UNIVERSIDADE FEDERAL DO PARANÁ
MICHELLE ALVES DE ABREU

INFLUÊNCIA DA VARIABILIDADE METEO-OCEANOGRÁFICA DO OCEANO ATLÂNTICO SUDOESTE SOBRE A PESCA INDUSTRIAL DE TAINHA *(Mugil liza)*

PONTAL DO PARANÁ
2018

MICHELLE ALVES DE ABREU

INFLUÊNCIA DA VARIABILIDADE METEO-OCEANOGRÁFICA DO OCEANO ATLÂNTICO SUDOESTE SOBRE A PESCA INDUSTRIAL DE TAINHA (*Mugil liza*)

Tese apresentada ao curso de Pós-Graduação em Sistemas Costeiros e Oceânicos, Setor de Ciências da Terra, Centro de Estudos do Mar, Universidade Federal do Paraná, como requisito parcial à obtenção do título de Doutor em Sistemas Costeiros e Oceânicos

Orientador: Prof. Dr. Mauricio Almeida Noernberg
Co-orientador: Prof. Dr. Rodrigo Pereira Medeiros

PONTAL DO PARANÁ
2018

CATALOGAÇÃO NA FONTE:
UFPR / SiBi - Biblioteca do Centro de Estudos do Mar
Elda Lopes Lira – CRB 9/1295

Abreu, Michelle Alves de
A162i Influência da variabilidade meteo-oceanográfica do oceano atlântico sudoeste sobre a pesca industrial de tainha (*Mugil liza*). / Michelle Alves Abreu Mota. – Pontal do Paraná, 2018.
93 f.: il.; 29 cm.

Orientador: Prof. Dr. Maurício Almeida Noernberg.

Tese (Doutorado) – Programa de Pós-Graduação em Sistemas Costeiros e Oceânicos, Centro de Estudos do Mar, Setor de Ciências da Terra, Universidade Federal do Paraná.

1. Gerenciamento pesqueiro. 2. Tainha. 3. Pesca industrial. 4. Sensoriamento remoto. 5. Oceanografia pesqueira. 6. Atlântico Sudoeste. I. Título. II. Noernberg, Mauricio Almeida. III. Universidade Federal do Paraná.

CDD 551.461

MINISTÉRIO DA EDUCAÇÃO
SETOR CIÊNCIAS DA TERRA
UNIVERSIDADE FEDERAL DO PARANÁ
PRÓ-REITORIA DE PESQUISA E PÓS-GRADUAÇÃO
PROGRAMA DE PÓS-GRADUAÇÃO SISTEMAS COSTEIROS E OCEÂNICOS

TERMO DE APROVAÇÃO

Os membros da Banca Examinadora designada pelo Colegiado do Programa de Pós-Graduação em SISTEMAS COSTEIROS E OCEÂNICOS da Universidade Federal do Paraná foram convocados para realizar a arguição da tese de Doutorado de **MICHELLE ALVES DE ABREU** intitulada: **Influência da variabilidade meteo-oceanográfica do oceano Atlântico Sudoeste sobre a pesca industrial de tainha (*Mugil liza*)**, após terem inquirido a aluna e realizado 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.

Pontal do Paraná, 23 de Março de 2018.

MAURICIO ALMEIDA NOERNBERG
Presidente da Banca Examinadora

LUIZ LAURENO MAFRA JÚNIOR
Avaliador Interno

JOCEMAR TOMASINO MENDONÇA
Avaliador Externo

HUGO BORNATOWSKI
Avaliador Externo

JOAO PAES VIEIRA SOBRINHO
Avaliador Externo

Ao autor da vida, o senhor Deus todo poderoso que fez os céus, a terra e o mar. A Ele seja dada toda glória, honra e louvor. A minha família, meu alicerce, meu amado esposo Moises e filho Cícero.

AGRADECIMENTOS

Ao meu orientador, Prof. Dr. Mauricio Noernberg, sempre presente em cada etapa da construção da tese, atendendo minhas dúvidas, dando ideias e apontando caminhos. Ao meu co-orientador Prof. Dr. Rodrigo Medeiros por aceitar o desafio de unir duas áreas tão distintas da oceanografia, pela paciência e disposição, nas correções minuciosas dos textos da área socioambiental.

Aos colegas do laboratório de Oceanografia Costeira e Geoprocessamento, Diana, Lígia, Nicole, Lucas, Davi e Guilherme. Meu especial agradecimento ao colega Mihael, quem me auxiliou nas análises que utilizei na tese.

Ao curso de Pós-graduação em Sistemas Costeiros e Oceânicos, do setor de Ciências da Terra, Universidade Federal do Paraná, na pessoa de sua coordenadora, Prof.ª Dr.ª Renata Hanae Nagai, pelo apoio recebido.

Aos membros da banca, Prof. Dr. João Paes Vieira S., Dr. Jocemar Tomasino Mendonça, Prof. Dr. Luiz Laureno Mafra Jr. e Dr. Hugo Bornatowski, pelas contribuições e sugestões.

À Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), pela bolsa de doutorado.

Puseste às águas divisa que não ultrapassarão, para que não tornem a cobrir a terra. Eis o mar vasto, imenso, no qual se movem seres sem conta, animais pequenos e grandes. Por ele transitam os navios e o leviatã que formaste para nele folgar. Todos esperam de ti que lhes dês de comer a seu tempo. A Glória do Senhor seja para sempre! Exulte o Senhor por suas obras!

Salmos*104:9;25-27;31*

RESUMO

A demanda por recursos pesqueiros tem aumentado ao longo das últimas décadas levando à sobre-explotação e declínio de muitas pescarias. Esses declínios poderiam ser reduzidos ou mesmo cessados se ferramentas adequadas de manejo fossem aplicadas. Especificamente, há uma necessidade urgente de incorporar a variabilidade ambiental nas estruturas de manejo atuais para permitir medidas de controle adaptativas. O objetivo do presente trabalho é propor que medidas de monitoramento oceanográfico sejam incorporadas ao manejo da pesca de tainha, uma atividade tradicional das comunidades pesqueiras da costa sul e sudeste do Brasil. Abordamos os aspectos relacionados ao manejo da pesca a partir da perspectiva da resiliência. Através do modelo do ciclo adaptativo, verificamos que não somente o esforço de pesca influencia a fase do recrutamento da espécie, mas também fatores ambientais. Considerando principalmente a influência do evento El Niño Oscilação Sul (ENSO), propomos a análise de séries temporais de pelo menos 7 anos de dados meteo-oceanográficos e sua relação com a pesca. Destacamos três aspectos para atingir uma pesca resiliente efetiva: um sistema de alocação de peixes flexível baseada na variabilidade ecossistêmica; uma alocação que priorize segurança alimentar e alívio da pobreza e um sistema de monitoramento que considere o ecossistema, a pesca e dimensões humanas. No segundo capítulo, utilizando a análise de ondaletas, avaliamos a variabilidade ambiental do oceano Atlântico Sudoeste em séries temporais mensais de parâmetros de sensoriamento remoto: temperatura da superfície do mar, clorofila-*a* e ventos, além do Índice Multivariado do ENSO e as relações desses parâmetros com a razão de captura por unidade de esforço (CPUE) entre os anos de 2003 e 2012. Os resultados indicaram uma forte associação da CPUE com o vento, em ciclos periódicos de 24 e 44 meses, que correspondem à periodicidade da corrente do Brasil e do ENSO, respectivamente. Verificamos um pico no valor de CPUE em 2011 em função das condições de vento e dos efeitos de um forte evento de La Niña. No capítulo 3, utilizamos modelos aditivos generalizados para analisar a influência do vento sobre a atividade de pesca da frota de traineiras na safra de tainha nos anos de 2010 a 2012. Os resultados mostram que o vento Sul influencia significativamente esta atividade, que não há diferença temporal significativa do esforço durante a safra de tainha e indicam duas áreas principais de pesca, em frente a desembocadura da Lagoa dos Patos e na costa norte do estado de SC.

Palavras-chave: gerenciamento pesqueiro, tainha, pesca industrial, sensoriamento remoto, oceanografia pesqueira, Atlântico Sudoeste.

ABSTRACT

The world demand for fisheries resources has been increasing over the last decades leading to overexploitation and decline in many fisheries. Such declines could be reduced or even halted if suitable management measures were enforced. Specifically, there is an urge to incorporate the environmental variability into the management framework and develop adaptive management measures. The aim of this work is to propose oceanographic monitoring measures into the management of mullet fishery, a resource traditionally exploited by fishers' communities in the South-Southeast Brazilian coast. We explored aspects related to fisheries management from the perspective of the resilience thinking. Using the adaptive cycle model, we could observe that the environmental factors also influence the species recruitment phase, in addition to the fishing effort. We proposed the analysis of time series of at least 7 years of meteorological and oceanographic data and their relation with mullet fisheries, considering the effects of the El Niño South Oscillation (ENSO) on the fishery. We highlighted three aspects to achieve effective resilient fisheries: a flexible fish allocation system based on ecosystem variability; a flexible fish allocation system that prioritize food security and poverty alleviation and a monitoring system that takes into consideration ecosystem, fisheries and human dimensions. On the second chapter, we used the wavelet analysis of monthly time series of remote sensing parameters: sea surface temperature, chlorophyll-*a* and sea surface winds and the Multivariate ENSO Index to assess the environmental variability of the Southwest Atlantic Ocean and their relation with the catch per unit of effort ratio (CPUE) between 2003 and 2012. The results pointed to a strong association between CPUE and the wind, in 24 and 44 months periodic cycles, which correspond to the Brazilian current and the ENSO periodicity, respectively. We found a CPUE peak in 2011, in function of the wind conditions and the effects of a strong La Niña event. On the chapter 3 we employed generalized additive models to analyze the spatial-temporal variability of mullet fishery and the influence of winds on purse seiner fleet activity during the mullet fishery season in the years of 2010–2012. Results showed that the South wind has significant influence on this activity, that there is no temporal variability on the effort during the fishing season and that fishing occurs mainly near the Patos lagoon entrance and on the SC north coast.

Keywords: fishery management, mullet, industrial fishery, remote sensing, fisheries oceanography, Southwest Atlantic.

SUMÁRIO

PREFÁCIO

A presente tese é apresentada na forma de artigos científicos, precedidos de uma introdução geral ao tema, com objetivos e hipóteses. Os capítulos correspondem aos artigos elaborados sequencialmente, apresentados de acordo com as normas das respectivas revistas-alvo com seus próprios resumos e referências bibliográficas. Tabelas e mapas com os dados brutos são apresentados ao final da tese como material suplementar.

O primeiro artigo "*Resilience thinking applied to fisheries management: perspectives for the mullet fishery in Southern-Southeastern Brazil*", publicado no periódico Regional Environmental Change traz uma abordagem teórica, utilizando o conceito de resiliência para avaliar o gerenciamento da pesca de tainha no Brasil e incluindo recomendações para uma pesca resiliente.

No segundo artigo "*Lebranche mullet catch rate related to mesoscale oceanography in the Southwest Atlantic*", submetido ao periódico Fisheries Oceanography, foram utilizadas séries temporais mensais de 10 anos de dados ambientais para explicar a variabilidade de Captura por Unidade de Esforço.

No último e terceiro artigo são apresentados os resultados da investigação da variabilidade espacial e temporal da pesca industrial de tainha pela frota de traineiras, com os dados do Programa Nacional de Rastreamento por Embarcações (PREPS) utilizando modelos aditivos generalizados (GAMs).

O último capítulo relata as considerações finais, resumindo as principais conclusões da tese, respondendo as hipóteses levantadas no início do estudo e como cada artigo contribuiu para o trabalho em geral.

1 INTRODUÇÃO GERAL

Segundo estimativas de 2013 da Organização das Nações Unidas para Alimentação e Agricultura (FAO, 2016) 31,4% dos estoques pesqueiros mundiais estavam sobreexplorados, ou seja, a níveis biologicamente insustentáveis. A pesca tem como desafios à sua expansão fatores como a sobrepesca, poluição e degradação dos habitats, elevados preços dos combustíveis, além de sistemas inadequados de governança (FAO, 2008). Face a isto, estudos afirmam que está em curso um declínio inevitável no *status* da pesca (MYERS & WORM, 2003; PAULY & ZELLER, 2016).

A administração da atividade pesqueira é uma tarefa complexa, pois a capacidade de reposição dos estoques pesqueiros está sujeita não somente a ação exploratória, mas também a inúmeras variáveis naturais que não podem ser controladas pelo homem. A variabilidade das populações de peixes e das atividades de pesca está estreitamente ligada à dinâmica meteorológica e do clima, enquanto as condições meteorológicas no mar influenciam diretamente a pesca, a variabilidade ambiental determina a distribuição, migração e abundância de peixes (LEHODEY et al., 2006). O entendimento das relações entre o clima e o recrutamento de peixes é essencial para aprimorar metodologias analíticas de avaliação e previsão de recrutamento, mudanças na abundância e pesca (desembarque), usadas para recomendar uma política pesqueira mais coerente a longo prazo (BOGRAD et al., 2014; HAIDVOGEL et al., 2013; MORISHITA, 2008).

A espécie-alvo desse estudo é a população sul da tainha (*Mugil liza* Valenciennes, 1836). As tainhas são encontradas em ambientes costeiros marinhos e estuarinos do Atlântico Sul, formando densos cardumes durante sua migração reprodutiva. Ocorrem em uma grande área geográfica que se estende desde o sul dos EUA (Flórida) até a Argentina, sendo comercialmente exploradas no Brasil e na Argentina (VIEIRA et al., 2008). Existem duas populações distintas dessa espécie na costa brasileira, uma ao norte e outra ao sul do estado do RJ, sendo esta explorada tanto pelo setor artesanal como pelo industrial (MAI et al., 2014). A tainha é uma espécie catádroma que passa a maior parte de seu ciclo de vida em ambientes estuarinos (estuários de planície, baías e lagoas costeiras) e inicia o processo de migração reprodutiva para o oceano no outono, para desovar no inverno (CHAO et al., 1985; VIEIRA et al., 2008). Este evento de migração é localmente conhecido nas comunidades costeiras do sul do Brasil como "corrida da tainha", quando este recurso se torna mais vulnerável à pesca devido à formação de cardumes em águas costeiras (VIEIRA & SCALABRIN, 1991b).

A migração, distribuição, disponibilidade e capturabilidade da tainha são marcadamente influenciadas pelas condições oceanográficas do Sistema Costeiro do

Atlântico Sudoeste (SCAS). O SCAS é influenciado pelas interações entre as correntes do Brasil e das Malvinas, a convergência subtropical formada por elas e o volume da descarga de água doce da bacia do Rio da Prata e do complexo Patos-Mirim através do estuário da Lagoa dos Patos (CASTELLO & MÖLLER, 1977; CIOTTI et al., 1995). Além desses processos, a temperatura da água, que é estratificada ao longo da plataforma continental, apresenta um ciclo sazonal pronunciado, típico de áreas temperadas (PALMA et al., 2008). A direção do vento na região é predominantemente de nordeste, exceto durante a passagem das frentes frias de sul durante o inverno austral (CAMPOS et al., 1995). A variabilidade sazonal nas condições oceanográficas no SCAS influencia vários comportamentos biológicos dos peixes e, portanto, a pesca (BARLETTA et al., 2010; MUELBERT & SINQUE, 1996).

A pesca da tainha destaca-se entre as atividades pesqueiras pela sua complexidade enquanto um sistema social e ecológico. A espécie é um recurso tradicional explorado pelas frotas artesanais no litoral sul e sudeste, sendo capturada por meio de arrasto de praia, redes de emalhe, cerco fixo, tarrafa e caceio (FAGUNDES et al., 2007; MENDONÇA, 2007; PINA & CHAVES, 2005). A captura da tainha também é realizada pela frota industrial que atua nas regiões Sudeste e Sul, principalmente com cerco (traineira). Neste caso como espécie alternativa, com permissão complementar, ou ainda, pela frota de emalhe de superfície, como espécie alvo (BRAZILIAN MINISTRY FOR FISHERIES AND AQUACULTURE, 2015). A pesca da tainha ocorre em todas as épocas do ano tanto em águas estuarinas quanto em águas costeiras, no entanto, é durante a fase de migração reprodutiva que essa atividade atinge seu ápice (OLIVEIRA & SOARES, 1996).

A migração reprodutiva tem início quando frentes frias com ventos de sul esfriam as águas superficiais em aproximadamente 5 °C, para temperaturas entre 19 e 21 °C, entre os meses de maio e julho (LEMOS et al., 2014; VIEIRA & SCALABRIN, 1991b) . A desova acontece sobre a plataforma continental. Os ovos e larvas são planctônicos e dependem de disponibilidade de alimento para sua sobrevivência e sucesso no recrutamento (CASTELLO et al., 2012; GALVÃO et al., 1997). O sucesso do recrutamento dos juvenis depende também de condições favoráveis ao transporte e sobrevivência das larvas planctônicas pelas correntes para a zona de arrebentação no início da primavera e ao deslocamento passivo destes juvenis ao longo da costa para o retorno ao estuário da Lagoa dos Patos (VIEIRA, 1991).

A capturabilidade pode conceitualmente ser considerada como a probabilidade de um peixe individual ser capturado. Essa probabilidade depende de diversos fatores além da tecnologia de pesca, como a disponibilidade de peixes nas áreas de pesca, que por sua vez depende do tempo, disponibilidade de outras espécies, e as condições ambientais (JUL-LARSEN et al., 2003). Compreender esses fatores é de grande valia não só para quantificar o impacto do esforço pesqueiro sobre a biomassa explotável do recurso, como também para se avaliar as estratégias de manejo pesqueiro com tendência a maiores chances de sucesso (HILBORN & WALTERS, 1992; STEPHENS & KREBS, 1986). Recentemente houve um grande aumento na exploração da tainha. A frota industrial de cerco (traineiras) tem direcionado suas capturas para a tainha, pois houve uma grande diminuição da abundância do principal recurso desta frota, a sardinha (*Sardinella brasiliensis*) no final da década de 1990. Além disso, a demanda por este recurso aumentou desde que as ovas processadas de tainha (*bottarga*) passaram a ser apreciadas como iguaria na Europa (MIRANDA et al., 2011).

A tainha é uma espécie bastante vulnerável à pesca excessiva por ser explorada justamente no seu período reprodutivo e por ser capturada em todos os estágios da vida: quando juvenis, nas lagoas e estuários; na fase adulta, no oceano (GARBIN et al., 2014). Em 2004, a tainha foi declarada sobre-explotada (Anexo II IN MMA nº 05 21/05/2004). O principal fator que levou o recurso a essa condição é a exploração da espécie tanto pela frota artesanal quanto pela frota industrial, especialmente, a partir da última década (BRAZILIAN MINISTRY FOR FISHERIES AND AQUACULTURE, 2015).

Para regular o acesso da frota industrial para essa pesca, o Estado estabeleceu novas regras de ordenamento em 2007 (IN nº 171/2008). Entre outras regras, uma zona de exclusão para as operações da frota industrial foi estabelecida, número limitado de licenças para as embarcações e restrição da atividade pesqueira ao período oficial da safra. Além disso, as traineiras maiores que 15m devem estar registradas no Programa Nacional de Monitoramento de Embarcações por Satélites (PREPS), para medidas de fiscalização, mas também para fornecer informações acerca da distribuição espacial e temporal da atividade pesqueira para propósitos de manejo ambiental e pesqueiro.

Recentemente, um estudo da avaliação do estoque estabeleceu o limite máximo de captura anual para a pesca da tainha em 4.367 t para as safras de 2017 a 2019 (SANT'ANA & KINAS, 2016). O estabelecimento de cotas ainda não é praticado na gestão dessa pesca e esse estudo propõe a inclusão dessas cotas como mais uma ferramenta para o manejo da tainha.

1.1 OBJETIVOS

Identificar a influência dos parâmetros meteorológicos e oceanográficos na pesca da tainha pela frota industrial de traineiras na costa sul e sudeste do Brasil. Desta forma, propor medidas de manejo que contemplem a variabilidade e a capturabilidade do estoque em função das condições ambientais.

1.2 OBJETIVOS ESPECÍFICOS

- Elaborar um modelo conceitual de avaliação do sistema socioecológico da pesca industrial de tainha, explorando o conceito de resiliência desse sistema.

- Avaliar a variabilidade temporal dos parâmetros oceanográficos e meteorológicos (temperatura da superfície do mar, clorofila-*a* e ventos na superfície do mar) na região de influência dessa atividade e o Índice Multivariado do El Niño – MEI ao longo de 10 anos e analisar sua correlação com a atividade de pesca.

- Identificar a influência dos ventos sobre a variabilidade espacial e temporal da atividade pesqueira da frota de traineiras (distribuição de horas de pesca).

1.3 HIPÓTESES

- Se houve predomínio de condições meteorológicas e oceanográficas favoráveis à migração da tainha em uma determinada safra, como anomalias negativas de temperatura da superfície do mar e anomalias positivas de ventos na superfície do mar, então houve uma maior taxa de captura pela frota de cerco (traineiras) nessa safra.

- Se houve maior predomínio de condições meteorológicas e oceanográficas favoráveis ao retorno das larvas planctônicas para os estuários em uma determinada safra, então o volume desembarcado aumentou no ano em que esses indivíduos se tornaram adultos (entre o 5º e o 6º ano consecutivo).

- Se houve intensa atividade pesqueira em determinadas áreas, então as condições meteo-oceanográficas dessas áreas definem as zonas preferenciais de pesca.

1.4 JUSTIFICATIVA

Os ecossistemas marinhos mudam de acordo com uma variedade de escalas de tempo, de sazonal a centenária e maiores. Muitas dessas escalas de tempo são forçadas por processos atmosféricos e relacionados ao clima, portanto, existe um consenso entre os cientistas que a variabilidade climática é um dos principais fatores de mudança nos estoques pesqueiros e na atividade de pesca (LEHODEY et al., 2006).

