Begossi et al., 2016; Lima et al., 2016; FAO 2015b) of fishing communities and the use of ecophysiological data on fish species.

Participatory information acquisition, in addition to making the process more reliable, has a number of benefits: (i) it provides the basis for promoting locally supported research, (ii) supports the implementation of correct planning measures according to fishermen's needs (iii) provides legal instruments for sustainable and participatory community development, (iv) strengthens national fisheries policies and local associations, (v) increases the degree of community involvement in their own decisions, (vi) strengthens citizenship, among others (Silva, 2014).

Similarly, we refer to physiological data in fishery science. Conservation physiology can be defined as the application of physiological theory, approaches, and tools to elucidate and address conservation problems in order to provide a mechanistic understanding of how environmental disturbances and threatening processes impact physiological responses, and thus ecological function, population resilience and species survival (Seebacher & Franklin, 2012). It is increasingly recognized that physiological tools for the assessment of individual stress level or health are very important for decision-making in conservation programmes and for developing cause-and-effect relationships (Beaulie & Constantini, 2014). Classifying anthropogenic activity as a "stressor," it is possible to look at comparisons and gradients of stress while providing results that are relevant to conservation (Cooke & O'Connor, 2010).

While environmental and biological factors are important when considering how a fish responds to a stressor, understanding the effects of various fishing methods has the potential to steer mitigation efforts because gear and method variations can be more directly controlled. Physiological data available, how the rates of discard mortality and of the sub-lethal effects of capture, for example, are limited and largely focused on North American and European fisheries, and/or limited to species relatively easy to obtain and maintain in captivity (Mckenzie et al., 2016), with very limited data available on small-scale fishing or in developing countries (Cook et al., 2018).

Fish discarded from commercial fisheries are exposed to multiple acute stressors. Fishing gear may lead to entanglement, physical trauma and/or confinement. Attempts to escape can lead to exhaustion during both capture and handling and, when on-board, fish are often air-exposed and face additional trauma. For fish discarded from fisheries, behavioural impairment (Brownscome et

al., 2013) due to stress and/or a failure to recover from the stress event can have fitness effects. Understanding the physiological mechanisms that lead to reflex impairment (such as activation of aerobic metabolism, for example) is important for linking the sublethal effects of stress to fitness (McLean et al., 2016). Stress proportional to duration and magnitude of disturbance. Ultimately, mortality results when the magnitude and duration of the stressor overcomes the adaptive stress-coping mechanisms available to the individual. Understanding the effects of stressors experienced by discarded and by catch-and-release (McLean et al., 2016) fish will better establish connections between fishing method and probability of survival, and can inform mitigation. The severity of stress associated with commercial fishing is directly related to gear type, fishing method and handling of captured fish (Cook et al., 2018). Overall, the post-stress levels of captured as bycatch individuals were higher compared to fish caught on beach trawls. And, specifically for some sciaenids, there was another type of stress response (besides the increase in the levels of primary and secondary stress responses). *Macrodon ancylodon* and *Cynoscion microlepidotus* showed a delayed response to capture stress, with cortisol levels similar to levels of unstressed fish (Author data, unpublished). And while this type of response may be a strategy associated with benthic fish habits (Vijayan & Moon, 1993), it can be detrimental when it comes to recovering fish stocks, especially fish captured as bycatch. Observations of delayed recovery in air-exposed fish have inspired questions about the effects of angling on post-release predation (Cook et al., 2015).

Mitigation strategies need to consider how the capture process can be modified to minimize the magnitude, duration or likelihood of stress and injury experienced. Probability of recapture following release and the factors influencing recapture similarly remain unknown, and relatively unstudied, for commercial fisheries. This is important when considering stressor action as effects to individual fish may be cumulative with every capture event. The practicality and efficacy of potential mitigation measures must be explored and tested for individual fisheries (Cook et al., 2018).

All this data can be imputed to a common online open access database, besides being used in mechanistic models. Examples of a global collaborative online database that provide small-scale fishing (SSF) information to help improve knowledge about this sector are OurFish (Canty et al., 2019), AFAM (McDonalds et al., 2018), and ISSF (Chuenpagdee et al., 2017).

#### 4.2 Improvement of the characterization of Small-scale fishing concept

Disaggregated information and separate analysis of large scale, small-scale, artisanal, recreational, marine, and inland fisheries create a better understanding of their respective roles and social and economic importance. A disaggregated analysis can underpin investment in reforms and in the capacity to develop and implement governance systems adapted to the local context of small-

scale fisheries. It can also help build political will for reforms founded on a greater understanding of the social, economic, nutritional, and cultural importance of these different sector segments. The diversity within each subsector, or industry segment, is enormous, with multiple areas of overlap between the subsectors providing a continuum, or spectrum, of production and marketing systems from shoreline collection of shellfish to electronic auctions and recreational fisheries (FAO, 2012).