Um entendimento da influência dos processos físicos oceanográficos na distribuição de espécies é fundamental para um maior entendimento e possível previsão de muitas pescarias pelágicas. O uso de métodos de sensoriamento remoto para examinar a oceanografia física vem se tornando cada vez mais importante dentro da oceanografia de pesca marinha, e muitos estudos utilizam dados de satélite para auxiliar na localização de áreas de pesca mais produtivas (WALUDA et al., 2001).

Além disso, alterações climáticas como o El Niño Oscilação Sul (ENSO) precisam ser incorporadas nas medidas de manejo da pesca, pois essas alterações influenciam condições meteorológicas e oceanográficas como a direção dos ventos, a taxa de precipitação e a salinidade e, portanto, a dinâmica populacional da espécie alvo desse estudo. Essas alterações ambientais também influenciam a atividade pesqueira, podendo ocasionar o fracasso de uma pescaria mesmo em anos de abundância de peixes. O monitoramento contínuo das condições ambientais é um dos fatores que possibilitará ajustes nas medidas de controle de esforço de pesca, flexibilizando-as ou tornando-as mais rígidas, em função dessas condições.

Existem basicamente duas formas de utilização dos dados de sensoriamento remoto para a gestão pesqueira. Uma é o monitoramento do ambiente para entender melhor os processos do ecossistema ou a biologia do estoque. A outra forma é a localização das populações de peixes, para aumentar a eficiência de pesca.

Os padrões sazonais na dinâmica de populações de peixes são bem conhecidos entre os cientistas e são levados em consideração para as operações de pesca (i.e., migrações sazonais para desova ou em busca de alimento). No entanto, mudanças abruptas apresentam questões mais difíceis: os peixes se deslocaram ou o estoque está em colapso? É devido a causas naturais ou sobrepesca? Os peixes voltarão ou serão substituídos por outra espécie? Ou, em termos gerais, há uma relação estacionária ou não estacionária entre clima e ecossistema? Entender essas questões é indispensável para a gestão dos recursos pesqueiros, especialmente em casos de espécies tão sensíveis às condições climáticas e oceanográficas, como é o caso da tainha.

A ocorrência de condições do tempo desfavoráveis para a captura de tainha e a disponibilidade de outros recursos de interesse na área de pesca, que por algum motivo são igualmente rentáveis, podem influenciar o desvio da frota pesqueira industrial de cerco do estoque de tainha.

Com base nas premissas de que condições meteorológicas e oceanográficas, associadas às questões de manutenção do lucro individual, influenciam esta pescaria e que informações a respeito deste tema são escassas, propõem-se estudar a influência de fatores meteorológicos e oceanográficos sobre a pesca de tainha pela frota industrial de traineiras.

2 RESILIENCE THINKING APPLIED TO FISHERIES MANAGEMENT: PERSPECTIVES FOR THE MULLET FISHERY IN SOUTHERN-SOUTHEASTERN BRAZIL

Conceito de resiliência aplicado ao gerenciamento da pesca: perspectivas para a pesca da tainha no Sul-Sudeste do Brasil.

Texto publicado na revista Regional Environmental Change (Reg Environ Change), ISSN 1436-3798, Fator de Impacto (JCR, 2016) = 3,153, Qualis CAPES = Estrato B2

Michelle Alves de Abreu-Mota1*: michelledeabreu@ufpr.br; Rodrigo Pereira Medeiros1: rodrigo.medeiros@ufpr.br; Mauricio Almeida Noernberg1: m.noernberg@ufpr.br
1. Centro de Estudos do Mar, Universidade Federal do Paraná. Av. Beira Mar s/n. Pontal do Paraná, PR, Brazil. CEP: 83255-976. Phone: +55 41 35118600
*corresponding author

2.1 ABSTRACT

The mullet fishery system encompasses a complex arrange of ecological and socioeconomic factors interacting in multiple scales on the Southern-Southeastern Brazilian coast. Similarly to other fisheries in developing countries, overfishing and poor governance have been threatening the resilience of the mullet fishery. In this paper, we explore aspects related to fisheries management from the perspective of the concept of resilience. The industrial and artisanal fishery sectors represent the different stakeholders. The main issues of concern are related to failures in the fisheries management to properly address equity in resource access and resource use sustainability among stakeholders. Asymmetry in technology and political and economic power affect food security and income generation especially for subsistence and small-scale fishing. Despite changes in rules-in-use, overfishing and conflicts between resource users are still relevant. Fishery dynamics and resource availability are greatly affected locally by forces such as pollution, urbanization, non-selective fishing, and regionally, by the El Niño Southern Oscillation (ENSO), and industrial (purse-seine) fishery. Considering the influence of ENSO on this fishery, a time span of at least seven years to investigate this system could provide better answers to improve the management. Effective resilient fisheries should rely on three aspects. First, a flexible fish allocation system based on ecosystem variability. Secondly, fish allocation should prioritize food security and poverty alleviation. Thirdly, a monitoring system should be implemented that takes into consideration ecosystem, fisheries and human dimensions to support a flexible and adaptive fisheries management, with resilient fisheries as an ultimate goal.

Keywords: adaptive cycle; Lebranche mullet; industrial fishery; climate change; Patos Lagoon Estuary.

2.2 INTRODUCTION

Humans have exploited fish populations for food and income throughout the centuries. Around 120 million people in the world rely on fisheries (World Bank 2012). Most of them live in developing countries where vulnerable livelihoods are at stake. Meanwhile, world fisheries are under increasing pressure due to factors such as human demand for food, overfishing, climate change, pollution, and habitat degradation (Sumaila et al. 2011; Doney et al. 2012).

The fisheries crisis is also affected by poor governance, which jeopardizes the potential of fisheries as means to alleviate poverty and provide food security (Béné et al. 2016). Institutional failures in the fisheries management have led to a lack of legitimacy in management bodies, low compliance, and poor ability to deal with the ecosystem dynamics and outside pressures (Acheson 2006; Eriksson et al. 2016). The focus on a command-and-control approach to governance (Holling and Meffe 1996) has excluded the system's nonlinearities, leading to critical transitions and the irreversible collapse of key ecosystem services (Beddington et al. 2007; Hagstrom and Levin 2017). Conversely, a better fit between the ecosystem dynamics and institutions is required to foster resilient fisheries (Folke et al. 2007). As stated by Hughes et al. (2005), "new paradigms, perspectives, policies, and governance systems are urgently needed to safeguard ecological systems for societal development and future generations."

Fisheries can be conceived as complex adaptive systems (Mahon et al. 2008), considering ecosystems and human populations as interconnected. The fishery system includes all marine resources, the coastal and marine environment, and the human populations that depend on it (Steffen et al. 2007; Allison et al. 2009; Folke et al. 2010). In this scenario, the challenge becomes how to deploy management tools in order to be flexible and adaptive (Armitage et al. 2009; Williams and Brown 2014).

Ecosystem-based marine resource management perspectives, such as the Ecosystem Approach to Fisheries (EAF), are receiving growing attention in the fisheries sector (Pomeroy and Berkes 1997; Garcia and Cochrane 2005; Rice 2011; Fletcher et al. 2014). The EAF emphasizes societal objectives, a broad range of ecosystem goods and services, and the integration of the environment, ecology, and human uses (Bianchi and Skjoldal 2008). Resilience has been considered one of the main goals of fisheries management (Miller et al. 2010), especially from the EAF's perspective (Bianchi and Skjoldal 2008). Resilience refers to a "measure of the persistence of systems and their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables" (Holling 1974). To build capacity by coping with uncertainty and surprises (Walker et al. 2004; Adger et al. 2005; Folke 2006) becomes central to the fishery management goals for resilient fisheries.

Brazil has been struggling to overcome the command-and-control rationale in order to encompass the resilience approach in fisheries management. Inconsistency in the legal framework and continuous changes in jurisdiction toward fisheries management have undermined perspectives for a proper institutional environment to implement the EAF (Medeiros et al. 2013; Silva et al. 2013). Emblematic of that context is the mullet fishery, one of the main fisheries in Southern and Southeastern Brazil (Herbst and Hanazaki 2014). This fishery occurs in different ecosystems (estuary and coastal waters) (Vieira et al. 2008), involves different fleets (from small to industrial scale) and fishing gear, is aimed to accomplish different fishing objectives (from providing food security to supplying international markets). Also, the mullet fishery exploits two distinctive stocks of mullet co-occurring along the Southern-Southeastern Brazilian Coast (Lemos et al. 2014) that are very sensitive to fluctuations of natural conditions (Vieira et al. 2008).

Recent conflicts have created opportunities for innovative approaches to this mullet fishery. Demanded by the public ministry, a national plan and fishing management body have been created for the mullet fishery. In this study, we use the resilience concept (Folke et al. 2010) and the Resilience Alliance framework (Resilience Alliance 2010) as the background to describe the mullet fishery in the studied region and to provide insights on how to incorporate the resilience concept into the management plan. We evaluated factors that may influence the collapse and recovery of this fishery, interpreted as a social-ecological system (SES) (Mahon et al. 2008) and suggest effective measures to promote its resilience.

2.3 THE MULLET FISHERY

Mugil liza (Lebranche mullet) is a medium-sized mullet with distribution from the Southern USA (Florida) to Argentina. Recruitment occurs at the age of 6 years, with females growing slower and living longer (Garbin et al. 2014). Mullet populations use estuaries as feeding and nursery areas; every year, dense schools of adults leave the estuaries in a reproductive migration. *M. liza* has a single spawning and migration period known as the mullet run (*corrida da tainha* in Portuguese). Local fishermen look forward to this event due to the possibility of large catches in a short time (Herbst and Hanazaki 2014). Spawning takes place along a northward migration path in waters with temperature ranging from 19 °C to 21 °C and at approximately 50 m deep (Lemos et al. 2016). Southern winds followed by low temperatures are the main climatic conditions that trigger this migration; this reproductive migration usually begins in May and ends in August (Herbst and Hanazaki 2014). A passive southward water movement carries larvae and juveniles by surface coastal currents for approximately 2–4 months after spawning (Lemos et al. 2014). Therefore, conditions such as temperature, salinity, sea currents, wind, and precipitation can all affect the availability of mullet populations to fishermen (Vieira et al. 2008; Mai et al. 2014). Winds are also an activity driving force because the prevalence of strong winds impairs working with purse seines.

In Brazil, the Lebranche mullet fishery is very active in the Southern-Southeastern states of Rio Grande do Sul (RS), Santa Catarina (SC), Paraná (PR), São Paulo (SP), and Rio de Janeiro (RJ). SC had the greatest relative participation in the total mullet production in the last 30 years (45%), followed by RS (30%), RJ (17%), SP (8%), and PR (less than 1%). Recent studies revealed the existence of two distinct population clusters exploited by Southern-Southeastern fleets (Mai et al. 2014; Lemos et al. 2017). Despite being caught by estuarine artisanal and subsistence fisheries all year long, the annual mullet run provides a well-defined harvest season for both coastal artisanal and industrial fisheries in Brazil and Argentina (Vieira et al. 2008).

This fishery is distinguished from other fishery activities by its complexity as the SES. Specifically, the mullet life cycle imposes strong constraints on fishing livelihoods in this region in Brazil. The mullet fishery is not only important as an economic activity but also as a historical, artistic, and cultural heritage with many regional cultural manifestations associated with it (Peres 2007).

The artisanal fleet on the Southern-Southeastern Brazilian coast captures mullet using beach seines, casting nets, fish traps, and drift nets (Pina and Chaves 2005). Despite imprecision in the total number of known fishers, about 160 fishing villages depend upon the mullet fishery along the coasts of Rio Grande do Sul, Santa Catarina, and Paraná (Lemos 2017). The industrial fishery mainly operates using purse seines, with the same fleet that exploits the Brazilian sardine (*Sardinella brasiliensis*) fishery – considering the mullet fishery as an alternative resource, and operating with complementary fishing permits (Miranda et al. 2011). The industrial exploitation has been increasing since the year 2000, followed by the collapse in Brazilian sardine fisheries, which freed purse seines to target the mullet and other pelagic fish stocks.

The mullet production in Brazil shows two distinct variations in recent years. The first, between 2000 and 2007, shows a rising production trend with a peak of 13,617 tons in 2007. The second, between 2008 and 2015, exhibits a downward production trend with average captures similar to those registered in 2000 (Figure 2.1). In 2004, the Brazilian federal government identified the Lebranche mullet as an overexploited species (Annex II of the Normative Instruction MMA No. 05 21/05/2004) due to unsustainable fishing pressure from artisanal and industrial fleets. Recently, the Ministry of the Environment described *Mugil liza* as a near-threatened species.

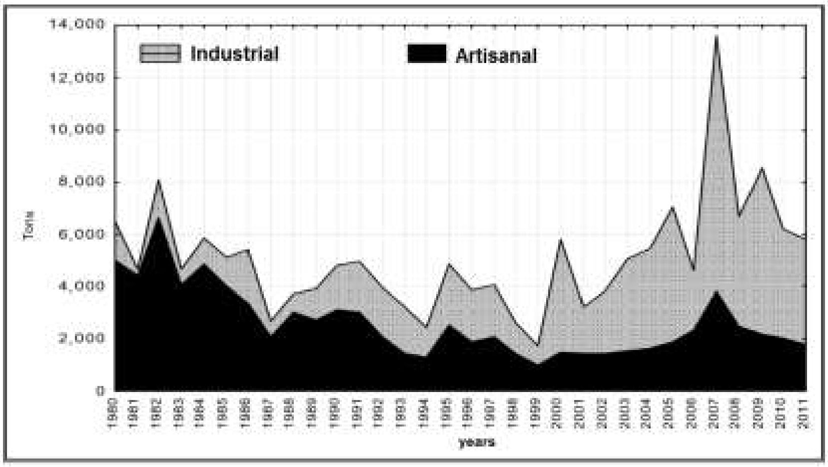


Fig. 2.1 Total annual mullet (*Mugil liza*) catches by artisanal and industrial sectors in Southern and Southeastern Brazil between 1980 and 2011 (Brazilian Ministry for Fisheries and Aquaculture, 2015)

The Patos Lagoon estuary (PLE) is the main nursery area for *M. liza* in Brazil. The PLE covers an area of 10,360 km^2 on the coastal plain in the Rio Grande do Sul State and is considered the world's largest choked-type coastal lagoon (Seeliger 2001) (Figure 2.2). *M. liza* is the second most important fishery resource in the PLE; nevertheless, this stock is being threatened by urbanization and industrialization projects around the PLE and meteorological changes caused by the El Niño Southern Oscillation (ENSO) (Vieira et al. 2008; Odebrecht et al. 2010).

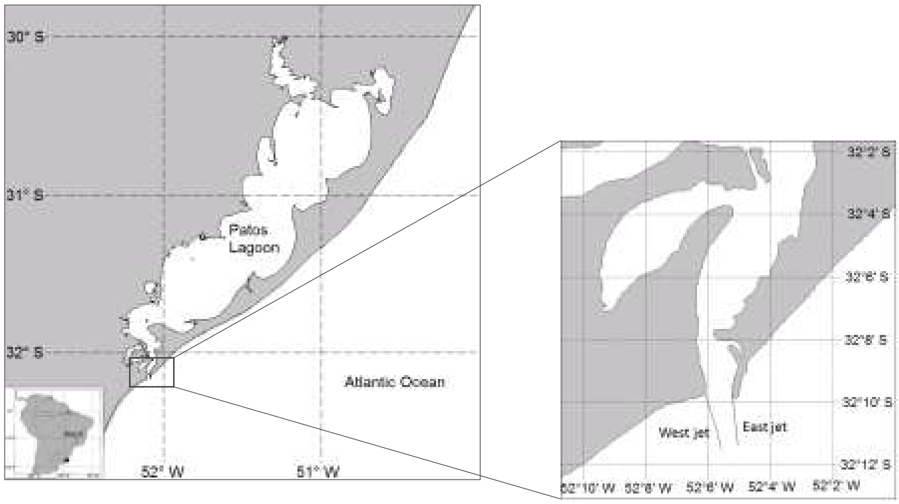


Fig. 2.2 The Patos Lagoon Estuary in Southern Brazil; the magnified view shows a pair of jetties at the estuary's entrance

The mullet's life cycle depends on interactions between oceanographic, meteorological, and anthropogenic factors in the continental shelf and estuaries. Therefore, the effective management of the mullet fishery needs to deal with effects from natural and human disturbances on the ontogenetic phase of the resource, its habitats, and the social groups involved with this fishery, including the fish supply chain.

2.4 METHOD

We began the analysis by defining the spatial and temporal boundaries of the focal system: management of the *M. liza* industrial fishery in Brazil and availability of resources to the artisanal sector (Table 2.1). Within this process, we identified the critical components that will form the basis of our assessment. Our assessment is a reinterpretation of secondary data from several analyses carried out on mullet and related fisheries (unpublished and published technical reports and publications in peer-reviewed journals).

Table 2.1: Sequence of the focal system assessment.

Assessment stage	What is identified in each step of assessment?
Main issues of concern	One or a few related issues of the focal system and its attributes that are valued by the stakeholders
Key components of the SSE	Uses of natural resources and services that are derived from the focal system and the key stakeholders
Disturbances, disruptions and uncertainty	Challenges to the management of the SES and the reliable supply of resources and services
Multiple spatial and temporal scales	Systems at scales above and below the focal system in terms of their social and ecological dimensions and historical timeline of changes

In the assessment's first stage we determined the main issues of concern by observing the SES attributes with value to stakeholders. Considering the main issue, we suggested a relevant time span over which to examine this system and evaluate whether the main issue is being actively managed.

Subsequently, we linked the main uses of SES by stakeholders to identify the SES key components according to the stakeholders' dependency on uses. We discussed conflicting uses and how they are currently managed.

Next, we identified the disturbances that have historically affected the focal system, represented a current issue of concern, or have the potential of being a future disturbance. We classified them as "pulse" if they occurred as a relatively discrete punctual event in time or as "press" if they occurred in a gradual and cumulative manner (Resilience Alliance, 2010). We discussed whether or not these disturbances are actively managed or suppressed, because this can be a key factor in the system's resilience. We concluded this step with a broad overview of the temporal changes in the system at different spatial scales to identify whether there is a relationship between spatial and temporal scales.

Once the focal system was analyzed, we interpreted the fishery dynamics from the perspective of adaptive cycles (Holling 2001). The SESs are interlinked in endless transformational cycles of growth, accumulation, restructuring, and renewal. The adaptive cycle is a heuristic model, a fundamental unit that contributes to the understanding of the dynamics of complex systems (Holling 2001). The cycle starts in a recently disturbed system in which rapid colonization leads to growth in the size of the system (the *r* phase – exploitation). This is followed by the conservation phase (*k*) when slow accumulation and storage of energy/material develops a more complex structure until a climax is attained. This may persist for some time until a periodic or unexpected disturbance occurs (e.g., wind, fire, disease, etc.). Such a disturbance rapidly disassembles the system's structure and functioning, leading to the release phase (Ω). Following the collapse, the system begins to renew itself and becomes available for the next phase of exploitation, the reorganization phase (α) (Holling 2001). This qualitative model captures how the system changes over time; it can be used to identify cyclical patterns of change and inform the timing of management interventions (Resilience Alliance 2010).

2.5 RESULTS

2.5.1 Main issues of concern

The main issue of concern to be addressed in the focal system is the management of the industrial fishery and availability of resources to the artisanal sector. The people involved in the capturing, processing, and commercialization of mullet are the main stakeholders in the industrial sector. Income generation and food security are the attributes of the system valued by these stakeholders.

The main stakeholders affected by the artisanal fishery are artisanal fishers and their families. Tourists, consumers, and merchants are stakeholders of both sectors. They also benefit from the cultural events related to the mullet fishery. Regional mullet festivals promote income generation during the low season (between April and November), helping to stabilize the community's income along the year. The artisanal sector has narrow and local distributions (close to the fishers' households) along the Southern and Southeastern Brazilian coast from RS to RJ. Meanwhile, the industrial sector mainly operates in four Brazilian states: RS, SC, SP, and RJ (Figure 2.3). The mullet fishery provides support for livelihood sustainability besides the provision of food security and income generation, which includes maintenance and transmission of traditional ecological knowledge, collective action, and sense of place and attachment to the fishing livelihood (Pinheiro et al. 2010; Herbst & Hanazaki 2014).

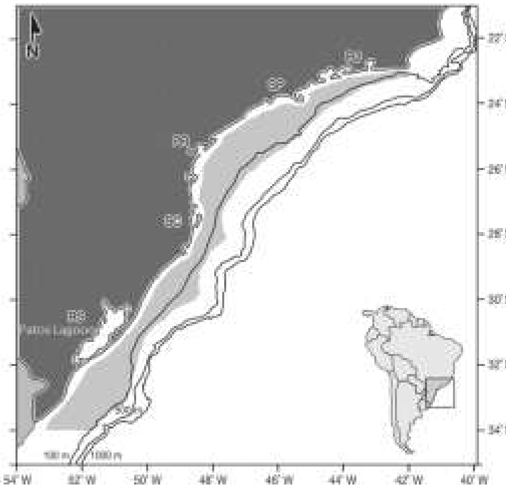


Fig. 2.3 Area where the *M. liza* fishery occurs on the Southern and Southeastern Brazilian coast as far as the 100 m isobath (Miranda et al. 2006)

2.5.2 The key components of the SES

The stakeholders' needs vary according to their levels of resource dependency; subsistence fishers have a stronger and more direct dependency than other stakeholders (Table 2.2).

Table 2.2: Uses of natural resources supplied by the system and their stakeholders. Stakeholders inside (outside) the focal system have direct (indirect) access to natural resources. (The Resilience Alliance 2010).