In this line, the United Nations Food and Agriculture Organization has proposed an index the definition of small-scale fisheries as a continuum, potentially based on an index of descriptive variables (Table 2). This approach also allows for considerable analysis and breakdown between different types of small-scale fishing. A similar matrix could be developed for the small scale postharvest sector, using some of the same characteristics, but also adding specific postharvest dimensions (FAO, 2017).

Table 2. Proposed index for small-scale fisheries characterization

Score	0	1	2	3
1	No vessel	<12m, <10GT	<24m, <50GT	>24m, >50GT
2	No engine	Outboard engine Small power	Inboard engine <400hp	Inboard engine >400hp
3	No mechanization	winch/hauler powered off engine	Independently powered gear deployment/hauling	Fully mechanized gear deployment and hauling
4	No storage	Ice box	Ice hold	Refrigerated hold
5	Individual and/or family members	Cooperative group	<2 paid crew	>2 paid crew
6	Owner/operator	Leased arrangement	Owner	Corporate business
7	Part-time/occasional	Full-time/but seasonal	Part-time all year	Full-time
8	<6 hours	Day trip	<4 days	>4 days
9	<100 metres from shoreline	<3 km from shoreline	<20km	>20km from shoreline
10	Household consumption/barter	Local direct sale	Sale to traders	Onboard processing and/or delivery to processors
11	For direct human consumption	Chilled	Frozen	Frozen/chilled for factory processing (for human consumption or fishmeal)

Score	0	1	2	3
12	Informal, not integrated (no fees)	Integrated (registered, untaxed)	Formal, integrated (licensed, landing fees)	Formal, integrated (licensed, taxed)

\*1-Size of fishing vessel (or equivalent range for fixed gears); 2- Motorization; 3- Mechanization; 4- Refrigeration/storage on board; 5- Labour/crew; 6- Fishing unit/ownership; 7- Time commitment; 8- Day trip/multiday; 9- Fishing grounds/zone/distance from shore; 10- Disposal of catch; 11- Utilization of catch, value added/preservation; 12- Integration into economy and/or management system. Taken from FAO (2017).

#### 4.3 Improvement of the develop of Public Politics for fisherman

An ecosystem approach aims to plan, develop and manage fisheries to meet societal needs and desires without jeopardizing the ability of future generations to benefit from the full range of goods and services provided by marine ecosystems (FAO, 2003). Thus, and from the points highlighted above (lack of data, subsidy problems, institutional changes and overexploitation of resources), coupled with the inherent diversity of small-scale fishing activities and the country, the integration of traditional knowledge, scientific knowledge and all stakeholders to know the current state of the fishery and fishery resources that carry out these activities and then create management plans appropriate to the current reality of the fishery and fishery resources.

Although collaborative management has emerged in Brazil in the 1980s, some factors have been limited to the development of collaborative coastal management until nowadays. Misrepresentation and legitimacy of user organizations; cultural policy and government praxis, and knowledge gaps are some of these factors (Seixas et al., 2019). The lack of flexibility and adequacy of government institutions creates additional barriers to the development of adaptive management processes. Adaptive management usually requires periodic adjustments guided by better knowledge, outcome evaluation, and new realities (Seixas et al., 2019).

## 5. CONCLUSIONS

The Brazilian fisheries scenario reflects the constant institutional changes and political interests of the management period. Throughout the four periods of fisheries management evaluated, the focus of industrial fishing policies on subsidies and information generation was highlighted. Due to the political-fishing scenario being renewed with each management period, fishery information is a mosaic, which makes comparisons and effective management plans difficult and should be universally reshaped, regardless of the electoral cycle. The lack of reliable statistics, partial estimates of landings data, lack of effective subsidies for the small-scale fisherman, reduced fish stocks and frequent biodiversity losses reflect this need. Thus, it is recommended to encourage collaborative management, so that fishermen (especially small-scale fishing), researchers and various public and

private institutions have participation in decision-making. And in this way, and through appropriate tools (such as physiological stress measures and a unified database, for example), contribute to management plans. In addition, create associative structures and improve small-scale fishermen's access to government policies.

#### Acknowledgements

This work was supported by the The National Council for Scientific and Technological Development National [141074 2016-7].

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#### Appendix 1 - Sources used to build fishing background

Management Period	Normative Basis	Statistics Competence	Subsidies Provision
STATE	Decree n° 23.672/1934a		
	Constitution of the Republic of the United States of Brazil/1934b		
	Law-Decree n° 218/1938a		
	Decree n° 291/1938b		X
	Law-Decree n° 794/1938c		
	<u>Law-Decree n° 1.633/1939a</u>	X	
	Law-Decree n° 1.688/1939b		
	Law-Decree n° 2.655/1940		X
	Law-Decree n° 3.045/1941a		X
	Law-Decree n° 3.118/1941b		X
	Law-Decree n° 5.030/1942		X
	Law-Decree n° 5.530/1943		
	Law-Decree n° 6843/1944		
	Law-Decree n° 8208/1945a		
	Law-Decree n° 8321/1945b		
	Law-Decree n° 8526/1945c		
	Law-Decree n° 9022/1946a		X
	Law-Decree n° 9415/1946b		
	Decree n° 50.872/1961		
	SUDEPE	Law n°10/1962	
Decree n° 51.868/1963			
Law-Decree n° 221/1967a			X
Decree n° 60.401/1967b		X	X
Law-Decree n° 1.217/1972			X
Law n° 5.878/1973a		X	
Decree n° 73.030/1973b			
Decree n° 73.632/1974a			

Management Period	Normative Basis	Statistics Competence	Subsidies Provision
	Law-Decree n° 1376/1974b		X
	Decree n° 85.394/1980	X	X
	Law n° 6.938/1981		
	<u>Ordinance n° 138/1984</u>		
	Law n° 7.735/1989	X	
	Law n° 8.287/1991		X
IBAMA	<u>Decree n° 1.694/1995a</u>	X	
	Decree n° 1.697/1995b		
	Law n° 9.649/1998a		
	Decree n° 2.681/1998b		
	Normative Instruction IBAMA n° 29/2002		
	Law n° 10.683/2003a		
	Law n° 10.779/2003b		X
	Law n° 10.836/2004		X
	Law n° 10.849/2004		X
	Decree n° 5.474/2005		X
	Law n° 11.516/2007		
	Law n° 11.699/2008		X
	Law n° 11.958/2009a		
	Law n° 11.959/2009b	X	
	Decree n° 6.981/2009c		
	Interministerial Ordinance MPA/MMA n° 02/2009		
	Decree n° 10.077/2010		X
	Law n° 12.512/2011		X
	Decree n° 8424/2015a		
	Decree n° 8425/2015b		
	Law n° 13.134/2015		X
MINISTRIES	Interministerial Ordinance MPA/MMA n° 5/2015c		
	Ministerial Reform/2015c		
	Decree n° 8973/2017a		
	Decree n° 8967/2017b		X
	Decree n° 8974/2017c		
	Decree n° 9.004/2017d	X	
	Provisional Measure n° 782/2017e		
	Law n° 13.502/2017f		
	Law n° 13.668/2018		
	Joint Ordinance MMA/ICMBio n° 261/2018		
	Interministerial Ordinance MMAR/MD n° 386/2018		
	Provisional Measure n° 870/2019a		
	Decree n° 9.667/2019b	X	
	Decree n° 9.759/2019c		
	Law n° 13.844 /2019d		
	Resolution n° 4.730/2019e		X
	Decree n°10.080/2019		X

## **Appendix – Internship Report - 3 months at Norwegian University of Science and Technology - NTNU (Campus Ålesund)**

Visiting Researcher in the Project: Norwegian-Brazilian partnership program on sustainable aquaculture systems. Project number UTF-2018-two-year/10077.

### 1. INTRODUCTION

Norway is the largest salmon-producing country in the world, with a production share of over 50%. Atlantic salmon is the dominant species in Norway, but salmon trout is also produced. In principle, the production process for farmed salmon is quite simple. At a hatchery, the salmon eggs and fry are nurtured in freshwater tanks. Between 16 and 22 months after they hatch, smolts are transferred to pens immersed in salt water. There, the fish are kept between 14 and 20 months. Salmon can be harvested at a weight of 1–2 kilos, but are usually harvested at larger sizes. Most common are harvesting weight of 4–6 kilos (Asche et al., 2018).

Over the years, Norwegian salmon farms have also become more and more specialized. The technology used in Norwegian salmon aquaculture has changed rapidly throughout the industry's short history (Asche & Roll, 2013). However, some problems are increasing in recent years. High levels of mortality and other losses within the aquaculture industry have received much attention over the last two years. Dead fish represent the largest proportion of these losses, but escapes and other causes also represent significant 'losses' to the industry. Fifty-three million fish were 'lost' from production in both 2016 and 2017, and losses of a similar level were experienced in 2018, with mortality accounting for 87.2% of this value. These statistics are of concern for all involved parties concerned with the future of aquaculture in Norway (Hjeltnes et al., 2019).