Natural resource uses	Stakeholders
Direct uses	Inside focal system
Economic	Fishers and other fishery industry workers
Cultural	Artisanal fishers
Subsistence	Artisanal fishers
Indirect uses	Outside focal system
Conservation	Researchers (Universities, Non-Governmental Organizations)
Management	Governmental institutions
Economic and recreational	Touristic sector
Delicacy	Consumers of the exported mullet roes

Cultural and economic uses occur concurrently with subsistence because artisanal fishermen consume and trade fish. Norms and behaviors that regulate a rigidly established and long-standing household division of labor are informal management practices embedded in the artisanal fishery.

Stakeholders outside the focal system are less dependent on the resource. Universities and Non-Governmental Organizations have been engaged in monitoring and researching the mullet fishery. Formal management measures for mullet fishery have been traditionally established by governmental institutions in a top-down process (Reis and D'Incao 2000) despite the recent designation of the Permanent Commission for the Management of Southern-Southeastern Pelagic Fishes (PCM-pelagic). The PCM-pelagic is a multi-stakeholder advisory fisheries management body, and the mullet fisheries have been one its main agendas since its designation in 2016. The touristic sector includes consumers in restaurants and fish markets as well as those who watch and collaborate with the collective small-scale beach seine fishing along the coast of SC and PR (Herbst & Hanazaki 2014). Consumers of the exported bottarga – a cured matured roe considered analogous to caviar (Seckendorff and Azevedo 2007; Lemos et al. 2016) use mullet for leisure dining and consumption of high-end dishes.

2.5.3 Disturbances, disruptions, and uncertainties

The disturbances that have affected the system and their attributes are detailed in Table 2.3.

Table 2.3: Disturbances in the focal system and their attributes (The Resilience Alliance 2010).

Disturbance	Pulse or press	Frequency of occurrence	Components most affected	Magnitude of impact (minor to severe)	Recent changes
Industrial fishery	Press	Annual since 2000's	• Biological • Social-economic	Severe	Management measures
Rio Grande Harbor jetties construction	Press	Continuous	• Ecosystemic • Biological • Social-economic	Minor	Harbor jetties extension
El Niño	Pulse	2 – 7 years	• Ecosystemic • Biological	Severe	More intense events
Future disturbances					
Climate change	Press	Continuous	• Ecosystemic	Severe	None

The industrial fishery is a relatively recent disturbance. This activity mostly threatens the system's quality, an effect that in recent decades has put fishermen's incomes at risk. The disturbances caused by PLE urbanization and industrialization, such as decreasing water quality or inadequate fishery surveillance by government sectors, have contributed to the decline of fish stocks in the estuary (Odebrecht et al. 2010).

A pair of long rocky jetties (~5 km) is a major feature in the PLE's mouth (Figure 2). This manmade construction, expanded between 2001 and 2011, created a long, easily navigable channel and resulted in increased ebb flow speeds (Möller Jr. and Fernandes, 2010). However, the species composition and densities of fish assemblages at sandy beaches adjacent to the PLE jetties seem to be unaffected by this structure (Rodrigues and Vieira 2013).

Meteorological changes caused by the ENSO phenomenon are major driving forces that control the inter-annual variability of structure and dynamics of fish communities in the estuary, causing great impact on fisheries (Fontoura et al. 2016). Mullet fisheries serve as a good example, because both juvenile and adult mullets decline in abundance during El Niño episodes of high rainfall and near-zero salinity

(Garcia et al. 2004; Vieira et al. 2008). Changes in the frequency and intensity of ENSO events, linked to global climatic changes, represent a future threat to the SES mullet fishery.

2.5.4 Multiple spatial and temporal scales

The evaluation of large-scale dynamics can help identifying the slow changes that facilitate system stability in a particular regime. The export market and the ENSO can be regarded as large-scale systems that influence the focal system in the social and ecological dimensions, respectively. The artisanal fishery and PLE ecosystem are small-scale systems that influence the focal system in the social and ecological dimensions, respectively. Figure 2.4 shows the historical changes in the focal system and in large/small-scale systems.

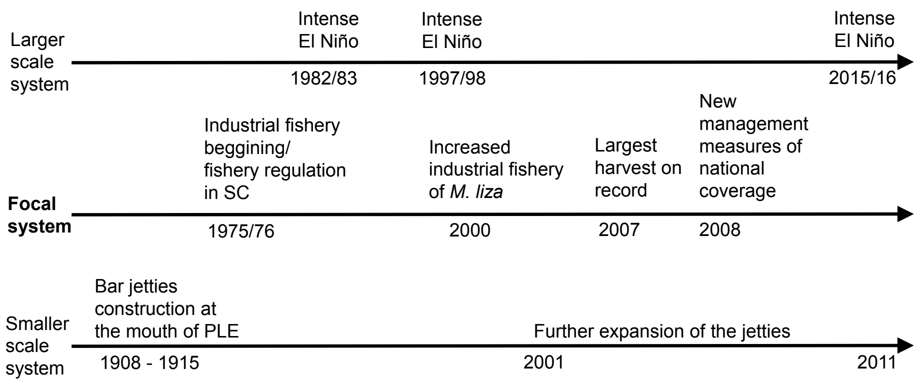


Fig. 2.4 Timeline of major events in the focal system and in the large/small-scale systems that interact with it

The starting point for the industrial fishery was approximately 40 years ago when part of the purse-seine fleet from SC started fishing mullet as a seasonal alternative to sardines. In 1976, conflicts over the resource led to the establishment of a no-take area for purse-seine fleet activities in SC (1,800 m from beaches and 300 m from rocky coasts) during the mullet season (SUDEPE ordinance n. 9N/1976).

The decline in sardine catches, mainly since the 2000s, along with the appreciation and increase in the price of *bottarga*, led to an increase in the industrial fleet targeting mullet. The production increased from an annual mean of 1,650 t in the 1990s to 4,100 t in the 2000s (Brazilian Ministry of Development, Industry and Export Market – MDIC). The reported peak in landings in 2007 prompted new management measures on national coverage to be established for the following season (2008).

The PLE is a small-scale system embedded within the focal system; however, it is also influenced by global events such as climate change. Such interactions of different scales were observed during the years of El Niño in 1982/1983 and 1997/1998. Specifically, the relative abundance of juveniles and catches of adults decreased as a consequence of low salinity and high precipitation conditions caused by El Niño (Vieira et al. 2008).

2.5.5 The system's dynamics – the adaptive cycle

The arrival of pre-recruits at the estuary's mouth demarks the r phase of the cycle (exploitation) (Figure 2.5). These pre-recruits may remain in the surf zone up to one year, waiting for the appropriate conditions (high salinity) to enter the estuary. During El Niño years, the exploitation phase is hindered by changes in biophysical conditions (Vieira et al. 2008). In the K phase (conservation), pre-recruits that entered the estuary remain in this area until the maturation age of six years, when specimens are recruited into the adult stock (Garbin et al. 2014). The artisanal fishery inside the estuaries is the main threat to the maintenance of sustainable levels of adult stocks.

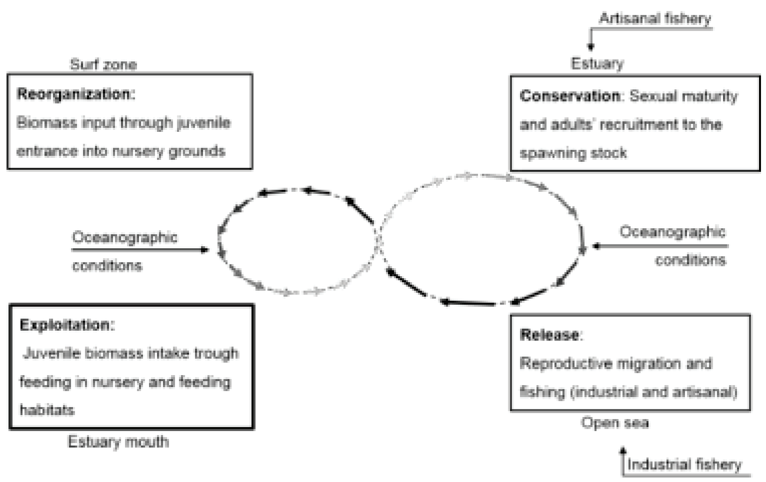


Fig.2.5 Schematic representation of the adaptive cycle of the mullet fishery on the Southern and Southeastern Brazilian coast. The arrows within the cycle represent the speed of flow. Grey and closely spaced arrows indicate a slowly changing situation; dark and long arrows indicate a rapidly changing situation. The phases of the cycle and events associated with them are described within rectangles. Each box represents and describes events occurring in each phase of the adaptive cycle. Long arrows outside the cycle indicate the main factors that influence the SES's resilience. Adapted from Kalikoski et al. (2010)

The Ω phase (release) occurs when adults leave the estuary in their annual reproductive migration to the open sea (Garbin et al. 2014). The success of this phase largely depends on meteorological and oceanographic conditions. The migration is triggered by the input of colder and saltier waters into the estuary caused by cold fronts during the austral autumn/winter. At this time, the stock becomes available to both industrial and artisanal fisheries.

Adults and larvae return to the estuary after spawning in the α phase (reorganization). Again, the meteorological and oceanographic conditions greatly influence the success of this phase. The relatively higher water temperatures in spring and summer benefit juvenile feeding and growth. During this stage, they are carried southwards by superficial coastal currents, eventually reaching the estuarine area and closing the cycle (González-Castro et al. 2011).

2.6 DISCUSSION

The mullet fisheries are managed under a mix of hybrid property rights along the Southern-Southeastern Brazilian coast. A common property regime is in place in several fishing villages along this coast (Pinheiro et al. 2009). Private property rights are enforced in offshore waters (from three nautical miles) where fishing permits are given only for purse seiners. In both occasions, fishing permits are granted by federal authorities in support of the fisheries management. Furthermore, sport and illegal fishing occurs under an open-access regime where there is no clear definition of how many fishers are allowed and how much can be captured. The lack of clarity in the criteria for fishing permits creates asymmetry in resource access and control. The exclusion of beneficiaries through physical and institutional means is particularly costly; the exploitation by one user reduces resource availability for others (sub-tractability) (Ostrom et al. 1999). These two factors have caused competition for the resource – in this case, between the artisanal and industrial fishing sectors. The current management options acknowledge such competition; however, the industrial sector enjoys a major advantage over the artisanal sector.

In 2008, the government established rules in the mullet fishery on the Southern-Southeastern Brazilian coast including a limit in the mullet fishing season, exclusion of areas for purse-seine operations, more rigid rules applied to the acquisition of fishing permits, and a gradual reduction in the number of permits granted to the industrial fleet operation. The main issue is already being actively managed; however, the criteria used to grant permits among vessels remain unclear. Fishing is regulated based solely on fleet size, which masks differences in fishing power and inhibits fairness in fish allocation among the fleets. Conflicting interests have been hampering the execution of these measures. The rules went through a series of alterations without prior implementation and evaluation in the years since 2008, impairing the attainment of resilience through these management measures.

The fishing seasons start with the beach seiners by May 1st (austral autumn), followed by the gillnetters and the purse seiners, with a time interval of 15 days in between fleets. Despite the attempt of balancing the access to resources, shifts in ecosystem dynamics – influencing both a late migration period, the migration path and the size of the spawning stock, as well as the difference in fishing power – can make the regulation mechanism unsuccessful and still privilege purse seiners. Recent discussion is considering the implementation of Individual Transferable Quotas (ITQs), based on an estimate of the mullet population size (Sant'ana & Kinas, 2016). ITQs are widely implemented in developed countries but not easily suitable to the complexity of small-scale fisheries (Berkes et al. 2001), or in a context of poor information on fisheries and resource users, as in Brazil.

In the fisheries context, a shift in the natural "state", for example, through overfishing, represents a loss of social-ecological resilience. This may result in a long-term collapse of the fishery, livelihoods, and capacity to cope with future disturbances in the social system (Bunce et al. 2009). In some cases, the species ability to cope with the synergic effects of shifts in ecosystems (e.g., climate change and the ENSO phenomenon) and overfishing is exceeded. For the Lebranche mullet, the late recruitment (~ 6 years, Garbin et al., 2014) masks inter-annual effects of these drivers of the fish populations, especially in a context of poor management and monitoring.

Policy and management, when feasible, must provide a portfolio of adaptive capacity at a range of scales to reduce vulnerability (Crowder and Norse 2008; Brierley and Kingsford 2009; Creighton et al. 2016). The vulnerability is reduced when governance promotes equitable and sustainable fisheries, embraces uncertainty, and encourages openness to learn and adapt (Holling 2001; Allen et al. 2014). Dealing with fisheries' vulnerability requires the capacity to deal with changes and disturbances as well as to foster resilient fisheries (Allison et al. 2009; Folke et al. 2010). Inefficiency in the fishery regulation system and declining trends in catches has been indicating an increase in vulnerability. The low adaptive capacity is greatly led by weakened institutional capacity (Medeiros et al. 2013) and the predominance of economic interest over social and ecosystem dynamics in the exploitation of mullet fishing.

The industrial fishery was recently boosted by the mullet roe export market. The consumers of exported *bottarga* are stakeholders outside the focal system, and therefore, have a low dependency on the resource; however, the industry sector has led to the generation of thousands of direct and indirect jobs. Meanwhile, an increase in the industrial fishery affects resource availability to the artisanal fishery sector. The *bottarga* is one of the main commodities of the industrial fishery in the region. It has high market prices and is exported to France, Italy, Spain, and Taiwan. According to the MDIC, the annual mean revenue generated by the mullet season between 2006 and 2013 was estimated at approximately US$ 11 million; US$ 6 million from the fishing sectors and US$ 5 million from the exportation of roe.

From a broader perspective, the exclusion of the industrial fishery as an attempt to preserve the resource is a management strategy that can actually affect the system's resilience. Restriction combined with poor governance can lead to low compliance and illegal fishing. Many vessels fish in prohibited fishing zones to recover high investments needed to perform purse-seine operations. The Vessel Satellite Monitoring System (in Portuguese: PREPS – Programa Nacional de Rastreamento de Embarcações por Satélite) enforces the operations of licensed vessels. However, this system is jeopardized when such vessels may also legally exploit other fish stocks such as the Brazilian sardine. Despite the potential social and economic impacts on the industrial sector, stakeholders from research and the small-scale fisheries sector have requested the exclusion of purse seines in order to reduce fishing effort, prioritize access to low-income and low-mobility resource users, and lower the impact of fishing methods.

Besides human influence, the local and regional ecosystems dynamics play an important role in mullet fisheries. According to fishers, when the austral autumn and winter seasons are colder than usual, with recurrent cold fronts, the migration shoals are denser, and catches are usually higher (Herbst and Hanazaki 2014). It is likely that oceanographic and meteorological conditions strongly affect the resource availability; the analysis of the variability of key physical variables such as sea surface temperature and winds at sea should, therefore, be included in the assessment of this system.

The official harvest season is established according to the migration displacement northwards during the release phase. However, recent reviews highlight the policy relevance in adaptively vulnerable SESs by understanding two critical stages in the Holling's Adaptive Cycle – release and reorganization – in order to forestall and overcome crises (Abel et al. 2006). The reorganization phase determines the success of recruitment, which is the fundamental process in the population dynamics that is responsible for fluctuations in stock size (Maunder et al. 2006).

For research purposes, a time interval of at least seven years is required to investigate this system, taking into account the ENSO effect, which has a periodicity of 2–7 years (Trenberth and Hoar 1996), and the recruitment mullet age allowed to fisheries. El Niño events have been observed to affect the inter-annual abundance variability of mullet populations during two crucial phases of the species' life cycle: juvenile recruitment into the estuary, and reproductive migration of mature adults out to sea (Vieira et al. 2008).

Hence, improved management of the mullet fishery requires careful consideration of a broad range of biophysical, cultural, and socio-economic factors including a critical analysis of the existing and potential management strategies (Maunder et al. 2006). The incorporation of environmental time series into stock assessments that would allow the inclusion of multiple data models may provide additional information to help to estimate model parameters, particularly when fishing observations (catch, effort, and length-frequencies) are missing (Maunder et al. 2006), as is the case of the mullet fishery in Brazil

2.7 CONCLUSIONS

The mullet fishery on the Southern-Southeastern Brazilian coast behaves as a complex multi-scale system in space and time. Slow and fast changes of key variables occur at local (estuary) and regional (coastal waters) levels. The system's resilience depends upon short-term changes in the fishing effort and long-term changes in the ocean's dynamics. More rigid input control mechanisms (such as fishing permits) should be taking place in periods of higher ecosystem vulnerability (such as El Niño years). Thereby, controls would be modulated by ecosystem dynamics in order to reduce pressure from fisheries. Allocation of fishing permits based on the acknowledgement of a stratified fleet in terms of fishing power should also be considered. Incorporation of resilience thinking in the case of the mullet fishery depends on acknowledging that limits should consider not only vessel behavior parameters but also shifts in ecosystem in space and time. Priority in fish allocation should be given to societal objectives in order to guarantee the continuance of fishing for providing food security and cultural values related to the mullet fishery.

This approach is in contrast to making decisions based on simple metrics of population size, such as catch per unit effort (CPUE) efficiency. The CPUE is considered controversial (Hilborn and Walters 1992; Harley et al. 2001; Maunder et al. 2006) when used as an abundance indicator because it does not necessarily reflect changes in mullet's abundance. Rather, its value is the result of fluctuations in environmental conditions, fishing efforts, or a combination of both (Miranda et al. 2006). Thereby, implementation of ITQs without clear consideration of ecosystem dynamics and the primary objectives of the fishing (providing food security and poverty alleviation) would increase asymmetry in mullet fisheries.

From a fisheries biology perspective, regardless of the environmental changes that might occur, it's assumed that the system reorganization can be achieved if a sufficient proportion of adults succeed in spawning, and therefore, producing a sufficient number of juveniles for the renewal phase. The adaptive cycle of the mullet industrial fishery is very dynamic, with other aspects beyond the fishery itself (e.g., ENSO events) influencing spawning success. To robustly assess this SES, it is, therefore, necessary to carefully delimit the effects from other influences on the mullet population. As previously discussed, the success of the release and reorganization phases strongly depends on oceanographic conditions. The long-term monitoring of such conditions, together with the responses from the industrial fishery (e.g., landings, fishing effort), will greatly improve our understanding of the adaptive cycle dynamics in this scenario, leading to improved sustainable management strategies.

Some authors have suggested that a total ban on the industrial mullet fishery is the only solution for the sustainability of this fishery (Miranda et al. 2011) in Brazil. Despite the impact of banning the whole industrial fleet, the focus on prioritizing primary objectives in fisheries management – such as providing food security, alleviating poverty, and fostering resilience – must prevail over private economic interests (Cochrane et al. 2011). Contrary to small-scale fisheries, especially those inside estuaries, purse seiners have the mobility and technology to migrate across fishing grounds and exploit new fishing resources. Moreover, given the vulnerability of the Lebranche mullet, fishing should be reduced by limiting prioritized societal objectives such as those advocated by the EAF (Fletcher and Bianchi 2014). Nevertheless, the current management measures are clearly insufficient to ensure the long-term sustainability of this fishery. This sustainability will only be achieved with a better understanding of the changing dynamics in the SES and the alignment of management strategies with fluctuations in the fishery's system.

Effective measures to promote effective resilient fisheries rely on three aspects. First, a fish allocation system should be implemented with a variable interannual number of fishing permits based on stock levels and on the shifts in ecosystem variability. Secondly, given the vulnerability of the mullet due to fishing pressure and ocean dynamics, fish allocation should prioritize primary objectives of fishing. Thirdly, a monitoring system should be implemented that takes into consideration ecosystem, fisheries and human dimensions to support a flexible and adaptive fisheries management, with resilient fisheries as an ultimate goal. However, to be effective, a capacity development should be formulated and implemented on all levels, from hook to cook, from the fisher to the manager and the scientist. To foster resilient fisheries relies greatly in our ability and willingness to achieve this medium, long-term and innovative goal.

2.8 ACKNOWLEDGEMENTS

M. A. Abreu-Mota is thankful to the Coordination for the Improvement of Higher Education Personnel (CAPES) for a Ph.D. scholarship. This study was developed as part of a graduate course on Coastal and Ocean Systems at the Federal University of Paraná (PGSISCO-UFPR).

2.9 REFERENCES

Abel N, Cumming DHM, Anderies JM (2006) Collapse and Reorganization in Social-Ecological Systems : Questions, Some Ideas, and Policy Implications. Ecol Soc 11:17. doi: https://doi.org/10.5751/es-01593-110117

Acheson JM (2006) Institutional Failure in Resource Management. Annu Rev Anthropol 35:117–34. doi: 10.1146/annurev.anthro.35.081705.123238

Adger WN, Hughes TP, Folke C, Carpenter SR, Rockström J (2005) Social-ecological resilience to coastal disasters. Science 309:1036–1039. doi: 10.1126/science.1112122

Allen CR, Angeler DG, Garmestani AS, Gunderson LH, Holling CS (2014) Panarchy : Theory and Application. Ecosystems 17:578–589. doi: 10.1007/s10021-013-9744-2

Allison EH, Perry AL, Badjeck M-C, Neil Adger W, Brown K, Conway D, Halls AS, Pilling GM, Reynolds JD, Andrew NL, Dulvy NK (2009) Vulnerability of national economies to the impacts of climate change on fisheries. Fish Fish 10:173–196. doi: 10.1111/j.1467-2979.2008.00310.x

Armitage DR, Plummer R, Berkes F, Arthur R, Charle AT, Hunt D, Iain J, Diduck AP, Doubleday NC, Johnson DS, Marschke M, McConney P, Pinkerton EW, Wollenberg EK (2009) Adaptive co-management for social– ecological complexity. Front Ecol Environ 7:95–102. doi: 10.1890/070089

Beddington JR, Agnew DJ, Clark CW (2007) Current problems in the management of marine fisheries. Science 316:1713–6. doi: 10.1126/science.1137362

Béné C, Arthur R, Norbury H, Allison EH, Beveridge M, Bush S, Campling L, Leschen W, Little D, Squires D, Thilsted SH, Troell M, Williams M (2016) Contribution of Fisheries and Aquaculture to Food Security and Poverty Reduction : Assessing the Current Evidence. World Dev 79:177–196. doi: 10.1016/j.worlddev.2015.11.007

Bianchi G, Skjoldal HR (2008) The Ecosystem approach to Fisheries. Centre for Agriculture and Bioscience International, Wallingford

Brierley AS, Kingsford MJ (2009) Impacts of Climate Change on Marine Organisms and Ecosystems. Curr Biol 19:602–614.