Salmon-lice (*Lepeophtheirus salmonis*) has been a problem for the aquaculture industry since its start in the seventies, and to try to get around the situation, the Norwegian government has instituted some quantity limits in farmed fish. There are several salmon louse thresholds. The general requirement is 0.5 adult female lice per fish per locality. However, for other licenses, such as organic salmon, for example, the threshold was lowered to 0.2 adult female lice per fish. In each locality, it is a legal requirement to count the lice every 14 days, and weekly if the sea temperature is 4 degrees or higher. All the key figures apply to those who have counted and reported lice. Lice control by frequent chemical treatment has led to development of resistance to the chemotherapeutants utilised, which has led to extensive use of cleaner-fish and non-medicinal treatments, as thermal de-licing procedures, for example. Non-medicinal treatments lead to stress and physical injury in the

treated fish, which may lead to death. Fish already impaired by other health problems e.g. infectious disease, are particularly badly affected (Hjeltnes et al., 2019).

Data obtained from BarentsWatch site (<https://www.barentswatch.no/>) for week 52 (December 23 to 29, 2019) show that of the 2% of the aquaculture sites which have reported lice are above the lice limit, corresponding to 11 farms. And 573 farms (98%) are below the current lice limit (Figure 1). However, these values fluctuate over time and season (see Figure 2), and it is urgent to develop more effective and less invasive techniques to control this problem.

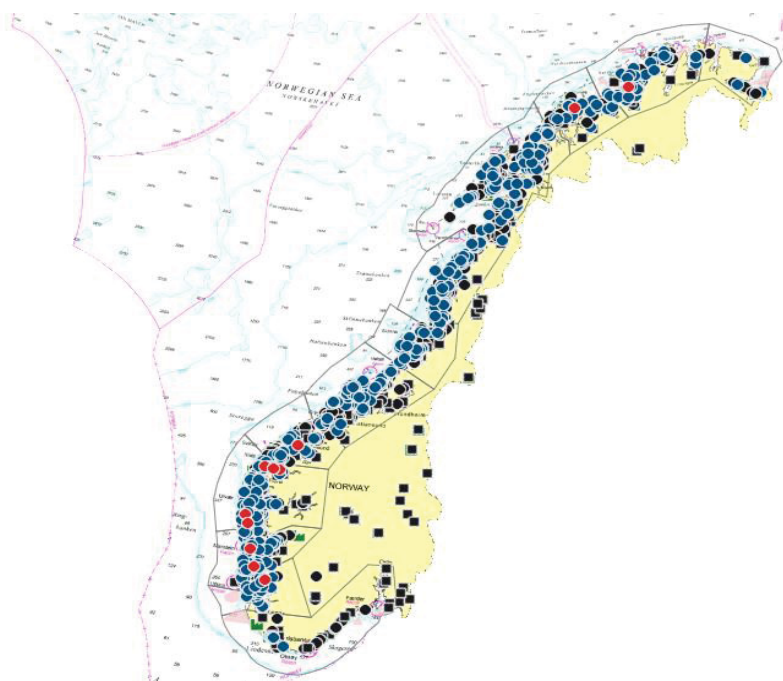


Figure 1. 1690 aquaculture sites along the coast of Norway. Legend: red circles = Aquaculture site above current lice limit; blue circles = Aquaculture site below current lice limit; black circles = Aquaculture site that has not reported for this week; black square = Land based locality. The reason might be a followed or closed down site, or that report has not been sent. Source: <https://www.barentswatch.no/>.

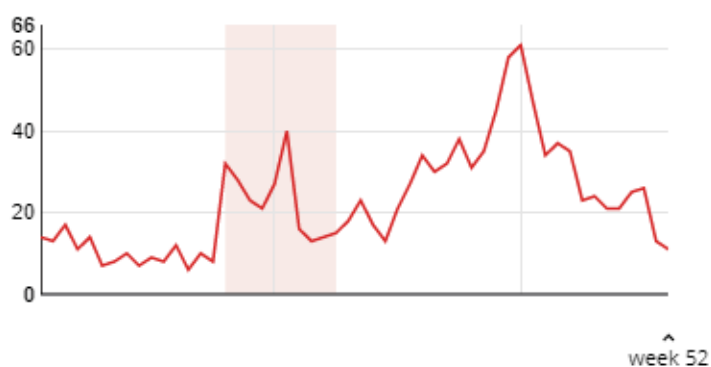


Figure 2. Amount of aquaculture sites above lice limit Week 1 (December 31, 2018 to January 6, 2019) to week 52 (December 23 to 29, 2019). Source: <https://www.barentswatch.no/>.

### 1.1 Thermal de-licing process

Thermal de-licing is based upon inactivation of the lice, which subsequently detach from the fish, following short term exposure to moderately heated water. It has been shown that salmonid fish can tolerate water temperatures of 20-34°C for shorter periods. It is considered likely that the upper temperature limit for salmon lice will lie around the same level, but that the difference in size between the two organisms will result in a shorter survival time for lice at suboptimal temperatures (Figure 3) (Grøntvedt et al., 2015).