Bunce M, Mee L, Rodwell LD, Gibb R (2009) Collapse and recovery in a remote small island — A tale of adaptive cycles or downward spirals ? Glob Environ Chang 19:213–226. doi: 10.1016/j.gloenvcha.2008.11.005

Cochrane KL, Andrew NL, Parma AM (2011) Primary fisheries management: A minimum requirement for provision of sustainable human benefits in small-scale fisheries. Fish Fish 12:275–288. doi: 10.1111/j.1467-2979.2010.00392.x.

Creighton C, Hobday AJ, Lockwood M, Pecl GT (2016) Adapting Management of Marine Environments to a Changing Climate : A Checklist to Guide Reform and Assess Progress. Ecosystems 19:187–219. doi: 10.1007/s10021-015-9925-2

Crowder L, Norse E (2008) Essential ecological insights for marine ecosystem-based management and marine spatial planning. Mar Policy 32:772–778. doi: 10.1016/j.marpol.2008.03.012

Doney SC, Ruckelshaus M, Duffy JE, Barry JP, Chan F, English CA, Galindo HM, Grebmeier JM, Hollowed AB, Knowlton N, Polovina J, Rabalais NN, Sydeman WJ, Talley LD (2012) Climate Change Impacts on Marine Ecosystems. Ann Rev Mar Sci 4:11–37. doi: 10.1146/annurev-marine-041911-111611

Eriksson H, Adhuri DS, Adrianto L, Andrew NL, Apriliani T, Daw T, Evans L, Garces L, Kamanyi E, Mwaipopo R, Purnomo AH, Sulu RJ, Beare DJ (2016) An ecosystem approach to small-scale fi sheries through participatory diagnosis in four tropical countries. Glob Environ Chang 36:56–66. doi: 10.1016/j.gloenvcha.2015.11.005

Fletcher PJ, Kelble CR, Nuttle WK, Kiker GA (2014) Using the integrated ecosystem assessment framework to build consensus and transfer information to managers. Ecol Indic 44:11–25. doi: 10.1016/j.ecolind.2014.03.024

Fletcher WJ, Bianchi G (2014) The FAO - EAF toolbox: Making the ecosystem approach accessible to all fisheries. Ocean Coast Manag 90:20–26. doi: 10.1016/j.ocecoaman.2013.12.014

Folke C (2006) Resilience : The emergence of a perspective for social – ecological systems analyses. Glob Environ Chang 16:253–267. doi: 10.1016/j.gloenvcha.2006.04.002

Folke C, Carpenter SR, Walker B, Scheffer M, Chapin T, Rockström J (2010) Resilience Thinking: Integrating Resilience, Adaptability and Transformability. Ecol Soc 15:20. doi: 10.5751/es-03610-150420

Folke C, Pritchard Jr. L, Berkes F, Colding J, Svedin U (2007) The Problem of Fit between Ecosystems and Institutions: Ten Years Later. Ecol Soc 12:30. doi: 10.5751/es-02064-120130

Fontoura NF, Vieira JP, Becker FG, Rodrigues LR, Malabarba LR, Schulz UH, Möller OO, Garcia AM, Vilella FS (2016) Aspects of fish conservation in the upper Patos Lagoon basin. J Fish Biol 89:315–336. doi: doi:10.1111/jfb.13005

Garbin T, Castello JP, Kinas PG (2014) Age, growth, and mortality of the mullet Mugil liza in Brazil's southern and southeastern coastal regions. Fish Res 149:61–68. doi: 10.1016/j.fishres.2013.09.008

Garcia AM, Vieira JP, Winemiller KO, Grimm a. M (2004) Comparison of 1982–1983 and 1997–1998 El Niño effects on the shallow-water fish assemblage of the Patos Lagoon estuary (Brazil). Estuaries 27:905–914. doi: 10.1007/bf02803417

Garcia S, Cochrane K (2005) Ecosystem approach to fisheries: a review of implementation guidelines. ICES J Mar Sci 62:311–318. doi: 10.1016/j.icesjms.2004.12.003

González-Castro, M.G., Macchi, G.J., Cosseau MB (2011) Studies on reproduction of the mullet Mugil platanus Gunther, 1880 (Actinopterygii, Mugilidae) from the Mar Chiquita coastal lagoon, Argentina: Similarities and differences with related species. Ital J Zool 78:343–353.

Hagstrom GI, Levin SA (2017) Marine Ecosystems as Complex Adaptive Systems : Emergent Patterns , Critical Transitions , and Public Goods. Ecosystems. doi: 10.1007/s10021-017-0114-3

Harley SJ, Myers RA, Dunn A (2001) A meta-analysis of the relationship between catch-per-unit-effort and abundance. Can J Fish Aquat Sci 58:1705–1772.

Herbst DF, Hanazaki N (2014) Local ecological knowledge of fishers about the life cycle and temporal patterns in the migration of mullet (Mugil liza) in Southern Brazil. Neotrop Ichthyol 12:879–890. doi: 10.1590/1982-0224-20130156

Hilborn R, Walters CL (1992) Quantitative fisheries stock assessment: choice, dynamics & uncertainty. Rev Fish Biol Fish 2:177–178. doi: 10.1007/BF00042883

Holling CS (2001) Understanding the Complexity of Economic, Ecological, and Social Systems. Ecosystems 4:390–405. doi: 10.1007/s10021-001-0101-5

Holling CS (1974) Resilience and Stability as Shown by Models of Ecological Systems. In: van den Driessche P (ed) Mathematical Problems in Biology. Springer, Berlin, pp 93–95.

Holling CS, Meffe GK (1996) Command and Control and the Pathology of Natural Resource Management. Conserv Biol 10:328–337. doi: 10.1046/j.1523-1739.1996.10020328.x

Hughes TP, Bellwood DR, Folke C, Steneck RS, Wilson J (2005) New paradigms for supporting the resilience of marine ecosystems. Trends Ecol Evol 20:380–386. doi: 10.1016/j.tree.2005.03.022

Kalikoski DC, Quevedo Neto P, Almudi T (2010) Building adaptive capacity to climate variability: The case of artisanal fisheries in the estuary of the Patos Lagoon, Brazil. Mar Policy 34:742–751. doi: 10.1016/j.marpol.2010.02.003

Lemos VM, Avila Troca DF, Castello JP, Paes Vieira J (2016) Tracking the southern Brazilian schools of Mugil liza during reproductive migration using VMS of purse seiners. Lat Am J Aquat Res 44:238–246. doi: 10.3856/vol44-issue2-fulltext-5

Lemos VM, Varela Jr. AS, Shwingel PR, Muelbert JH, Vieira JP (2014) Migration and reproductive biology of Mugil liza (Teleostei: Mugilidae) in south Brazil. J Fish Biol 85:671–687. doi: 10.1111/jfb.12452

Mahon R, Mcconney P, Roy RN (2008) Governing fisheries as complex adaptive systems. Mar Policy 32:104–112. doi: 10.1016/j.marpol.2007.04.011

Mai ACG, Miño CI, Marins LFF, Monteiro-Neto C, Miranda L, Schwingel PR, Lemos VM, Gonzalez-Castro M, Castello JP, Vieira JP (2014) Microsatellite variation and genetic structuring in Mugil liza (Teleostei: Mugilidae) populations from Argentina and Brazil. Estuar Coast Shelf Sci 149:80–86. doi: 10.1016/j.ecss.2014.07.013

Maunder M, Sibert J, Fonteneau a, Hampton J, Kleiber P, Harley S (2006) Interpreting catch per unit effort data to assess the status of individual stocks and communities. ICES J Mar Sci 63:1373–1385. doi: 10.1016/j.icesjms.2006.05.008

Medeiros RP, Guainais JHDG, Santos LO, Spach HL, Silva CNS, Foppa CC, Cattani AP, Rainho AP (2013) Estratégias para a redução da fauna acompanhante na frota artesanal de arrasto do camarão sete-barbas: perspectivas para a gestão pesqueira. Bol do Inst Pesca 39:339–358. doi: 10.20950/1678-2305.2013v39n3p339

Miller K, Charles A, Barange M, Brander K, Gallucci VF, Gasalla MA, Khan A, Munro G, Murtugudde R, Ommer RE, Perry RI (2010) Climate change, uncertainty, and resilient fisheries : Institutional responses through integrative science. Prog Oceanogr 87:338–346. doi: 10.1016/j.pocean.2010.09.014

Odebrecht C, Abreu PC, Bemvenuti CE, Copertino M, Muelbert JH, Vieira JP, Seeliger U (2010) The Patos Lagoon Estuary, Southern Brazil. In: Kennish MJ, Paerl HW (eds) Coastal Lagoons: Critical Habitats of Environmental Change. CRC Press, Boca Raton, pp 433–456

Ostrom E, Burger J, Field C, Norgaard R, Policansky D (1999) Revisiting the Commons: Local Lessons, Global Challenges. Science 284:278–282. doi: 10.1126/science.284.5412.278

Pina JV, Chaves PT (2005) A pesca de tainha e parati na Baía de Guaratuba, Paraná, Brasil. Acta Biol Parana 34:103–113. doi: 10.5380/abpr.v34i0.957

Pomeroy RS, Berkes F (1997) Two to tango : the role of government in fisheries. Mar Policy 21:465–480. doi: 10.1016/s0308-597x(97)00017-1

Reis EG, D'Incao F (2000) The present status of artisanal fisheries of extreme Southern Brazil : an effort towards community-based management. Ocean Coast Manag 43:585–595. doi: 10.1016/S0964-5691(00)00048-X

Resilience Alliance (2010) Assessing resilience in social-ecological systems: workbook for practitioners. http://www.resalliance.org/3871.php. Accessed 29 Oct 2017

Rice J (2011) Managing fisheries well: delivering the promises of an ecosystem approach. Fish Fish 12:209–231. doi: 10.1111/j.1467-2979.2011.00416.x

Rodrigues FL, Vieira JP (2013) Surf zone fish abundance and diversity at two sandy beaches separated by long rocky jetties. J Mar Biol Assoc United Kingdom 93:867–875. doi: 10.1017/S0025315412001531

Sant'ana R, Kinas PG (2016) Avaliação do Estoque de Tainha (Mugil liza): ampliação dos modelos Bayesianos de Dinâmica de Biomassa para múltiplas séries de CPUE, com adição de temperatura superficial do mar e capturabilidade autocorrelacionada. In: Oceana. http://brasil.oceana.org/sites/default/files/avaliacao_de_estoque_tainha_oceana_-_integra.pdf. Accessed 19 Feb 2018

Seeliger U (2001) The Patos Lagoon Estuary, Brazil. In: Seeliger U, Kjerfve B (eds) Coastal Marine Ecosystems of Latin America. Springer, Berlin, pp 167–183

Silva CNS, Broadhurst MK, Medeiros RP, Dias JH (2013) Resolving environmental issues in the southern Brazilian artisanal penaeid-trawl fishery through adaptive co-management. Mar Policy 42:133–141. doi: 10.1016/j.marpol.2013.02.002

Steffen E, Crutzen PJ, McNeill JR (2007) The Anthropocene: are humans now overwhelming the great forces of nature? Ambio 36:614–621. doi: 10.1579/0044-7447(2007)36[614:TAAHNO]2.0.CO;2

Sumaila UR, Cheung WWL, Lam VWY, Pauly D, Herrick S (2011) Climate change impacts on the biophysics and economics of world fisheries. Nat Clim Chang 1:449–456. doi: 10.1038/nclimate1301

Trenberth KE, Hoar TJ (1996) The 1990-1995 El Niño Southern Oscillation Event: longest on record. Geophys Res Lett 23:57–60. doi: 10.1029/95GL03602

Vieira JP, Garcia AM, Grimm AM (2008) Evidences of El Niño Effects on the Mullet Fishery of the Patos Lagoon Estuary. Brazilian Arch Biol Technol 51:433–440. doi: 10.1590/S1516-89132008000200025

Walker B, Holling CS, Carpenter SR, Kinzig A (2004) Resilience, adaptability and transformability in social– ecological systems. Ecol Soc 9:5.

Williams BK, Brown ED (2014) Adaptive Management: From More Talk to Real Action. Environ Manage 53:465–479. doi: 10.1007/s00267-013-0205-7

World Bank (2012) Hidden harvest : the global contribution of capture fisheries. World Bank. http://documents.worldbank.org/curated/en/515701468152718292/Hidden-harvest-the-global-contribution-of-capture-fisheries. Accessed 29 Oct 2017

3 LEBRANCHE MULLET CATCH RATE RELATED TO MESOSCALE OCEANOGRAPHY IN THE SOUTHWEST ATLANTIC

Environmental effects on the mullet CPUE

Taxa de captura de tainha em relação a oceanografia de mesoscala no Atlântico Sudoeste

Efeitos ambientais sobre a CPUE de tainha

Revista pretendida: Fisheries Oceanography (Fish. Oceanogr), ISSN (1365-2419), Fator de Impacto = 1,578, Qualis CAPES = Estrato A2.

Michelle Alves de Abreu-Mota[1], Mauricio Almeida Noernberg[1] and Rodrigo Pereira Medeiros[1]

1.Centro de Estudos do Mar, Universidade Federal do Paraná. Av. Beira Mar s/n.
Pontal do Paraná, PR, Brazil. CEP: 83255-976. Phone: +55 41 35118600

3.1 ACKNOWLEDGMENTS

M. A. Abreu-Mota is thankful to the Coordination for the Improvement of Higher Education Personnel (CAPES) for a Ph.D. scholarship. This study was developed as part of a graduate course on Coastal and Ocean Systems at the Federal University of Paraná (PGSISCO-UFPR).

3.2 ABSTRACT

This research investigates the relations between Catch per Unit of Effort (CPUE) of lebranche mullet, a commercial fish traditionally exploited in the South-Southeast Brazilian coast, and the environmental variability by means of wavelet analysis. Monthly CPUE was calculated from the official purse seiner's landings for the Brazilian states of Santa Catarina and São Paulo. We used a climate index (Multivariate ENSO Index – MEI) and regional monthly satellite imagery data (Sea Surface Temperature, Chlorophyll-*a* and Sea Surface Winds) to explore the environmental variability. We carried out cross wavelet and phase analysis to investigate dependency between CPUE and each environmental time series. Results indicated a strong association with wind speed in periodic cycles of 24 and 44 months, the periodic bands of the Brazilian coastal current and ENSO, respectively. Cold episodes of ENSO matched increased mullet catch rate for the years 2006, 2008 and 2011. Chlorophyll-*a* lagged CPUE and we hypothesize that

the match between mullet initial life stages and primary productivity results in an increased larval survival probability, which can be detectable in a 5-6 years' time span. The results indicate that the wind is the main driver of shifts on CPUE variability. However, CPUE may also reflect catchability trends. Nevertheless, the wavelet approach appears to be a powerful and reliable tool for environmental time series analysis considering the non-stationary nature of such time series and could have important applications in fisheries science.
Keywords: mullet, wavelet analysis, industrial fishery, remote sensing, El Niño Southern Oscillation, Southwest Atlantic, Patos Lagoon Estuary.

3.3 INTRODUCTION

Marine fish stocks and catches vary seasonally and interannually due to environmental variability at similar scales. Understanding the array of factors that drives the fish population dynamics is both a primary objective of fisheries science and a requirement for sound management when fish species are of commercial or conservation interest (Planque et al., 2010; Santos, 2000).

Physical oceanographic processes are strong drivers of change in fish populations and therefore, in fisheries. Fish prefer a combined optimum of physical and biological conditions to find suitable habitat for feeding, spawning, migration and protection (Palacios et al., 2006). The use of environmental data for the preparation of oceanographic analyses and forecasts in support of fishery operations will depend on an adequate understanding of the complex linkage between marine environmental and biological processes (Makris et al., 2009).

The need to account for shifting climatic states by adjusting fishery management reference values is increasingly being acknowledged (Busch et al., 2016; Clark et al., 2003; Ho et al., 2016). Synergistic effects of climate change and harvesting can alter the resilience of exploited species and influence long-term sustainability (Fogarty, 2002).

We explored the linkages between the environmental changes and the dynamics of marine resources on the Brazilian southeast coast with particular emphasis on the lebranche mullet (*Mugil liza* Valenciennes). The industrial purse seiner fleet has intensified it's targeting on this resource since the 2000's in response to the declines on the sardine (*Sardinella brasilienses* Steindachner) fishery, the main target fish for this fleet as well as due to the economic potential of mature roe (Lemos et al., 2016; Miranda et al., 2011).

Mullet is a catadromous fish, which feeds and grows inside lagoons and estuaries, migrating out to the sea in schools for breeding and spawning purposes (González Castro et al., 2009; Vieira & Scalabrin, 1991a). The coastal area between 23° and 38° S (from the State of São Paulo, Brazil to Argentina) shelters the southern population of this species (Mai et al., 2014). This population supports a large local fishery, deeply tied to the identity of many coastal communities on the southern and southeastern regions of Brazil (24-34°S). The Figure 3.1 shows the areas where the industrial fishery acts: on the Brazilian states of Rio Grande do Sul (RS), Santa Catarina (SC), São Paulo (SP) and Rio de Janeiro (RJ).

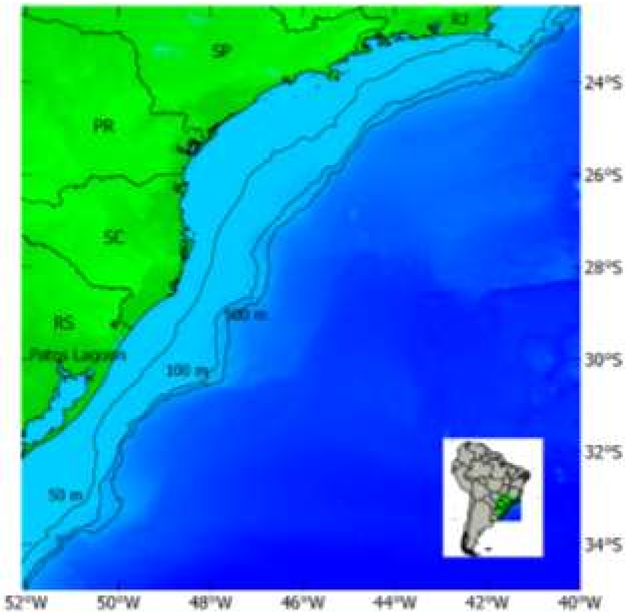


Fig. 3.1: Area where the lebranche mullet fishery occurs on the Southern and Southeastern Brazilian coast, as far as the 50m isobath.

Fishers focus their efforts to target this fish during its northward reproductive migration, between May and August, resulting in a high productivity of fisheries in some localities (Herbst & Hanazaki, 2014; Miranda & Carneiro, 2007). The main climatic conditions required for the mullet to start migrating is South wind followed by decreased water temperatures. Spawning takes place along the migration path in waters with a temperature from 19 to 21 °C and at a depth of approximately 50 m (Lemos et al., 2016; Vieira & Scalabrin, 1991a). A passive southward movement carries the larvae and juveniles by surface coastal currents for approximately 2 – 4 months after spawning (Lemos et al., 2014), during the austral spring – when the prevalence of northeast wind favors the upwelling of nutrient rich waters to the surface layers (Lopes et al., 2006).

The conventional methods for exploring the association between climate variability and population fluctuations involve time-series analysis. Although such studies do not identify the underlying mechanisms linking climate forcing and fish production, they can reveal a substantial amount of information on the temporal and spatial coherence between physical and biological properties and thus on the dynamics of the ecosystems (Mènard et al., 2007).

The main objective of this paper is to examine the interannual fluctuations of environmental and Catch per Unit of Effort (CPUE) data and estimate the degree to which they are linked at the different time scales. We compared local oceanographic variables (chlorophyll-*a*, sea surface temperature and winds) and a global climate index (MEI) to CPUE results by means of a cross wavelet analysis (normalized wavelet coherence).

3.4 MATERIAL AND METHODS

3.4.1 Data

We analyzed monthly landings of mullet for 2003 – 2012 from purse seiner fishery landed on the states of SC and SP. Our analysis is restricted to these states because both landing series are relatively more complete (with less missing values) and present unit of effort data, in this case, the number of purse seiners in operation. Missing data were interpolated using linear interpolation method. Fishery data from SC were published in the Santa Catarina State Fishery Activity Monitoring Project, maintained by the Center for Technological Sciences, Land and Sea (CTTMar) from the Itajaí Valley University (UNIVALI). Fishery data from SP derived from the Marine and Estuarine Fishery Activity Monitoring Program of the Fisheries Institute.

Time series of monthly data between 2003 and 2012 of sea surface temperature (SST), the phytoplankton pigment concentration, chlorophyll-*a* (Chl-*a*), and wind intensity were derived from satellite observations for the Southwest Atlantic. We examined the variability on the oceanic area limited by the 1000m isobath between 22 – 34° S, which includes the mullet industrial fishery area in the region (Figure 3.2).

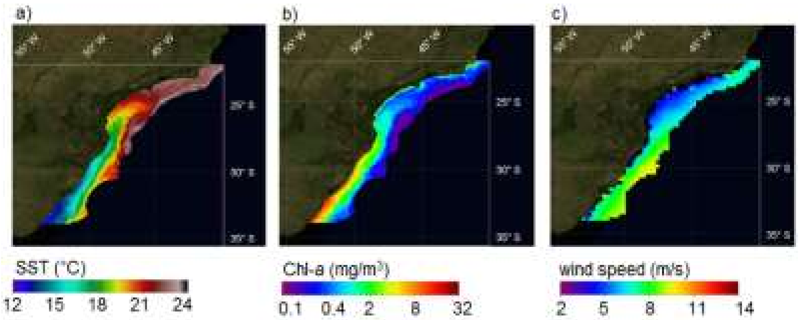


Fig. 3.2: Satellite remote sensing data showing June 2007 monthly mean a) SST, b) chlorophyll-a concentration, both derived from the Moderate Resolution Imaging Spectroradiometer Aqua images, and c) sea surface winds derived from Cross-Calibrated, Multi-Platform Ocean Surface Wind Velocity Product.

Information on SST and Chl-*a* derived from data collected by the Moderate Resolution Imaging Spectrometer (MODIS), on the National Aeronautics and Space Administration (NASA) Aqua satellite. Aqua's orbit around the Earth is timed so that it passes south to north over the equator in the afternoon, in a sun-synchronous, near-polar, circular orbit. Aqua MODIS view the entire Earth's surface every 2 days, acquiring data in 36 spectral bands. Data are available at 4.6 km spatial resolution for the global oceans and are available for download at <https://oceandata.sci.gsfc.nasa.gov/MODIS-Aqua/Mapped/Monthly/4km>.

Wind intensity data derived from the Cross-Calibrated, Multi-Platform (CCMP) Ocean Surface Wind Velocity Product. This ocean surface (10 m) wind product, mapped to a 0.25° × 0.25° cylindrical grid, incorporates cross-calibrated satellite winds derived from different satellite instruments – microwave radiometers and scaterometers using the Variational Analysis Method (VAM). VAM merges these data with *in situ* data and an initial estimate of the wind field (Atlas et al., 2011). Data are available for download at <http://data.remss.com/ccmp>.

Images were pre-processed using the NASA software SeaDAS v. 7.3.2. Pre-processing of these data consisted of removing the average seasonal cycle, i.e. subtracting the monthly climatology from the values of each respective month.

We have chosen the Multivariate El Niño Southern Oscillation (ENSO) index (MEI) to investigate the relations between ENSO and mullet fishery, as Soppa et al. (2011) found significant correlation between the MEI and the SST on the Southwestern Atlantic.

The Multivariate ENSO Index (MEI) is based on the six main observed variables over the tropical Pacific: sea-level pressure, zonal and meridional components of the surface wind, sea surface temperature, surface air temperature, and total cloudiness fraction of the sky. The MEI is calculated as the first unrotated Principal Component of all six observed fields combined (Wolter & Timlin, 1998). MEI data is available for download at <https://www.esrl.noaa.gov/psd/enso/mei.ext/index.html>.

3.4.2 Analysis

Population time series are typically noisy, exhibiting nonlinear behavior, and are often strongly non-stationary (Cazelles & Stone, 2003). Wavelet spectral analysis is a powerful mathematical tool that overcomes such constraints by performing a localized spectral decomposition of the signal, determining the dominant modes of variability and how those modes vary in time and scale (Torrence & Compo, 1998). Furthermore, cross-wavelets and phase analysis generalize these possibilities to the analyses of dependencies between two signals.

The Continuous Wavelet Transform (CWT) performs a time-frequency analysis of the signal, which permits the identification of different periodic components and their time evolution all along the time series. It is well suited to analyzing signals with changing spectra, revealing aspects of data that other signal analysis techniques miss, such as trends, abrupt changes, breakdown points and discontinuities (Nakken, 1999). Furthermore, cross-wavelets and phase analysis generalize these possibilities to the analyses of dependencies between two time-series.

We can characterize a wavelet by how localized it is in time (Δt) and frequency (Δω or the bandwidth). Without properly defining Δt and Δω, we will note that there is a limit to how small the uncertainty product Δt·Δω can be. One particular wavelet, the Morlet, is defined as

$$\psi o(\eta) = \pi^{-1/4}\, e^{i\omega 0\eta} e^{-\frac{1}{2}\eta^{2}}$$

Where $\omega 0$ is dimensionless frequency and η is dimensionless time. When using wavelets for feature extraction purposes, the Morlet wavelet (with $\omega 0$=6) is a good choice, since it provides a good balance between time and frequency localization (Grinsted et al., 2004). It is one of the best mother functions in terms of reproducing the frequency decomposition of the signal (Kirby, 2005). It has often been successfully used in the study of environmental variables, such as SST, North Atlantic Oscillation or ENSO (Maraun & Kurths, 2004; Torrence & Compo, 1998; Torrence & Webster, 1999) and ecological variables, such as catch of tuna (Mènard et al., 2007; Rouyer et al., 2008) and swordfish (Corbineau et al., 2008).

The idea behind the CWT is to apply the wavelet as a bandpass filter to the time series. The wavelet is stretched in time by varying its scale (s), so that $\eta = s \cdot t$, and normalizing it to have unit energy. The CWT of a time series (x_n, n=1, …, N) with uniform time steps δt, is defined as the convolution of x_n with the scaled and normalized wavelet. We write:

$$W_n^X(s) = \sqrt{\frac{\delta t}{s}} \sum_{n'=1}^{N} x_{n'} \psi \left[(n' - n) \frac{\delta t}{s} \right]$$

We define the wavelet power as $|W_n^X(s)|^2$. The complex argument of $W_n^X(s)$ can be interpreted as the local phase.

The CWT has edge artifacts because the wavelet is not completely localized in time. It is useful to introduce a Cone of Influence (COI), i.e. the region where edge effects are present (regions below the cone of influence indicate an important edge effect because of the finite length of the series and therefore values should be interpreted cautiously (Torrence & Compo, 1998).

The univariate CWT can be extended to quantify statistical relationships between two time series x_n and y_n. The wavelet coherence (WTC) can be thought of as the local correlation between two CWTs. The significance level of the WTC was determined using Monte Carlo methods. The cross wavelet transform and wavelet coherence were calculated using the methodology developed by Grinsted et al. (2004).

3.5 RESULTS AND DISCUSSION

We identified the influence of the environmental parameters on the mullet harvest season and found links to study synchronicity of time series by means of wavelet analysis, but such approach provided no information on the underlying ecological processes that could determine these patterns. We thus attempt to examine some hypothesis supported by the results.

CPUE time series shows two distinctive maximum peaks: in the 2007 and 2011 fishery seasons (Fig. 3.3). The 2007 fishery season is acknowledged as the historical peak of mullet production on the region and the second highest CPUE was registered. The complete table of values for the time series are shown in the Appendix section (Annex 2).

The local WPS for mullet catch rate (Fig. 3.4) shows the presence of an annual cycle (12.8-month), which corresponds to the annual mullet harvest, during the reproductive migration. This cycle was present in almost the entire time series, from 2005 until 2012.

Our results indicated the presence of statistical association between mullet catch rate and environmental variables series and that these associations appeared transient (non-stationary) in time. In the sequence, we present the results for the environmental variability and its associations with mullet CPUE.

SST anomaly values varied from -1.694 (August 2007) to 1.759 (February 2010) (Fig. 3.3). Another intense positive anomaly of 1.474 occurred in June 2005 (winter season). The global WPS of the SST time series showed an intense significant 41.5-month period and other minor periodic bands between 3 and 16.6 months (Fig. 3.4). The strong positive anomaly detected in June 2005 appeared in the WPS as an 11-month periodicity event. The 41.5-month periodic band event was significantly detected in the local WPS in January 2008, when a cold anomaly event occurred. The SST wavelet also detected significant 4–10-month cycle events during March and August 2006, from September 2006 to March 2008 and from October 2010 to May 2012.

The SST dominant cycle of variability agreed with the MEI main periodicity, indicating that SST variability is strongly influenced by the ENSO. The WTC plot for SST and MEI (Annex 3) revealed a SST lag of 14.5 months in response to the ENSO events.

The WTC plot for CPUE and SST (Fig. 3.5) detected the prevalence of an out-of-phase relation between SST and CPUE. We detected an out-of-phase relation between CPUE and SST from June to October 2003 $(r = 0.85)$ and from April to October 2011$(r = 0.72)$. This WTC plot showed that the SST strong negative anomaly registered in 2007 had no effect on the CPUE, because the phase arrows indicated that CPUE positive peak occurred prior to the SST negative peak.

Chl-*a* anomalies varied from -0.2172 (July 2009) to 0.2628 (August 2007) (Fig. 3.3). The maximum peak appears as a 10-month periodic cycle (Fig. 3.4). Another 6-month cycle occurred between July 2005 and June 2006 and minor 2–4-month periodic bands were identified between November 2009 and May 2010, in July 2011 and from May to July 2012 (Fig. 3.4). The 2007 Chl-*a* peak agreed with the lowest SST register, in 2007.

The local WPS of Chl-*a* time series exhibits a main 26.7-month cycle (Fig. 3.4) occurring from 2004 to 2006 (significantly only in March-April 2006). This cycle can be associated to ENSO periodicity. The WTC between Chl-*a* and MEI (Annex 3) detected a Chl-*a* lag of 1.5 month and 2 months in response to the 2007 and 2011 La Niña events, respectively.

The WTC plot for CPUE and Chl-*a* (Fig. 3.5) shows three different periods of correlation, with lags of Chl-a in relation to CPUE: Chl-a lagged CPUE by c. 5 months (r=0.76) between June 2004 and August 2005 (r=0.75), c. 8 months between September 2005 and July 2008 (r=0.72-0.80)and c. 3 months in 2011 (r=0.74-0.84).

An out-of-phase relation between CPUE and Chl-*a* prevailed, indicating minimum primary productivity values during the mullet harvest season. Mullet adults are predominantly detritus feeders (Oliveira & Soares, 1996) and do not feed during the reproductive migration. Chl-*a*, therefore, is not an indicator for potential fishing grounds for mullets.

The match-mismatch hypothesis could explain the relation between mullet and Chl-*a* variability. This hypothesis proposes that most fish in temperate waters spawn at a fixed time, while the prey of larvae (zooplankton) depend on the variation in time of onset and duration of spring blooms (Cushing, 1990).

Our results support the existence of a synchrony between the initial life stages and prey availability for mullet. Mullet larval marine stage feeds on zooplankton, while the juveniles that reach the surf zone feed on benthonic microalgae (Vieira, 1991). A match between prey and larval abundance can result in high larval fish growth rates and high survival. Therefore, we hypothesize that larger adult fish stocks could be detectable in a 5–6 years' time span after a major phytoplankton bloom, when those larvae of fish would be at their first maturity (Garbin et al., 2014).

We detected an intense Chl-*a* positive anomaly in 2005. Other peaks of primary productivity could be observed (e.g. in 2007 and 2010); however, their effect on the CPUE could not be detectable in our time series. According to our hypothesis, this event would result in an increased recruitment, and consequently, an intense fishery around 2011. In fact, the CPUE time series shows a peak of catch rate in 2011, although other environmental influences may have contributed to the 2011 peak, as we detected a match of negative SST, positive wind speed and effects of the strong La Niña event of 2010 during that period.

The wind anomalies time series shows a positive anomaly peak (2.194) in September 2009 (Fig. 3.3); the lowest negative anomaly peak (-1.233) were registered in August 2004. We detected a period of intense wind speed positive anomalies, from December 2010 to March 2011 (1.1 to 1.652).

We detected a dominant cycle of 9.4 month in the global WPS of the wind (Fig. 3.4), occurring from July 2008 to March 2009 and from August 2010 to October 2011. Our results detected a secondary cycle of 3–4-month periodicity in January 2004, July–December 2007 and April–August 2010.

Wind speed and mullet catch rates had the highest correlation ($r = 0.75 - 0.87$) in the interannual periodicity, between 26 and 44 months (Fig. 3.5). Such periodicity was dominant in an in-phase relation from March 2006 to April 2009 (cycles between 27 and 44 months; $r = 0.8 - 0.88$) and during the 2011 harvest season (from May to July), with three months periodicity($r = 0.74$). Prior to the 2011 CPUE peak, we can observe the persistence of strong winds in the beginning of 2011 (Fig. 3.3).

The prevalence of strong winds might benefit the mullet spawning aggregation and lead the schools to offshore waters, favoring the industrial fishery, as purse seiners can operate in this area. On the other hand, such conditions might impair working with purse-seiners. We hypothesize that during periods of strong winds, fishing is risky, but there are windows of opportunity for excellent catches results.

Positive and negative MEI values are related to El Niño and La Niña phenomenon, respectively (Fig. 3.3). The strongest El Niño in the time-series occurred between November 2009 and February 2010 (maximum value of 1.52 in January 2010). The strongest La Niña occurred between July 2010 and March 2011 (minimum values of -1.9 in August 2010).

The global WPS for the MEI shows a main periodicity of 41.5 months (Fig. 3.4). Such an event could be detected in the local WPS during 2007–2008, as a La Niña event. In the period from February 2009 to October 2010, the local WPS detected an event of 18.7 months periodicity, when a strong El Niño/La Niña oscillation was detected.

The WTC for CPUE and MEI (Fig. 3.5) showed periods of strong correlation between CPUE and MEI during the years 2006$(r = 0.75)$, 2008 $(r = 0.80)$ and 2011$(r = 0.85)$. The phase vectors indicate an out-of-phase relation with a CPUE lag of 4.5 months for the event registered in 2006, 2.5 months lag in 2008 and c.2 months, in 2011.

Variations in population abundance are very often associated with large-scale climate indices. They do not have necessarily a strong link with local weather condition, but can be good predictors of ecological processes (Stenseth et al., 2003; Hallett et al., 2004). The ENSO represents periods of anomalous conditions occurring in the tropical Pacific Ocean every 3 to 7 years (Trenberth, 1997). The warm phase of ENSO, El Niño, triggers higher than average rainfall over the southern Brazilian coast (Grimm et al., 1998; Grimm & Tedeschi, 2009). The cold phase, La Niña, results in drier than normal conditions at subtropical latitudes of South America (southern Brazil to central Argentina) during the winter season (Ropelewski & Halpert, 1987). We hypothesize that the anomalous dry winter resulted from the previous La Ninã would favor the pre-spawning aggregation of maturing mullet adults leading to larger shoals of mullet during the 2011 fishery season.

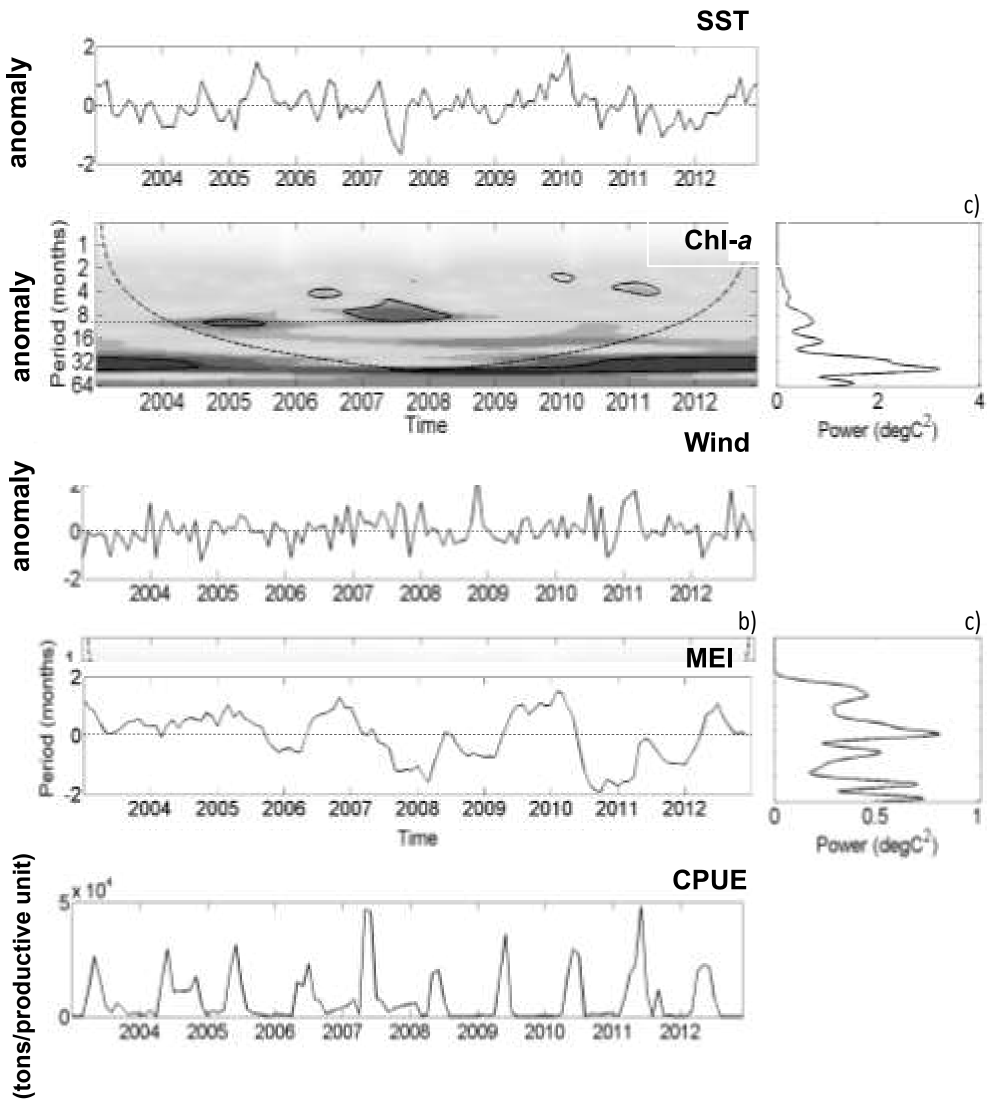


Fig. 3.3: Time series of monthly averaged anomalies for the study area of Sea Surface Temperature (SST); Chlorophyll-a (Chl-*a*); Sea surface wind speed and time series of Catch per Unit of effort (CPUE) of mullet.

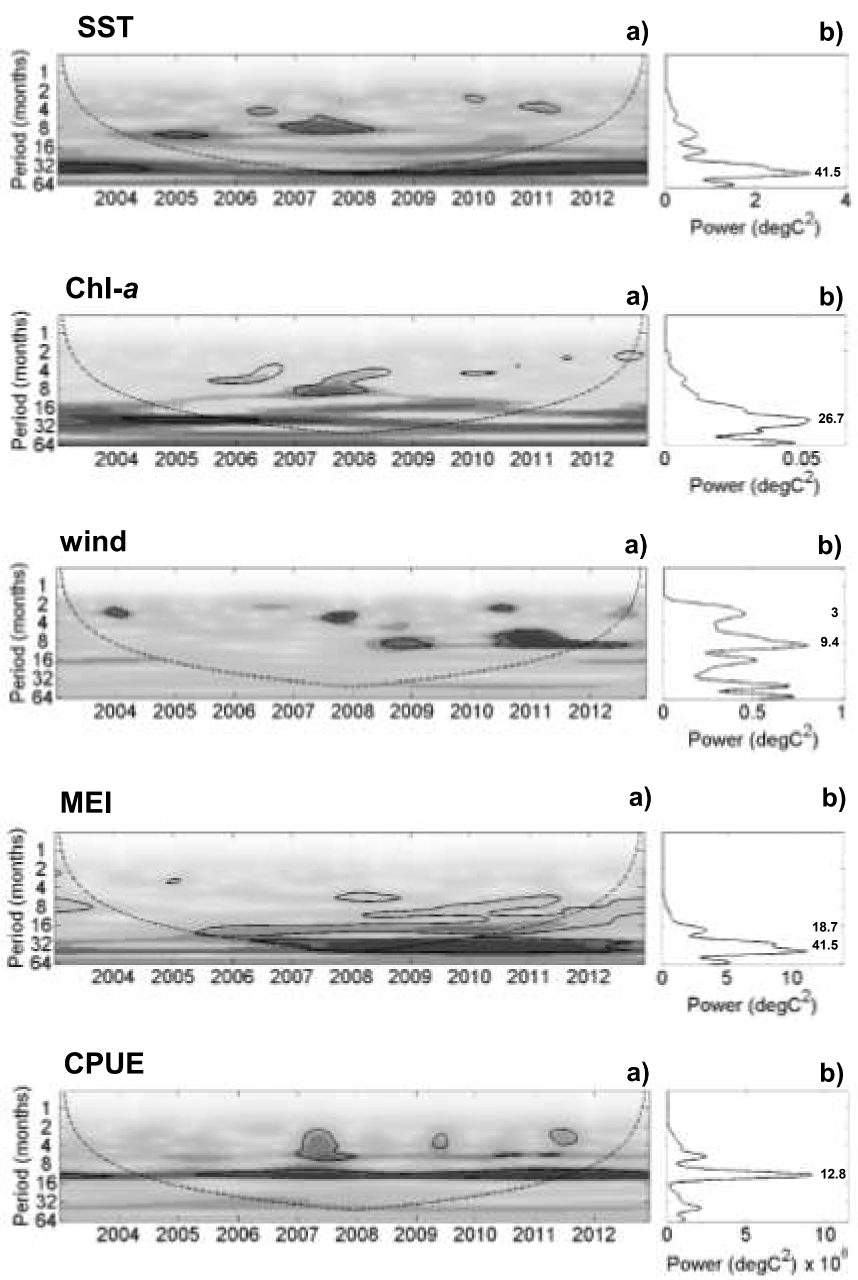


Fig. 3.4: Wavelet analysis of the monthly data of environmental parameters: Sea Surface Temperature (SST); Chlorophyll-*a*; wind speed at sea surface; Multivariate ENSO Index (MEI) and mullet CPUE between 2003 and 2012, where a) shows the local wavelet power spectrum and b) shows the global wavelet power spectrum. The local wavelet power spectrum gives a measure of the variance distribution of the time series according to time and for each period. The dashed line shows the 5% significance.