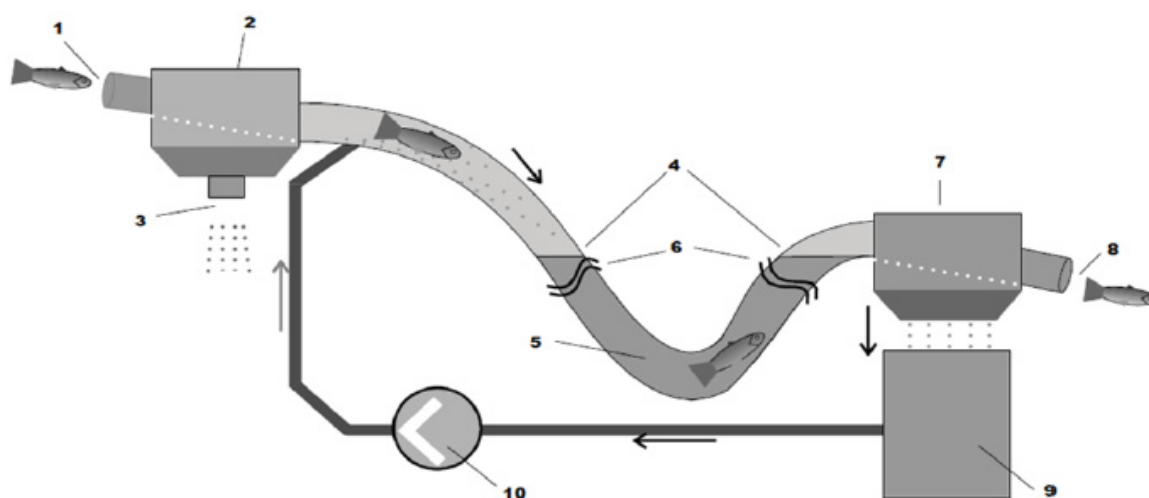


Figure 3. Schematic diagram of Thermolicer®. 1. The fish enters via the fish pump. 2. Water strainer/removal of seawater. 3. Seawater is filtered and released from the system. 4. The fish are introduced to tepid water. 5. The fish move through the system filled with tepid water. 6. Water level in the treatment chamber. 7. Tepid water removed. 8. Fish leave the system. 9. Tepid water led back to the heating tank for filtering, aeration and reheating. 10. Treatment water is pumped back to the treatment chamber (Taken from Grøntvedt et al., 2015).

Thus, in order to assess the influence of the thermolicer de-licing procedure on different physiological and genetic aspects of *Salmo salar* and to improve knowledge about stress levels in aquaculture activities, biological samples were collected at the SalMar marine farm in Froya (Figure 4), on December 15<sup>th</sup> and 16<sup>th</sup> 2019.

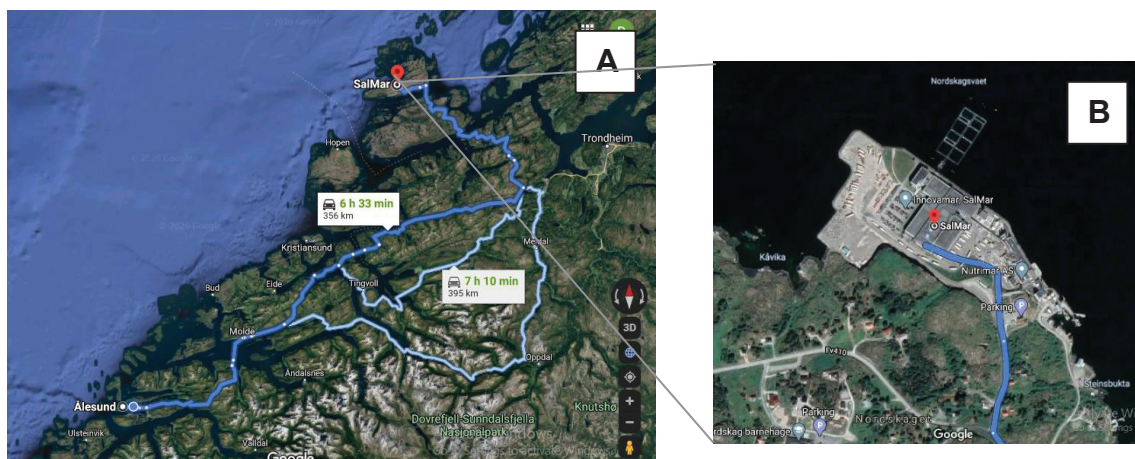
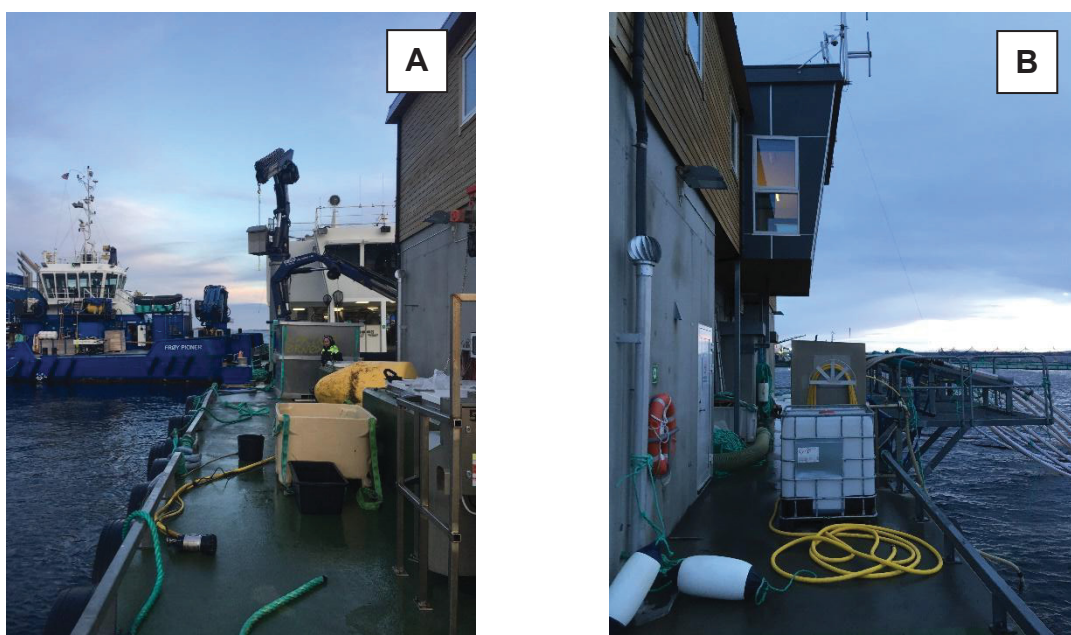