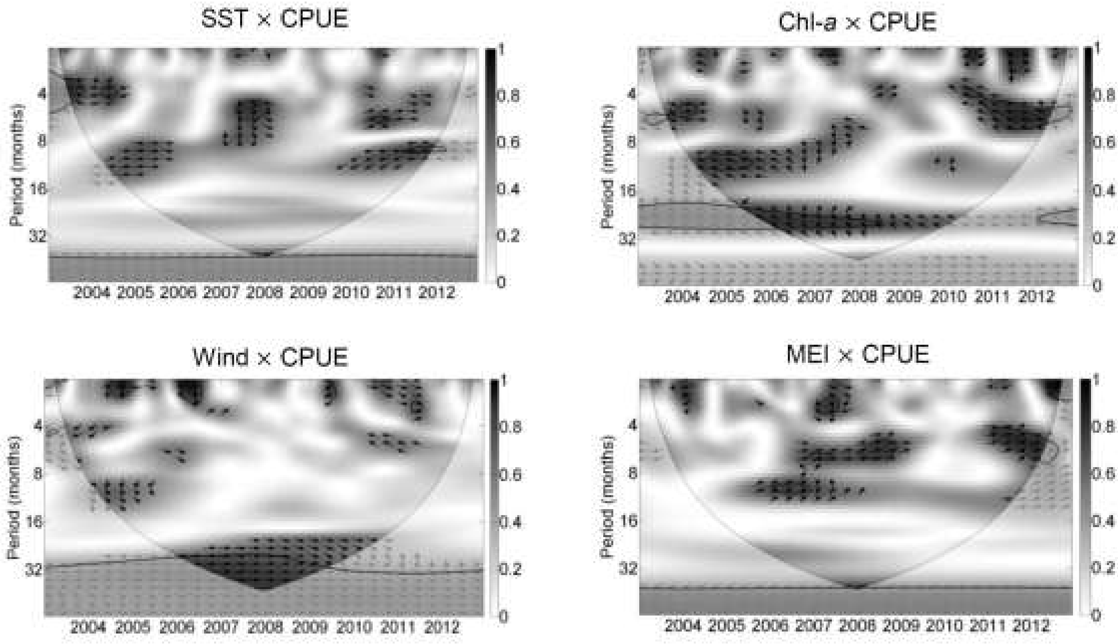


Fig. 3.5: Wavelet coherence (WTC) between Catch per Unit of Effort (CPUE) (series 2) and Sea Surface Temperature (SST); Chlorophyll-a (Chl-a), wind and Multivariate ENSO Index (MEI) time series (series 1). The WTC finds regions in time frequency space where the two time series co-vary (but do not necessarily have high power). The 5% significance level against red noise is shown as a thick contour. The opaque areas are regions below the cone of influence. Arrows indicate the relative phase relationship between the series (pointing right: in-phase; left: anti-phase; down: series 1 leading series 2 by 90°; up: series 2 leading series 1 by 90°).

3.6 CONCLUSIONS

According to Vieira et al. (2008), El Niño events cause the decline of mullet juveniles in the estuary and impair pre-spawning aggregation and migration of maturing mullet adults in response to a less effective intrusion of salty water during the anomalous El Niño conditions. During the study period, we could not detect El Niño effects on the mullet harvest, since no strong El Niño was registered.

Our study detected the associations between wind regime, changes in sea surface temperature and climate variability and CPUE fluctuations. CPUE had positive correlation with wind speed, and negative correlation with SST. We identified a strong La Niña event with positive effects on the mullet catch rate, which lagged this event by 2 months.

Several studies have demonstrated the mullet reproductive migration dependency on SST and winds (Herbst & Hanazaki, 2014; Lemos et al., 2014, 2016). We could identify the influence of negative SST anomaly on the mullet harvest success in 2011 and the influence of positive wind speed anomaly on the mullet catch rates during

2006–2008 and 2011. The results indicate that the wind is the parameter that better responds to the environmental fluctuations and most appropriately indicates CPUE variability, as the correlation between MEI and local wind speed was stronger than the correlation between MEI and SST (Annex 3) .

We found 24 – 44 months wind periodicity, which could be related to the Brazilian coastal current and ENSO variability, respectively. The wavelet coherence identified a statistically significant relationship between CPUE and MEI. However, we did not find the same relationship between CPUE and SST. These results suggest that fluctuations in mullet catches could be the result of SST fluctuations but in synergy with other environmental variables, which are also affected by the ENSO pattern.

The wavelet approaches helped answering some of the fundamental questions associated with climate variability and mullet catch rates fluctuations, taking into account the non-stationary nature of such time series and the possible occurrence of transient states (Mènard et al. 2007).

CPUEs, however, cannot be considered as proxies of the true abundance (Hilborn and Walters 1992; Maunder et al. 2006). The catch rates may reflect catchability trends and targeting strategies. According to Santana et al. (2017), mullet biomass decreased from 2009 to 2012. Our results showed an increase in CPUE in 2011. Besides, the industrial fleet catchability is enhanced by the prevalence of south winds during the migration, which lead the mullet schools towards deeper waters (Herbst and Hanazaki 2014).

The present management measures for mullet fishery in Brazil include the reduction of the number of licenses for the industrial purse seiner operation. We argue that this measure could be ineffective to ensure the resource sustainability, since the environmental conditions might affect the catchability, resulting in increased CPUE even when there is a decreasing trend in the biomass.

3.7 REFERENCES

Atlas, R., Hoffman, R. N., Ardizzone, J., Leidner, S. M., Jusem, J. C., Smith, D. K., & Gombos, D. (2011). A Cross-calibrated, Multiplatform Ocean Surface Wind Velocity Product for Meteorological and Oceanographic Applications. Bulletin of the American Meteorological Society, 92(2), 157–174. http://doi.org/10.1175/2010BAMS2946.1

Busch, D. S., Grif, R., Link, J., Abrams, K., Baker, J., Brainard, R. E., … Merrick, R. (2016). Climate science strategy of the US National Marine Fisheries Service. Marine Policy, 74, 58–67. http://doi.org/10.1016/j.marpol.2016.09.001

Cazelles, B., & Stone, L. (2003). Detection of imperfect population synchrony in an uncertain world. Journal of Animal Ecology, 72(6), 953–968. http://doi.org/10.1046/j.1365-2656.2003.00763.x

Clark, R. A., Fox, C. J., Viner, D., & Livermore, M. (2003). North Sea cod and climate change—modeling the effects of temperature on population dynamics. Global Change Biology, 9, 1669–1680. http://doi.org/10.1046/j.1365-2486.2003.00685.x

Corbineau, A., Rouyer, T., Cazelles, B., Fromentin, J.-M., Fonteneau, A., & Ménard, F. (2008). Time series analysis of tuna and swordfish catches and climate variability in the Indian Ocean (1968-2003). Aquatic Living Resources, 21(3), 277–285. http://doi.org/10.1051/alr:2008045

Fogarty, M. J. (2002). Climate variability and ocean ecosystem dynamics: implications for sustainability. In W. Steffen, J. Jager, D. J. Carson, & C. Bradshaw (Eds.), Proceedings of the Global Change Open Science Conference (pp. 27–29). Amsterdam.

González Castro, M., Abachian, V., & Perrotta, R. G. (2009). Age and growth of the striped mullet, Mugil platanus (Actinopterygii, Mugilidae), in a southwestern Atlantic coastal lagoon (37°32'S-57°19'W): A proposal for a life-history model. Journal of Applied Ichthyology, 25(1), 61–66. http://doi.org/10.1111/j.1439-0426.2008.01170.x

Grinsted, A., Moore, J. C., & Jevrejeva, S. (2004). Application of the cross wavelet transform and wavelet coherence to geophysical time series. Nonlinear Processes in Geophysics, 11, 561–566. http://doi.org/10.5194/npg-11-561-2004

Herbst, D. F., & Hanazaki, N. (2014). Local ecological knowledge of fishers about the life cycle and temporal patterns in the migration of mullet (Mugil liza) in Southern Brazil. Neotropical Ichthyology, 12(4), 879–890. http://doi.org/10.1590/1982-0224-20130156

Ho, C., Chen, J., Nobuyuki, Y., Lur, H., & Lu, H. (2016). Ocean & Coastal Management Mitigating uncertainty and enhancing resilience to climate change in the fi sheries sector in Taiwan : Policy implications for food security. Ocean and Coastal Management, 130(2), 355–372. http://doi.org/10.1016/j.ocecoaman.2016.06.020

Kirby, J. F. (2005). Which wavelet best reproduces the Fourier power spectrum? Computers & Geosciences, 31(7), 846–864. http://doi.org/10.1016/j.cageo.2005.01.014

Lemos, V. M., Avila Troca, D. F., Castello, J. P., & Paes Vieira, J. (2016). Tracking the southern Brazilian schools of Mugil liza during reproductive migration using VMS of purse seiners. Latin American Journal of Aquatic Research, 44(2), 238–246. http://doi.org/10.3856/vol44-issue2-fulltext-5

Lemos, V. M., Varela Jr., A. S., Shwingel, P. R., Muelbert, J. H., & Vieira, J. P. (2014). Migration and reproductive biology of Mugil liza (Teleostei: Mugilidae) in south Brazil. Journal of Fish Biology, 85(3), 671–687. http://doi.org/10.1111/jfb.12452

Lopes, R. M., Katsuragawa, M., Dias, J. F., Montú, M. A., Muelbert, J. H., Gorri, C., & Brandini, F. P. (2006). Zooplankton and ichthyoplankton distribution on the southern Brazilian shelf : an overview. Scientia Marina, 70, 189–202. http://doi.org/10.3989/scimar.2006.70n2189

Mai, A. C. G., Miño, C. I., Marins, L. F. F., Monteiro-Neto, C., Miranda, L., Schwingel, P. R., … Vieira, J. P. (2014). Microsatellite variation and genetic structuring in Mugil liza (Teleostei: Mugilidae) populations from Argentina and Brazil. Estuarine, Coastal and Shelf Science, 149, 80–86. http://doi.org/10.1016/j.ecss.2014.07.013

Makris, N. C., Ratilal, P., Jagannathan, S., Gong, Z., Andrews, M., Bertsatos, I., … Jech, J. M. (2009). Critical Population Density Triggers Rapid Formation of Vast Oceanic Fish Shoals. Science, 323(5922), 1734–1737. http://doi.org/10.1126/science.1169441

Maraun, D., & Kurths, J. (2004). Cross wavelet analysis: significance testing and pitfalls. Nonlinear Processes in Geophysics, 11(4), 505–514. http://doi.org/10.5194/npg-11-505-2004

Mènard, F., Marsac, F., Bellier, E., & Cazelles, B. (2007). Climatic oscillations and tuna catch rates in the Indian Ocean : a wavelet approach to time series analysis. Fisheries Oceanography, 16(1), 95–104. http://doi.org/10.1111/j.1365-2419.2006.00415.x

Miranda, L. V., & Carneiro, M. H. (2007). A pesca da tainha Mugil platanus (Perciformes: Mugilidae) Desembarcada no Estado de São Paulo Subsídio ao Ordenamento. Série Relatórios Técnicos, 30, 1–13.

Miranda, L. V., Carneiro, M. H., Peres, M. B., Cergole, M. C., & Mendonça, J. T. (2011). Contribuições ao processo de ordenamento da pesca da espécie Mugil liza (Teleostei: mugilidae) nas regiões Sudeste e Sul do Brasil entre os anos de 2006 e 2010. Série Relatórios Técnicos, 49, 1–23.

Nakken, M. (1999). Wavelet analysis of rainfall–runoff variability isolating climatic from anthropogenic patterns. Environmental Modelling & Software, 14(4), 283–295. http://doi.org/10.1016/S1364-8152(98)00080-2

Palacios, D. M., Bograd, S. J., Foley, D. G., & Schwing, F. B. (2006). Oceanographic characteristics of biological hot spots in the North Pacific : A remote sensing perspective. Deep Sea Research II, 53, 250–269. http://doi.org/10.1016/j.dsr2.2006.03.004

Planque, B., Loots, C., Petitgas, P., Lindstrøm, U., & Vaz, S. (2010). Understanding what controls the spatial distribution of fish populations using a multi-model approach. Fisheries Oceanography, 20(1), 1–17. http://doi.org/10.1111/j.1365-2419.2010.00546.x

Rouyer, T., Fromentin, J., Stenseth, N. C., & Cazelles, B. (2008). Analysing multiple time series and extending significance testing in wavelet analysis. Marine Ecology Progress Series, 359, 11–23. http://doi.org/10.3354/meps07330

Santos, A. M. P. (2000). Fisheries oceanography using satellite and airborne remote sensing methods : a review. Fisheries Research, 49, 1–20.

Torrence, C., & Compo, G. P. (1998). A Practical Guide to Wavelet Analysis. Bulletin of the American Meteorological Society, 79, 61–78. http://doi.org/10.1175/1520-0477(1998)079<0061:APGTWA>2.0.CO;2

Torrence, C., & Webster, P. J. (1999). Interdecadal Changes in the ENSO–Monsoon System. Journal of Climate, 12(8), 2679–2690. http://doi.org/10.1175/1520-0442(1999)012<2679:icitem>2.0.co;2

Vieira, J. P., & Scalabrin, C. (1991). Migração reprodutiva da “tainha” (Mugil platanus Gunther,1980) no sul do Brasil. Atlântica, 12, 131–141.

Wolter, K., & Timlin, M. S. (1998). Measuring the strength of ENSO events - how does 1997/98 rank? Weather, 53, 315–324.

4 SPATIAL-TEMPORAL VARIABILITY AND WIND INFLUENCE ON MULLET (MUGIL LIZA) PURSE SEINE FISHERY IN SOUTHWEST ATLANTIC

Variabilidade espacial e temporal e influência dos ventos sobre a pesca de tainha (*Mugil liza*) por traineiras no Atlântico Sudoeste

Revista pretendida: Fisheries Research (Fish Res), ISSN (0165-7836), Fator de Impacto (JCR, 2017) = 2,185, Qualis CAPES = Estrato A2

Michelle Alves de Abreu-Mota1*: michelledeabreu@ufpr.br; Rodrigo Pereira Medeiros1: rodrigo.medeiros@ufpr.br; Mauricio Almeida Noernberg1: m.noernberg@ufpr.br

1. Centro de Estudos do Mar, Universidade Federal do Paraná. Av. Beira Mar s/n. Pontal do Paraná, PR, Brazil. CEP: 83255-976. Phone: +55 41 35118600

4.1 ABSTRACT

The mullet fishery is characterized by well-defined harvest seasons for artisanal and industrial fishery in South-Southeast Brazilian and Argentinean coasts. In this study we investigate the industrial purse seiner mullet fishery on the South-Southeast Brazilian coast, which prevails over the remaining industrial fleet. Mullet biology is strongly affected by oceanic and atmospheric conditions, which can also affect fishing operations success. In this study, we applied Generalized Additive Models (GAMs) to analyze the influence of the predictors u and v wind components, latitude, longitude, purse seine fishing days during the mullet fishery season from 2010 to 2012. We obtained fishery data from the national vessel monitoring system (PREPS). Our results showed that v wind had positive and u wind had negative correlation with fishing activity. Spatial predictors showed intense fishery activity on the SC state north coast and near the Patos Lagoon estuary mouth. There were no temporal variations in the mullet fishery within days and months of the harvest season. We recommend the implementation of wind monitoring system to support a flexible and adaptive fisheries management and further investigations on the environmental influence, including the sea state as an explanatory variable in the model. We also recommend interviewing the vessels' masters to enquire what influences the decision to choose the fishing points.

Keywords: Generalized Additive Models; mullet; industrial fishery; fisheries management; sea surface winds; fisheries oceanography

4.2 INTRODUCTION

The Lebranche mullet (*Mugil liza*) fishery is one of the main fisheries in the south-southeast Brazil., occurring in different ecosystems (estuarine and coastal waters) (Vieira et al., 2008), involving different fleets (from small to industrial scales) and fishing gears.

The annual mullet run provides a well-defined harvest season for both coastal artisanal and industrial fisheries in Brazil and Argentina (Vieira et al. 2008). The main conditions for the mullet start migrating is South winds followed by low temperatures. They start migrating between April and June (late austral autumn), depending on the interannual variations in oceanographic and environmental conditions (Mai et al., 2014; Vieira & Scalabrin, 1991b).

The industrial purse seiner fleet has been intensifying its targeting on this resource since the 2000's, in response to the declines on the sardine (*Sardinella brasilienses*) fishery, the main target fish for this fleet as well as to the economic potential of mature roe (Miranda et al., 2011). The unsustainable fishing pressure from artisanal and industrial fleets have led the Brazilian Ministry of the Environment to describe *M. liza* as a near threatened species (Annex II of the Normative Instruction MMA No. 05 21/05/2004).

The increased targeting led to new management measures of national coverage, implemented since 2008. One of the criteria considered for the concession and renovation of the Complementary Fishing Authorizations is the vessel's register in the PREPS (in Portuguese: Programa Nacional de Rastreamento das Embarcações por Satélite), the national vessel monitoring system.

Aspects beyond changes on fish populations can affect fishing activity. Physical oceanographic processes are strong drivers of change in fish populations and therefore, in fisheries. Oceanic and atmospheric conditions are also a direct driving force of the fishing operation because the prevalence of severe conditions might impair working with purse seines.

Particularly, the mullet fishery strongly depends on oceanic and atmospheric conditions; however, environmental conditions favorable to fish abundance do not necessarily lead to high fish catches. The prevalence of strong South winds might hamper the mullet to move near shore, and become available to artisanal fishery (Herbst & Hanazaki, 2014). Abreu-Mota et al. (2018, under review) analyzed the influence of oceanographic conditions on the catch rate of mullet by purse seiner fishery and found relatively greater influence of wind on the success of industrial fishery activity.

In this study, we aim to analyze the influence of winds on the spatial and temporal variability of purse seiners' displacement while fishing mullet during the fishery seasons of 2010 – 2012 on the South-Southeast Brazilian coast.

4.3 METHODS

4.3.1 Study area

More than 95% of the mullet catches occurs between the States of Rio Grande do Sul and Santa Catarina (24-34°S) (Vieira & Scalabrin, 1991b). Approximately 70% of the purse seiner fleet is from the state of Santa Catarina (Brazilian Ministry for Fisheries and Aquaculture, 2015); however, this fleet has great mobility, fishing along the South and Southeast coasts, in estuaries and coastal areas, up to the 50 m isobath (Lemos et al., 2016; Vieira et al., 2008). We delimited our analysis in the region between 23° and 34° S as far as the 50 m isobath (Fig. 4.1). Distinct population clusters of *M. liza* are delimited by approximately the 23° S latitude (North and South populations) (Mai et al., 2014).

This region is under the influence of the fresh Plata plume waters, derived from the Río de La Plata (AR) and warm–salty subtropical shelf waters, which are primarily influenced by the Brazil Current (Piola et al., 2008, 2000). The wind circulation pattern presents strong seasonality. During the austral summer, Northeast winds prevail in the region. In autumn and winter, Southwest winds start to blow, with greater intensities on latitudes greater than 32° S (Lima et al., 1996).

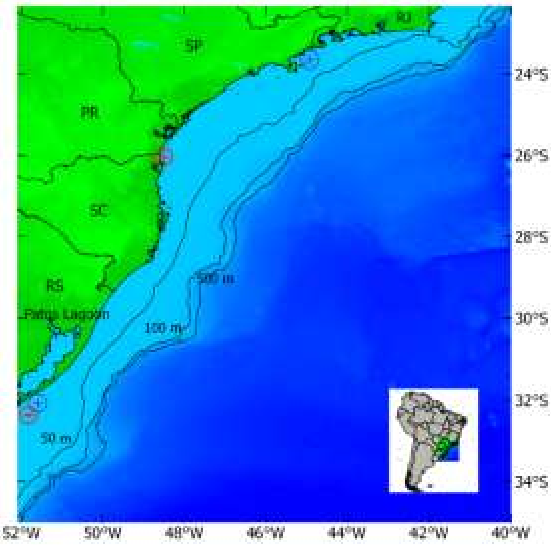


Fig. 4.1: Area where purse seine mullet fishery occurs along the Brazilian coast, as far as the 50 m isobath. Equal sign colors indicate locals of simultaneous fishing activities and the signal indicates the relative fishing intensities between the locals, according to GAMs results

The Patos Lagoon estuary (PLE) is the main nursery area for *M. liza* in Brazil. It is considered the world's largest choked-type coastal lagoon (Seeliger, 2001). *M. liza* is one of the most important fishery resource in the PLE; nevertheless, this stock is being threatened by urbanization and industrialization projects around the PLE and climate changes due to the more intense and frequent El Niño Southern Oscillation (ENSO) events (Odebrecht et al., 2010; Vieira et al., 2008).

4.3.2 Data

Daily wind data were derived from satellite observations from the Cross-Calibrated, Multi-Platform (CCMP) Ocean Surface Wind Velocity Product. This ocean surface (10 m) wind product, mapped to a 0.25° × 0.25° cylindrical grid, incorporates cross-calibrated satellite winds derived from different satellite instruments – microwave radiometers and scaterometers using the Variational Analysis Method (VAM) (Atlas et al., 2011). VAM merges these data with *in situ* data and an initial estimate of the wind field (Atlas et al., 2011). Data are available for download at <http://data.remss.com/ccmp>.

Purse seiner fishing effort derived from data collected through the PREPS. We generated fishing activity maps by selecting the points where each vessel navigated in the Speed Compatible with Fishing Operation (SCFO), between 0 and 4 knots, and were not docked in harbors. We considered hours spent in fishing activity as an effort measure. We selected wind and purse seiner data collected during the mullet harvest season (between May 15 and August 14) from 2010 and 2012.

4.3.3 Computational Analysis

The co-variates u and v components of wind, latitude, longitude and days were employed to Generalized Additive Models – GAMs (Wood, 2006) to predict the response variable (hours of fishing). GAMs were selected over linear and generalized linear models due to their ability to deal with non-linear relationship between response and explanatory variables (Davies et al., 2014).

Models were fitted using Poisson distribution family because fishing hours are discrete count data. The thirteen candidate models were ranked by AIC values (Zuur et al., 2009). All GAM computations and graphics were performed by R (R Development Core Team, 2017), with the GAM set-up based on the add-on packages 'mgcv' (Wood, 2011), 'MuMIn' (Bartoń, 2016) and 'dev- tools' (Wickham & Chang, 2016).

4.4 RESULTS AND DISCUSSION

We present and discuss results for the model below. All the remaining models have corrected Akaike value > 5 and Akaike weights < 0.01.

$$HFA \sim s_1(LAT) + s_2(LONG) + s_3(DAY) + s_4(U) + s_5(V)$$

Where 'HFA' represents the number of hours of fishing activity assumed to have a Poisson distribution; s_1 to s_6 represent penalized regression splines; in brackets are the co-variates.

Table 4.1: Model adjusted by corrected Akaike value (AICc). Estimated degrees of freedom of the model (df), loglikehood (loglik), AICc, Delta Akaike (dAIC), Akaike weights (AICw), adjusted R-squared (R2adj) and Deviance explained (Dev%) are provided for each model. The model was adjusted with Poisson Family

Response variable	selected model	df	logLik	AICc	DAICc	AICw	R2adju	Dev%
HFA	hfa ~ s(lat) + s(long) + s(day) + factor(month) + year + s(v) + s(u)	49	-28295.84	56691.8	0.00	1	0.109	10.3

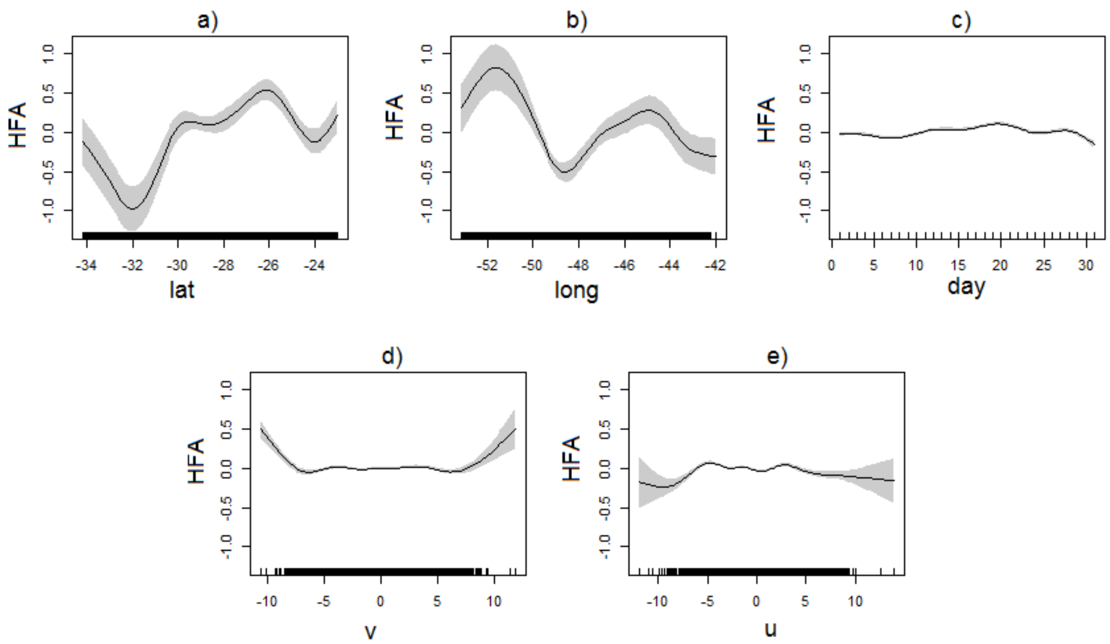


Fig. 4.2. Generalized additive model output of hours of fishing activity for the purse seiners. Lines represent the smoothed curve of the additive effect of explanatory variables on hours of fishing activity and shades 95% pointwise confidence limits of the GAM estimate. Wind is measured in m/s.

The wind *v* component has greater influence on HFA than the *u* component (Fig. 4.2d-e) Extremes of meridional wind (*v* – positive to the North) positively affected HFA; meanwhile, extremes of zonal wind (*u* – positive to the East) seems to negatively affect HFA. Although both North and South winds might favor fishing activity, we could detect slightly greater fishing activity during northward wind conditions. These conditions are typical of the passage of cold fronts in the region and is the main environmental trigger for the mullet start migrate. The model results showed that a minority of vessels operates during such extreme meridional wind conditions; however, they spend more time on fishing activity, probably due to more difficult work conditions.

HFA has greater spatial than temporal (daily) influence. The GAMs analysis did not detect HFA differences within the days of the fishing season (Fig. 4.2c). Results identified the proximity of the Patos lagoon estuary (32° S, 52° W) as the local of greater fishing activity (Fig. 4.2 a-b). There is also an intense purse seiner activity between the North coast of SC and the South coast of PR States (26° S, 49° W). Fishing on these both locals do not occur simultaneously. There is a third local, between the SP and RJ coasts (24° S, 45° W), where we could identify fishing activity simultaneously to the Southern portion of the study area. The spatial variability of HFA is summarized on the map shown in Fig. 4.1.

The purse seiners have great mobility, as the vessels' movements follows the fishes' migration path northwards. The results indicated local differences on fishing intensities according to the vessels' displacements. We have also identified simultaneously north (between the SP and RJ coasts) and south (near the Patos lagoon estuary) fishing activities. The purse seiners activity registered on the North have probably been targeting sardines (*Sardinela brasilienses*) during May, since the sardine recruitment closure during 2010-2012 occurs between June 15 and July 31.

4.5 CONCLUSIONS

Our results for winds influence on fishery activity showed that vessels spend more time fishing as wind speed increases. During strong wind conditions, the vessels increased activity could have been due to more difficult work conditions. We recommend analysis of logbook data to check if increased catches occurred during such increased HFA.

When northeast winds start to blow, mullet approximate the coast and become unavailable to purse seiners (Herbst & Hanazaki, 2014), i.e., favorable conditions to artisanal fishery do not necessarily favors the purse seine industrial fishery. Therefore, the implementation of wind monitoring system could help identify the fishery activity variability, supporting a flexible and adaptive fisheries management.

Our results showed two distinct regions of likely intense activity of mullet fishery. The mullet south population fishery occurs mainly near the Patos lagoon estuary and near the SC North coasts. We recommend further investigation on variability of winds and Sea Surface Temperature on these specific regions during fishing seasons. Besides, we recommend interviews with fishers to identify the aspects that contribute to choosing the fishing grounds: if they are fishing near ports because it increases profitability or because the environmental conditions on these areas are the key factors defining the fishing grounds.

Moreover, as the prevalence of rough sea conditions might hamper operations with purse seiners, we recommend further investigations on the environmental influence, including the sea state as an explanatory variable in the model.

4.6 REFERENCES

Atlas, R., Hoffman, R. N., Ardizzone, J., Leidner, S. M., Jusem, J. C., Smith, D. K., & Gombos, D. (2011). A Cross-calibrated, Multiplatform Ocean Surface Wind Velocity Product for Meteorological and Oceanographic Applications. Bulletin of the American Meteorological Society, 92(2), 157–174. http://doi.org/10.1175/2010BAMS2946.1

Bartoń, K. (2016). MuMIn: Multi-Model Inference R Package Version.

Brazilian Ministry for Fisheries and Aquaculture. (2015). Plano de gestão para o uso sustentável da tainha, Mugil liza Valenciennes, 1836, no Sudeste e Sul do Brasil. Brasília: Ministério da Pesca e Aquicultura.

Davies, T. K., Mees, C. C., & Milner-Gulland, E. J. (2014). Modelling the spatial behaviour of a tropical tuna purse seine fleet. PLoS One, 9. http://doi.org/10.1371/journal.pone.0114037

Herbst, D. F., & Hanazaki, N. (2014). Local ecological knowledge of fishers about the life cycle and temporal patterns in the migration of mullet (Mugil liza) in Southern Brazil. Neotropical Ichthyology, 12(4), 879–890. http://doi.org/10.1590/1982-0224-20130156

Lemos, V. M., Avila Troca, D. F., Castello, J. P., & Paes Vieira, J. (2016). Tracking the southern Brazilian schools of Mugil liza during reproductive migration using VMS of purse seiners. Latin American Journal of Aquatic Research, 44(2), 238–246. http://doi.org/10.3856/vol44-issue2-fulltext-5

Lima, I. D., Garcia, C. a. E., & Möller, O. O. (1996). Ocean surface processes on the southern Brazilian shelf: characterization and seasonal variability. Continental Shelf Research, 16(10), 1307–1317. http://doi.org/10.1016/0278-4343(95)00066-6

Mai, A. C. G., Miño, C. I., Marins, L. F. F., Monteiro-Neto, C., Miranda, L., Schwingel, P. R., … Vieira, J. P. (2014). Microsatellite variation and genetic structuring in Mugil liza (Teleostei: Mugilidae) populations from Argentina and Brazil. Estuarine, Coastal and Shelf Science, 149, 80–86. http://doi.org/10.1016/j.ecss.2014.07.013

Miranda, L. V., Carneiro, M. H., Peres, M. B., Cergole, M. C., & Mendonça, J. T. (2011). Contribuições ao processo de ordenamento da pesca da espécie Mugil liza (Teleostei: mugilidae) nas regiões Sudeste e Sul do Brasil entre os anos de 2006 e 2010. Série Relatórios Técnicos, 49, 1–23.

Odebrecht, C., Abreu, P. C., Bemvenuti, C. E., Copertino, M., Muelbert, J. H., Vieira, J. P., & Seeliger, U. (2010). The Patos Lagoon Estuary, Southern Brazil. In M. J. Kennish & H. W. Paerl (Eds.), Coastal Lagoons: Critical Habitats of Environmental Change (pp. 433–456). Boca Raton: CRC Press. http://doi.org/https://doi.org/10.1201/ebk1420088304-c17

Piola, A. R., Möller, O. O., Guerrero, R. a., & Campos, E. J. D. (2008). Variability of the subtropical shelf front off eastern South America: Winter 2003 and summer 2004. Continental Shelf Research, 28(13), 1639–1648. http://doi.org/10.1016/j.csr.2008.03.013

Piola, R., Campos, E. J. D., Möller Jr, O. O., Charo, M., & Martinez, C. (2000). Subtropical Shelf Front off eastern South America. Journal of Geophysical Research, 105, 6565–6578.

Seeliger, U. (2001). The Patos Lagoon Estuary, Brazil. In U. Seeliger & B. Kjerfve (Eds.), Coastal Marine Ecosystems of Latin America (pp. 167–183). Berlin: Springer. http://doi.org/10.1007/978-3-662-04482-7

Vieira, J. P., Garcia, A. M., & Grimm, A. M. (2008). Evidences of El Niño Effects on the Mullet Fishery of the Patos Lagoon Estuary. Brazilian Archives of Biology and Technology, 51, 433–440. http://doi.org/10.1590/S1516-89132008000200025

Vieira, J. P., & Scalabrin, C. (1991). Migração reprodutiva da tainha (Mugil platanus Günther, 1980) no Sul do Brasil. Atlântica, Rio Grande, 13, 131–141. http://doi.org/2236-7586

Wickham, H., & Chang, W. (2016). Devtools: Tools to Make Developing R Packages Easier. Retrieved from https://cran.r-project.org/package=devtools

Wood, S. N. (2006). Generalized additive models: an introduction with R. Boca Raton: CRC Press.

Zuur, A. F., Ieno, E. N., Walker, N. J., Saveliev, A. A., & Smith, G. M. (2009). Mixed Effects Models and Extensions in Ecology with R. New York: Springer Science Business Media.

CONSIDERAÇÕES FINAIS E RECOMENDAÇÕES

Cada artigo da tese está vinculado a um dos três objetivos específicos inicialmente propostos. O objetivo geral de propor medidas de manejo que comtemplem a variabilidade espacial e temporal das condições meteo-oceanográficas da área de estudo foi atingido no artigo 1. Esse trabalho destacou a necessidade da abordagem socioambiental ao gerenciamento da atividade pesqueira, sendo que a implementação das medidas sugeridas envolveria as etapas de pesquisa concebidas nos artigos 2 e 3. Desta forma, todos os trabalhos se complementam na construção do objetivo principal.

Em relação as hipóteses, a conclusão a que se chegou é apresentada a seguir:

1. Se houve predomínio de condições meteorológicas e oceanográficas favoráveis à migração da tainha em uma determinada safra, como anomalias negativas de temperatura da superfície do mar e anomalias positivas de ventos na superfície do mar, então houve uma maior taxa de captura pela frota de cerco (traineiras) nessa safra.

Conclusão: as safras de 2007 e 2011 foram marcadas por intensas capturas. As condições ambientais nesses momentos – forte anomalia negativa de TSM em 2007, forte La Niña e intensa anomalia positiva de ventos em 2011 – contribuem para corroborar essa hipótese.

2. Se houve maior predomínio de condições meteorológicas e oceanográficas favoráveis ao retorno das larvas planctônicas para os estuários em uma determinada safra, então o volume desembarcado aumentou no ano em que esses indivíduos se tornaram adultos (entre o 5º e o 6º ano consecutivo).

Conclusão: para avaliar condições oceanográficas favoráveis ao retorno das larvas, utilizamos a clorofila-*a*. Embasando-se na hipótese de "*match-mismatch*", observou-se que a desova de tainha tende a se antecipar às florações fitoplanctônicas, para haver disponibilidade de alimento para as larvas de peixes. De fato, verificamos na primavera de 2005 uma forte anomalia positiva de produção primária e no 6º ano consecutivo, em 2011, uma intensa captura de tainhas. No entanto, outros fatores podem ter contribuído para essa grande captura, como de fato verificou-se a ocorrência de ventos intensos em 2011 proporcionando aumento da capturabilidade pela frota industrial. Além disso, não podemos afirmar que os adultos capturados em 2011 correspondem as larvas de 2005. Portanto, não é possível afirmar essa hipótese como verdadeira apenas com base nos dados avaliados. Sugere-se o monitoramento de séries temporais maiores, abrangendo mais ciclos de recrutamento da espécie.

3. Se houve intensa atividade pesqueira em determinadas áreas, então as condições meteo-oceanográficas dessas áreas definem as zonas preferenciais de pesca.

Conclusão: neste estudo identificamos duas áreas principais de pesca nas safras de 2010 a 2012, ao norte do estado de SC e em frente a desembocadura da Lagoa dos Patos, próximo à costa e aos portos de desembarque. Recomenda-se a realização de entrevistas com os mestres das traineiras para verificar se o fator econômico influencia a decisão da escolha dos locais de pesca. Recomenda-se também a análise da variabilidade diária de ventos e de TSM nas safras de 2010 a 2012 para podermos testar a validade da hipótese proposta.

Finalmente, em relação ao objetivo principal, entre os parâmetros ambientais analisados, TSM, clorofila-a e ventos, detectamos a variabilidade da pesca (CPUE e atividade pesqueira) em função principalmente dos ventos. No entanto, ao analisar a CPUE utilizamos médias mensais, ou seja, não necessariamente indica que a pesca intensa ocorra durante condições de ventos fortes. Na análise da atividade pesqueira utilizamos dados diários. As horas de pesca, no entanto, são insuficientes para concluir que durante condições de ventos intensos, aumente a captura, ou seja, o aumento das horas de pesca em função dos ventos pode ter ocorrido em função da dificuldade das condições de operação de pesca. Recomenda-se, portanto, a utilização de dados de captura em dias de ventos intensos.

REFERÊNCIAS

ABEL, N.; CUMMING, D. H. M.; ANDERIES, J. M. Collapse and Reorganization in Social-Ecological Systems : Questions , Some Ideas , and Policy Implications. **Ecology and Society**, v. 11, n. 1, p. 17, 2006.

ACHESON, J. M. Institutional Failure in Resource Management. **The Annual Review of Anthropology**, v. 35, p. 117–34, 2006.

ADGER, W. N.; HUGHES, T. P.; FOLKE, C.; CARPENTER, S. R.; ROCKSTRÖM, J. Social-ecological resilience to coastal disasters. **Science** v. 309, n. 5737, p. 1036–1039, 2005.

ALLEN, C. R.; ANGELER, D. G.; GARMESTANI, A. S.; GUNDERSON, L. H.; HOLLING, C. S. Panarchy : Theory and Application. **Ecosystems**, v. 17, n. 4, p. 578–589, 2014.

ALLISON, E. H.; PERRY, A. L.; BADJECK, M.-C.; NEIL ADGER, W.; BROWN, K.; CONWAY, D.; HALLS, A. S.; PILLING, G. M.; REYNOLDS, J. D.; ANDREW, N. L.; DULVY, N. K. Vulnerability of national economies to the impacts of climate change on fisheries. **Fish and Fisheries**, v. 10, p. 173–196, 2009.

ARMITAGE, D. R.; PLUMMER, R.; BERKES, F.; ARTHUR, R.; CHARLE, A. T.; HUNT, D.; IAIN, J.; DIDUCK, A. P.; DOUBLEDAY, N. C.; JOHNSON, D. S.; MARSCHKE, M.; MCCONNEY, P.; PINKERTON, E. W.; WOLLENBERG, E. K. Adaptive co-management for social– ecological complexity. **Frontiers in Ecology and the Environment**, v. 7, n. 2, p. 95–102, 2009.

ATLAS, R.; HOFFMAN, R. N.; ARDIZZONE, J.; LEIDNER, S. M.; JUSEM, J. C.; SMITH, D. K.; GOMBOS, D. A Cross-calibrated, Multiplatform Ocean Surface Wind Velocity Product for Meteorological and Oceanographic Applications. **Bulletin of the American Meteorological Society**, v. 92, n. 2, p. 157–174, 2011.

BARLETTA, M.; JAUREGUIZAR, A. J.; BAIGUN, C.; FONTOURA, N. F.; AGOSTINHO, A. A.; ALMEIDA-VAL, V. M. F.; VAL, A. L.; TORRES, R. A.; JIMENES-SEGURA, L. F.; GIARRIZZO, T.; FABRÉ, N. N.; BATISTA, V. S.; LASSO, C.; TAPHORN, D. C.; COSTA, M. F.; CHAVES, P. T.; VIEIRA, J. P.; CORRÊA, M. F. M. Fish and aquatic habitat conservation in South America: A continental overview with emphasis on neotropical systems. **Journal of Fish Biology**, v. 76, n. 9, p. 2118–2176, 2010.

BARTOŃ, K. **MuMIn: Multi-Model Inference R Package Version**.

BEDDINGTON, J. R.; AGNEW, D. J.; CLARK, C. W. Current problems in the management of marine fisheries. **Science**, v. 316, n. 5832, p. 1713–6, 2007.

BÉNÉ, C.; ARTHUR, R.; NORBURY, H.; ALLISON, E. H.; BEVERIDGE, M.; BUSH, S.; CAMPLING, L.; LESCHEN, W.; LITTLE, D.; SQUIRES, D.; THILSTED, S. H.; TROELL, M.; WILLIAMS, M. Contribution of Fisheries and Aquaculture to Food Security and Poverty Reduction : Assessing the Current Evidence. **World Development**, v. 79, p. 177–196, 2016.

BERKES, F.; MAHON, R.; MCCONNEY, P.; POLLNAC, R.; POMEROY, R. **Managing Small-Scale Fisheries: Alternative Directions and Methods**. Ottawa: International Development Research Centre, 2001.

BIANCHI, G.; SKJOLDAL, H. R. **The Ecosystem approach to Fisheries**. Wallingford: Centre for Agriculture and Bioscience International, 2008.

BOGRAD, S. J.; HAZEN, E. L.; HOWELL, E. A.; HOLLOWED, A. B. The fate of fisheries oceanography: Introduction to the special issue. **Fisheries Oceanography**, v. 27, n. 4, p. 21–25, 2014.

BRAZILIAN MINISTRY FOR FISHERIES AND AQUACULTURE. **Plano de gestão para o uso sustentável da tainha, Mugil liza Valenciennes, 1836, no Sudeste e Sul do Brasil.** Brasília: Ministério da Pesca e Aquicultura, 2015.

BRIERLEY, A. S.; KINGSFORD, M. J. Impacts of Climate Change on Marine Organisms and Ecosystems. **Current Biology**, v. 19, n. 14, p. 602–614, 2009.

BUNCE, M.; MEE, L.; RODWELL, L. D.; GIBB, R. Collapse and recovery in a remote small island — A tale of adaptive cycles or downward spirals ? **Global Environmental Change**, v. 19, p. 213–226, 2009.

BUSCH, D. S.; GRIF, R.; LINK, J.; ABRAMS, K.; BAKER, J.; BRAINARD, R. E.; FORD, M.; HARE, J. A.; HIMES-CORNELL, A.; HOLLOWED, A.; MANTUA, N. J.; MCCLATCHIE, S.; MCCLURE, M.; NELSON, M. W.; OSGOOD, K.; PETERSON, J. O.; RUST, M.; SABA, V.; SIGLER, M. F.; et al. Climate science strategy of the US National Marine Fisheries Service. **Marine Policy**, v. 74, p. 58–67, 2016.