Figure 4. Route traveled from NTNU to SalMar facility (A), seen from facility (B), through which there was access to the farms.

The farm is about half an hour from the coast (Figure 5), and consists of two departments (harvesting and processing). The facility has a capacity of around 150,000 tonnes of salmon, while each of four up-to-date holding pens can accommodate some 350 tonnes of live fish (<https://www.salmar.no>).



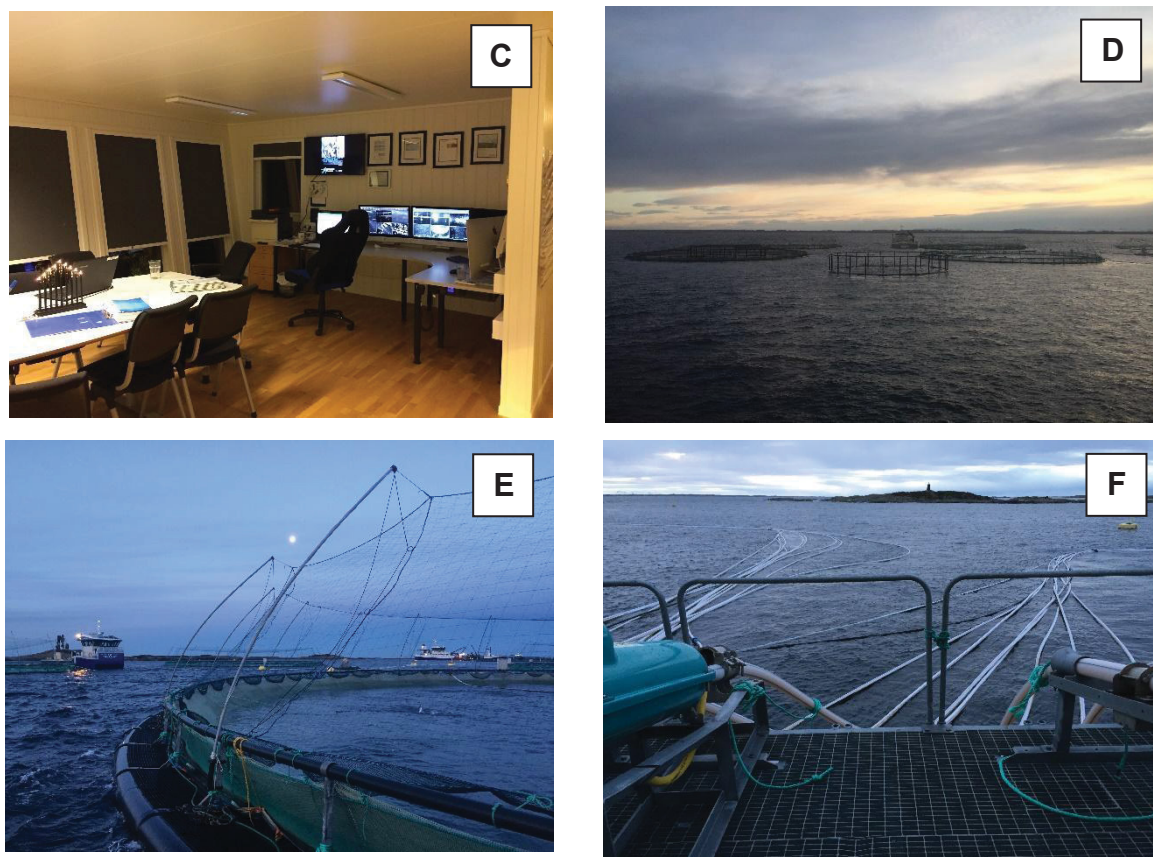


Figure 5. Background of the farm structure in Froya. Overview of the facility and support boat (A), and fish feeding structure (B). C. 24h monitoring system of fish in the tank. D- E. general view of the cultivation tanks. F. zoom of the fish feeding system, with the ducts feeding each tank.

The samples consisted of blood, feces, mucus, gills, and muscle obtained at four different treatments: T1- before the de-licing removal procedures (24 fish); T2: during de-licing removal procedures (24 fish in visual good condition); T3: 14h after de-licing procedures (about 24 fish); T4: 18h after de-licing procedures (about 24 fish) (Figure 6).



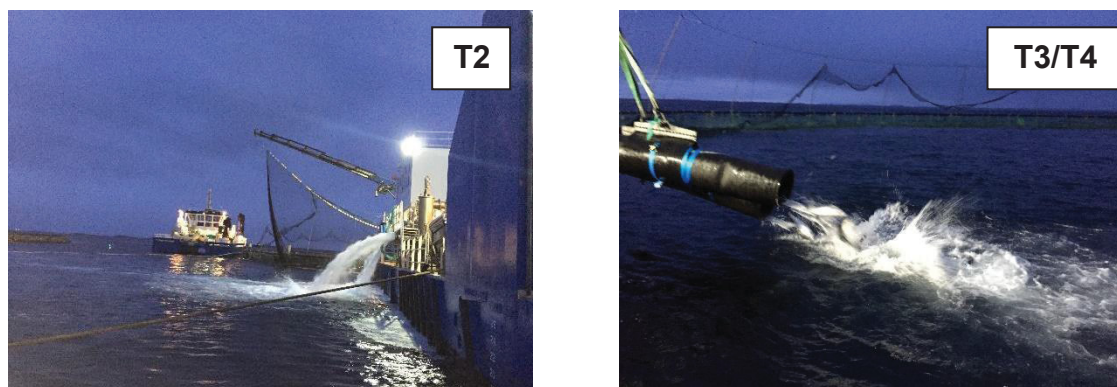


Figure 6. Treatment scheme: before (T1), during (T2), and after (T3 and T4) delicing-process, after 14h (T3), and 18h (T4).

Before each treatment, the fish were anesthetized in benzocaine until loss of balance (Figure 7A) and before taking samples, the fish were sacrificed with a blow to the head. Samples were collected in the following order: collection of mucus (2 times/fish), blood (2 times/fish), feces, muscle and gills. Mucus samples were taken from the dorsal portion of the fish from swabs and preserved both in RNAlater stabilization solution how in ice. Blood samples were collected by caudal puncture with BD Vacutainer Eclipse Blood collection needles along with Vacutainer test tubes (grey cap and purple cap) (Figure 7B). After blood collection, samples were centrifuged in a microcentrifuge (1500 rpm for 20 min) and the plasma was separated and kept frozen. Samples of fish faeces were collected by manual stripping, with moderate thumb and forefinger movements on the abdomen. Stripping started in line at the front of the pelvic fins and finished at the anus, and samples were collected in a 15 mL plastic centrifuge tubes. Samples of muscle and gills were taken with a tweezers and scissors, and preserved in RNAlater. Throughout the sampling, the fish will be measured (total length - cm), weighed (g) (Figure 7C) and determined the gender.





Figure 7. Sampling scheme: anesthetic use (A), blood samples collection (B), and after (C) de-licing process.

## 2. Characteristics of the samples collected

A total of 96 fish were sampled, including blood (2 times per fish), mucus (2 times per fish), feces, gills and red muscle. The proportion of females and males was similar between treatments, with a higher percentage of males in the treatment - after 18h (Figure 8). Individuals' weight and length were quite similar between treatments (Table 1).

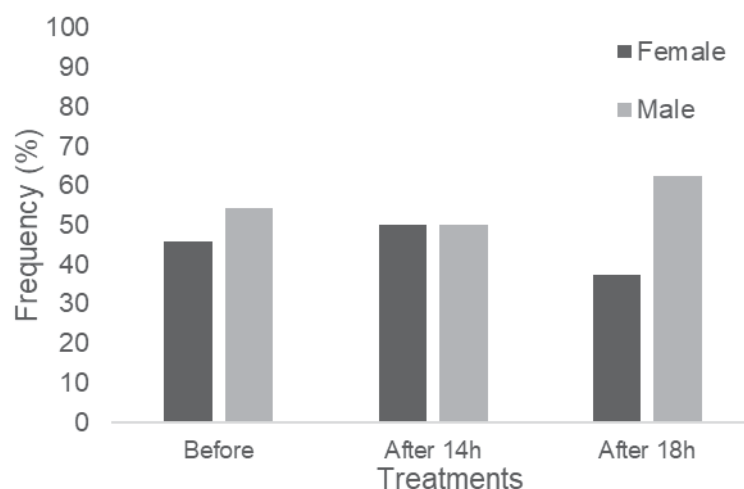


Figure 8. Gender frequency (%) among 72 individuals sampled in the before, after 14h, and after 18h de-licing process treatments.

Table 1. Biometric parameters of the 96 individuals sampled in each treatment

Biometric parameters	Treatments			
	Before	During	After 14h	After 18h
Total length (cm)	46 - 62 (55.2)	48 - 64 (55.3)	50 - 60 (56.2)	52 - 63 (56.7)
Weight (kg)	907.5 - 3040.5 (1981)	1333-3079 (2006.4)	1326 - 2582 (2028.8)	1374 - 3100 (2102.9)

\* The values shown are minimum-maximum (average).

From the samples collected, studies will be carried out to:

- a) To evaluate the stress response of *Salmo salar* submitted to mechanical de-licing treatment, through physiological markers cortisol, lactate, glucose and chloride concentrations, and to compare the level of response before, during and after de-licing process

H1: After 18 h the individuals return to stress levels close to those of the individuals of the first treatment (before de-licing process).

H2: The variability in the levels of physiological stress is related to the gender of individuals.

- b) Can genetic markers of acute stress help understand/verify/support findings/complement biochemical markers of stress during mechanical de-licing in field?

H1: Common biochemical biomarkers of stress have a higher individual variation within sampling groups.

H2: Standard deviation between individual results are higher for biochemical biomarkers than genetic markers of acute stress.

H3: Genetic markers complement biochemical markers of acute stress and gives a better understanding of the stress level.

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## EPILOGUE

From the results obtained in the first chapter, the specificity of the physiological response by different marine fishing resources to acute capture stress is evident, highlighting different sensitivities - inter and intraspecific, and different abilities by species in the response to stress. In the second chapter, we highlight some recurring points of the Brazilian historical-current fisheries policy that contribute to the unsustainability of fisheries and resilience of fish and artisanal fishermen that depend on these activities. Of these points, it can be mentioned above all the lack of knowledge about the species caught, the focus on development policies for industrial fishing and the lack of effective subsidies for artisanal fishermen. These data demonstrate the urgent need for a paradigm shift in the way in which we manage our species, and it is extremely necessary to consider the variability of the sensitivity of the species caught both in stock management, as well as for planning in marine aquaculture and public policies. Due to the innumerable challenges inherent to the fishing sectors in food production and in the sustainability of fishing resources, the balance between incentives, extractive fishing and aquatic activities is a global challenge. Nations with a domain of production and technology, and with great industrial support in aquaculture, such as Norway, for example, face routine problems related to the cultivation of fish, such as lice, escapes and diseases that reduce a large part of production and investment. To get around these problems, researchers and the government are constantly investing in research (mainly related to physiological stress) to develop new, more effective and less invasive management technologies. Likewise, nations that have undergone a paradigm shift related to fishing and resource use are applying physiological knowledge of species to reduce mortality from bycatch fish and/or recreational fishing and to create stock management policies. For Brazil, this period is even more crucial, mainly because the country is still incipient in the commercial aquaculture production of native species of marine fish and has in its fisheries policy, top-down management. Thus the generation of knowledge in ecophysiology and public policies is extremely necessary, in order to propose measures that allow to maximize (in a sustainable way) the goods and services obtained from the use of natural resources, in addition to providing social and economic benefits. The assessment of physiological stress is an excellent tool to predict how species can respond to environmental challenges and

assist in choosing fish with better aptitude in aquaculture activities. Besides that, the data generated in this study can assist in the choice of species with the best potential in aquaculture activities, as well as mediate conservation plans for more sensitive species. The comparison of Brazilian scenarios with successful international scenarios, both related to public policies (small scale fisheries reform, for example), and to technologies aimed at aquaculture (salmon aquaculture in Norway, for example), may be relevant extremely useful insights for the management of fisheries and natural resources and for Brazilian aquaculture. Obviously, the implementation of new measures and tools in Brazilian fisheries policies is not an easy and immediate task, however, the consequences of the continuation of this scenario of irresponsible exploitation of fishing resources and the lack of effective policies for the resilience of artisanal fishermen are incalculable.

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