CAMPOS, E. J.; GONCALVES, J.; IKEDA, Y. Water mass characteristics and geostrophic circulation in the South Brazil Bight: summer of 1991. **Journal of Geophysical Research**, v. 100, p. 18537–18550, 1995.

CASTELLO, J. P.; MÖLLER, O. O. On the relationship between rainfall and shrimp production in the estuary of the Patos Lagoon (Rio Grande do Sul, Brazil). **Atlântica**, v. 3, p. 67–74, 1977.

CASTELLO, J.; VIEIRA, J.; LEMOS, V.; MORAES, L.; GARBIN, A.; SCHWINGEL, P. Síntese, controvérsia e o que sabemos de novo sobre a tainha (Mugil liza). In: II SIMPOSIO IBEROAMERICANO DE ECOLOGÍA REPRODUCTIVA, RECLUTAMIENTO Y PESQUERÍAS. **Anais...** Mar del Plata: 2012.

CAZELLES, B.; STONE, L. Detection of imperfect population synchrony in an uncertain world. **Journal of Animal Ecology**, v. 72, n. 6, p. 953–968, 2003.
CHAO, L. H.; PEREIRA, L. E.; VIEIRA, J. P. Estuarine fish community of the dos Patos Lagoon, Brazil. A baseline study. **Fish community ecology in estuaries and coastal lagoons: Towards an ecosystem integration**, p. 429–450, 1985.

CIOTTI, A. M.; ODEBRECHT, C.; FILLMANN, G.; MOLLER JR., O. O. Freshwater outflow and subtropical convergence influence on phyto- plankton biomass on the southern Brazilian continental shelf. **Continental Shelf Research**, v. 15, p. 1737–1756, 1995.

CLARK, R. A.; FOX, C. J.; VINER, D.; LIVERMORE, M. North Sea cod and climate change—modeling the effects of temperature on population dynamics. **Global Change Biology**, v. 9, p. 1669–1680, 2003.

COCHRANE, K. L.; ANDREW, N. L.; PARMA, A. M. Primary fisheries management: A minimum requirement for provision of sustainable human benefits in small-scale fisheries. **Fish and Fisheries**, v. 12, p. 275–288, 2011.

CORBINEAU, A.; ROUYER, T.; CAZELLES, B.; FROMENTIN, J.-M.; FONTENEAU, A.; MÉNARD, F. Time series analysis of tuna and swordfish catches and climate variability in the Indian Ocean (1968-2003). **Aquatic Living Resources**, v. 21, n. 3, p. 277–285, 2008.

CREIGHTON, C.; HOBDAY, A. J.; LOCKWOOD, M.; PECL, G. T. Adapting Management of Marine Environments to a Changing Climate : A Checklist to

Guide Reform and Assess Progress. **Ecosystems**, v. 19, n. 2, p. 187–219, 2016.

CROWDER, L.; NORSE, E. Essential ecological insights for marine ecosystem-based management and marine spatial planning. **Marine Policy**, v. 32, p. 772–778, 2008.

CUSHING, D. H. Plankton Production and Year Class Strength in Fish Populations - an Update of the Match Mismatch Hypothesis. **Advances in Marine Biology**, v. 26, p. 249–294, 1990.

DAVIES, T. K.; MEES, C. C.; MILNER-GULLAND, E. J. Modelling the spatial behaviour of a tropical tuna purse seine fleet. **PLoS One**, v. 9, 2014.

DONEY, S. C.; RUCKELSHAUS, M.; DUFFY, J. E.; BARRY, J. P.; CHAN, F.; ENGLISH, C. A.; GALINDO, H. M.; GREBMEIER, J. M.; HOLLOWED, A. B.; KNOWLTON, N.; POLOVINA, J.; RABALAIS, N. N.; SYDEMAN, W. J.; TALLEY, L. D. Climate Change Impacts on Marine Ecosystems. **The Annual Review of Marine Science**, v. 4, n. 1, p. 11–37, 2012.

ERIKSSON, H.; ADHURI, D. S.; ADRIANTO, L.; ANDREW, N. L.; APRILIANI, T.; DAW, T.; EVANS, L.; GARCES, L.; KAMANYI, E.; MWAIPOPO, R.; PURNOMO, A. H.; SULU, R. J.; BEARE, D. J. An ecosystem approach to small-scale fi sheries through participatory diagnosis in four tropical countries. **Global Environmental Change**, v. 36, p. 56–66, 2016.

FAGUNDES, L.; TOMÁS, A. R. G.; CASARINI, L. M.; BUENO, E. F.; LOPES, G. M.; MACHADO, D. A. L.; ROSA, R. A.; BRAGA, A. C. A.; CAMARGO, F. B. F.; OBERG, I. M. F.; PELLEGRINI, S. O. P. A pesca de arrasto de praia na ilha de São Vicente, São Paulo, Brasil. **Série Relatórios Técnicos**, v. 29, p. 1–43, 2007.

FAO. **The State of World Fisheries and Aquaculture 2008**. Rome: FAO Fisheries and Aquaculture Department, 2008.

FAO. **The State of World Fisheries and Aquaculture 2016**. Contributing to food security and nutrition for all. Rome: FAO Fisheries and Aquaculture Department, 2016.

FLETCHER, P. J.; KELBLE, C. R.; NUTTLE, W. K.; KIKER, G. A. Using the integrated ecosystem assessment framework to build consensus and transfer

information to managers. **Ecological Indicators**, v. 44, p. 11–25, 2014.
FLETCHER, W. J.; BIANCHI, G. The FAO - EAF toolbox: Making the ecosystem approach accessible to all fisheries. **Ocean & Coastal Management**, v. 90, p. 20–26, 2014.

FOGARTY, M. J. Climate variability and ocean ecosystem dynamics: implications for sustainability. In: GLOBAL CHANGE OPEN SCIENCE CONFERENCE, 2002, Amsterdam. **Proceedings…**Amsterdam: 2002, p.27-29.

FOLKE, C. Resilience : The emergence of a perspective for social – ecological systems analyses. **Global Environmental Change**, v. 16, n. 3, p. 253–267, 2006.

FOLKE, C.; CARPENTER, S. R.; WALKER, B.; SCHEFFER, M.; CHAPIN, T.; ROCKSTRÖM, J. Resilience Thinking: Integrating Resilience, Adaptability and Transformability. **Ecology and Society**, v. 15, n. 4, p. 20, 2010.
FOLKE, C.; PRITCHARD JR., L.; BERKES, F.; COLDING, J.; SVEDIN, U. The Problem of Fit between Ecosystems and Institutions : Ten Years Later. **Ecology and Society**, v. 12, n. 1, p. 30, 2007.

FONTOURA, N. F.; VIEIRA, J. P.; BECKER, F. G.; RODRIGUES, L. R.; MALABARBA, L. R.; SCHULZ, U. H.; MÖLLER, O. O.; GARCIA, A. M.; VILELLA, F. S. Aspects of fish conservation in the upper Patos Lagoon basin. **Journal of Fish Biology**, v. 89, p. 315–336, 2016.

GALVÃO, M.S.N.; FENERICH-VERANI, N.; YAMANAKA, N.; OLIVEIRA, I. R. histologia do sistema digestivo da tainha durante as fases larval e juvenil. **Boletim do Instituto de Pesca**, v. 24, p. 91–100, 1997.

GARBIN, T.; CASTELLO, J. P.; KINAS, P. G. Age, growth, and mortality of the mullet Mugil liza in Brazil's southern and southeastern coastal regions. **Fisheries Research**, v. 149, n. 2014, p. 61–68, jan. 2014.

GARCIA, A. M.; VIEIRA, J. P.; WINEMILLER, K. O.; GRIMM, A. M. Comparison of 1982–1983 and 1997–1998 El Niño effects on the shallow-water fish assemblage of the Patos Lagoon estuary (Brazil). **Estuaries**, v. 27, n. 6, p. 905–914, 2004.

GARCIA, S.; COCHRANE, K. Ecosystem approach to fisheries: a review of implementation guidelines. **ICES Journal of Marine Science**, v. 62, n. 3, p. 311–318, maio 2005.

GONZÁLEZ-CASTRO, M.G., MACCHI, G.J., COSSEAU, M. B. Studies on reproduction of the mullet Mugil platanus Gunther, 1880 (Actinopterygii, Mugilidae) from the Mar Chiquita coastal lagoon, Argentina: Similarities and differences with related species. **Italian Journal of Zoology**, v. 78, n. 3, p. 343–353, 2011.

GONZÁLEZ CASTRO, M.; ABACHIAN, V.; PERROTTA, R. G. Age and growth of the striped mullet, Mugil platanus (Actinopterygii, Mugilidae), in a southwestern Atlantic coastal lagoon (37°32'S-57°19'W): A proposal for a life-history model. **Journal of Applied Ichthyology**, v. 25, n. 1, p. 61–66, 2009.

GRIMM, A. M.; FERRAZ, S. E. T.; GOMES, J. Precipitation anomalies in Southern Brasil associated with El Niño and La Niña Events. **Journal of Climate**, v. 11, p. 2863–2880., 1998.

GRIMM, A. M.; TEDESCHI, R. G. ENSO and extreme rainfall events in South America. **Journal of Climate**, v. 22, n. 7, p. 1589–1609, 2009.

GRINSTED, A.; MOORE, J. C.; JEVREJEVA, S. Application of the cross wavelet transform and wavelet coherence to geophysical time series. **Nonlinear Processes in Geophysics**, v. 11, p. 561–566, 2004.

GUNDERSON, L.; KINZIG, A.; QUINLAN, A.; WALKER, B. **Assessing resilience in social-ecological systems: workbook for practitioners.** Resilience Alliance, 2010.

HAGSTROM, G. I.; LEVIN, S. A. Marine Ecosystems as Complex Adaptive Systems : Emergent Patterns , Critical Transitions , and Public Goods. **Ecosystems**, v. 20, n. 3, p. 458-476, 2017.

HAIDVOGEL, D. B.; TURNER, E.; CURCHITSER, E. N.; HOFMANN, E. E. Looking forward: Transdisciplinary modeling, environmental forecasting, and management. **Oceanography**, v. 26, n. 4, p. 128–135, 2013.

HALLETT, T. B.; COULSON, T.; PILKINGTON, J. G.; CLUTTON-BROCK, T. H.; PEMBERTON, J. M.; GRENFELL, B. T. Why large-scale climate indices seem to predict ecological processes better than local weather. **Nature**, v. 430, n. 6995, p. 71–75, 2004.

HARLEY, S. J.; MYERS, R. A.; DUNN, A. A meta-analysis of the relationship between catch-per-unit-effort and abundance. **Canadian Journal of Fisheries**

and Aquatic Sciences, v. 58, p. 1705–1772, 2001.

HERBST, D. F.; HANAZAKI, N. Local ecological knowledge of fishers about the life cycle and temporal patterns in the migration of mullet (Mugil liza) in Southern Brazil. **Neotropical Ichthyology**, v. 12, n. 4, p. 879–890, 2014.

HILBORN, R.; WALTERS, C. L. Quantitative fisheries stock assessment: choice, dynamics & uncertainty. **Reviews in Fish Biology and Fisheries**, v. 2, n. 2, p. 177–178, 1992.

HO, C.; CHEN, J.; NOBUYUKI, Y.; LUR, H.; LU, H. Ocean & Coastal Management Mitigating uncertainty and enhancing resilience to climate change in the fi sheries sector in Taiwan : Policy implications for food security. **Ocean and Coastal Management**, v. 130, n. 2, p. 355–372, 2016.

HOLLING, C. S. Resilience and Stability as Shown by Models of Ecological Systems. In: VAN DEN DRIESSCHE, P. (Ed.). . **Mathematical Problems in Biology**. Berlin: Springer, 1974. p. 93–95.
HOLLING, C. S. Understanding the Complexity of Economic, Ecological, and Social Systems. **Ecosystems**, v. 4, p. 390–405, 2001.

HOLLING, C. S.; MEFFE, G. K. Command and Control and the Pathology of Natural Resource Management. **Conservation Biology**, v. 10, n. 2, p. 328–337, 1996.

HUGHES, T. P.; BELLWOOD, D. R.; FOLKE, C.; STENECK, R. S.; WILSON, J. New paradigms for supporting the resilience of marine ecosystems. **Trends in Ecology and Evolution**, v. 20, n. 7, p. 380–386, 2005.

JUL-LARSEN, E.; KOLDING, J.; OVERÅ, R.; NIELSEN, J. R.; ZWIETEN, P. A. M. VAN. **Management, Co-Management or No Management? Major Dilemmas in Southern African Freshwater Fisheries**. Rome: Food and Agriculture Organization of the United Nations, 2003.

KALIKOSKI, D. C.; QUEVEDO NETO, P.; ALMUDI, T. Building adaptive capacity to climate variability: The case of artisanal fisheries in the estuary of the Patos Lagoon, Brazil. **Marine Policy**, v. 34, n. 4, p. 742–751, 2010.

KIRBY, J. F. Which wavelet best reproduces the Fourier power spectrum? **Computers & Geosciences**, v. 31, n. 7, p. 846–864, 2005.

LEHODEY, P.; ALHEIT, J.; BARANGE, M.; BAUMGARTNER, T.; BEAUGRAND, G.; DRINKWATER, K. F.; FROMENTIN, J.-M.; HARE, S. R.; OTTERSEN, G.; PERRY, R. I.; ROY, C.; VAN DER LINGEN, C. D.; WERNER, F.; OTHERS. Climate Variability, Fish, and Fisheries. **Journal of Climate**, v. 19, n. 20, p. 5009–5030, 2006.

LEMOS, V. M. **Subsídios para a implementação do Plano de Gestão e do Uso Sustentável da Tainha (Mugil liza) na região Sul do Brasil**. Rio Grande, Ministério da Pesca e Aquicultura, 2017. 43 p. Relatório técnico.

LEMOS, V. M.; AVILA TROCA, D. F.; CASTELLO, J. P.; PAES VIEIRA, J. Tracking the southern Brazilian schools of Mugil liza during reproductive migration using VMS of purse seiners. **Latin American Journal of Aquatic Research**, v. 44, n. 2, p. 238–246, 2016.

LEMOS, V. M.; VARELA JR., A. S.; SHWINGEL, P. R.; MUELBERT, J. H.; VIEIRA, J. P. Migration and reproductive biology of Mugil liza (Teleostei: Mugilidae) in south Brazil. **Journal of Fish Biology**, v. 85, n. 3, p. 671–687, 2014.

LIMA, I. D.; GARCIA, C. A. E.; MÖLLER, O. O. Ocean surface processes on the southern Brazilian shelf: characterization and seasonal variability. **Continental Shelf Research**, v. 16, n. 10, p. 1307–1317, ago. 1996.

LOPES, R. M.; KATSURAGAWA, M.; DIAS, J. F.; MONTÚ, M. A.; MUELBERT, J. H.; GORRI, C.; BRANDINI, F. P. Zooplankton and ichthyoplankton distribution on the southern Brazilian shelf : an overview. **Scientia Marina**, v. 70, p. 189–202, 2006.

MAHON, R.; FANNING, L.; MCCONNEY, P. A governance perspective on the large marine ecosystem approach. **Marine Policy**, v. 33, n. 2, p. 317–321, 2009.

MAHON, R.; MCCONNEY, P.; ROY, R. N. Governing fisheries as complex adaptive systems. **Marine Policy**, v. 32, p. 104–112, 2008.

MAI, A. C. G.; MIÑO, C. I.; MARINS, L. F. F.; MONTEIRO-NETO, C.; MIRANDA, L.; SCHWINGEL, P. R.; LEMOS, V. M.; GONZALEZ-CASTRO, M.; CASTELLO, J. P.; VIEIRA, J. P. Microsatellite variation and genetic structuring in Mugil liza (Teleostei: Mugilidae) populations from Argentina and Brazil. **Estuarine, Coastal and Shelf Science**, v. 149, p. 80–86, ago. 2014.

MAKRIS, N. C.; RATILAL, P.; JAGANNATHAN, S.; GONG, Z.; ANDREWS, M.; BERTSATOS, I.; GODØ, O. R.; NERO, R. W.; JECH, J. M. Critical Population Density Triggers Rapid Formation of Vast Oceanic Fish Shoals. **Science**, v. 323, n. 5922, p. 1734–1737, 2009.

MARAUN, D.; KURTHS, J. Cross wavelet analysis: significance testing and pitfalls. **Nonlinear Processes in Geophysics**, v. 11, n. 4, p. 505–514, 2004.

MAUNDER, M.; SIBERT, J.; FONTENEAU, A; HAMPTON, J.; KLEIBER, P.; HARLEY, S. Interpreting catch per unit effort data to assess the status of individual stocks and communities. **ICES Journal of Marine Science**, v. 63, n. 8, p. 1373–1385, set. 2006.

MEDEIROS, R. P.; GUAINAIS, J. H. D. G.; SANTOS, L. O.; SPACH, H. L.; SILVA, C. N. S.; FOPPA, C. C.; CATTANI, A. P.; RAINHO, A. P. Estratégias para a redução da fauna acompanhante na frota artesanal de arrasto do camarão sete-barbas: perspectivas para a gestão pesqueira. **Boletim do Instituto de Pesca**, v. 39, n. 3, p. 339–358, 2013.

MÈNARD, F.; MARSAC, F.; BELLIER, E.; CAZELLES, B. Climatic oscillations and tuna catch rates in the Indian Ocean : a wavelet approach to time series analysis. **Fisheries oceanography**, v. 16, n. 1, p. 95–104, 2007.

MENDONÇA, J. T. **Gestão dos recursos pesqueiros do Complexo Estuarino-lagunar de Cananéia, Iguape e Ilha Comprida, litoral sul de São Paulo, Brasil**. Universidade Federal de São Carlos, 2007.

MILLER, K.; CHARLES, A.; BARANGE, M.; BRANDER, K.; GALLUCCI, V. F.; GASALLA, M. A.; KHAN, A.; MUNRO, G.; MURTUGUDDE, R.; OMMER, R. E.; PERRY, R. I. Climate change, uncertainty, and resilient fisheries : Institutional responses through integrative science. **Progress in Oceanography**, v. 87, n. 1–4, p. 338–346, 2010.

MIRANDA, L. V.; CARNEIRO, M. H. A pesca da tainha Mugil platanus (Perciformes: Mugilidae) Desembarcada no Estado de São Paulo Subsídio ao Ordenamento. **Série Relatórios Técnicos**, v. 30, p. 1–13, 2007.

MIRANDA, L. V.; CARNEIRO, M. H.; PERES, M. B.; CERGOLE, M. C.; MENDONÇA, J. T. Contribuições ao processo de ordenamento da pesca da espécie Mugil liza (Teleostei: mugilidae) nas regiões Sudeste e Sul do Brasil entre os anos de 2006 e 2010. **Série Relatórios Técnicos**, v. 49, p. 1–23,

2011.
MIRANDA, L. V.; MENDONÇA, J. T.; CERGOLE, M. C. Diagnóstico do estoque e orientações para o ordenamento da pesca de Mugil platanus (Gunther 1880). In: ROSSI-WONGTSCHOWSKI, C. L. D. B.; ÁVILA-DA-SILVA, A. O.; CERGOLE, M. C. (Eds.). . **Série Documentos REVIZEE Score sul**. São Paulo: Instituto Oceanográfico, 2006. p. 38–48.

MÖLLER JR., O. O.; FERNANDES, E. H. L. Hidrologia e hidrodinâmica. In: SEELIGER, U.; ODEBRECHT, C. (Eds.). . **O estuário da Lagoa dos Patos: um século de transformações**. Rio Grande: FURG, 2010. p. 17–30.
MORISHITA, J. What is the ecosystem approach for fisheries management? **Marine Policy**, v. 32, n. 1, p. 19–26, 2008.

MUELBERT, J. H.; SINQUE, C. Distribution of bluefish (Pomatomus saltatrix) larvae along the continental shelf off southern Brazil. **Marine and Freshwater Research**, v. 47, p. 311–314, 1996.

MYERS, R. A.; WORM, B. Rapid worldwide depletion of predatory fish communities. **Nature**, v. 423, p. 280, 2003.

NAKKEN, M. Wavelet analysis of rainfall–runoff variability isolating climatic from anthropogenic patterns. **Environmental Modelling & Software**, v. 14, n. 4, p. 283–295, 1999.

OCEANA. **Pesca da tainha - informações que você precisa saber**. Disponível em: <http://brasil.oceana.org/pesca-da-tainha-informacoes-que-voce-precisa-saber>. Acesso em: 13 jun. 2017.

ODEBRECHT, C.; ABREU, P. C.; BEMVENUTI, C. E.; COPERTINO, M.; MUELBERT, J. H.; VIEIRA, J. P.; SEELIGER, U. The Patos Lagoon Estuary, Southern Brazil. In: KENNISH, M. J.; PAERL, H. W. (Eds.). . **Coastal Lagoons: Critical Habitats of Environmental Change**. Boca Raton: CRC Press, 2010. p. 433–456.

OLIVEIRA, I. R.; SOARES, L. S. H. Alimentação da Tainha Mugil platanus GÜNTHER, 1880 (Pisces: Mugilidae) da região estuarino-lagunar de Cananéia, São Paulo, Brazil. **Boletim do Instituto de Pesca**, v. 23, p. 95–104, 1996.

OSTROM, E.; BURGER, J.; FIELD, C.; NORGAARD, R.; POLICANSKY, D. Revisiting the Commons: Local Lessons, Global Challenges. **Science**, v. 284, p. 278–282, 1999.

PALACIOS, D. M.; BOGRAD, S. J.; FOLEY, D. G.; SCHWING, F. B. Oceanographic characteristics of biological hot spots in the North Pacific : A remote sensing perspective. **Deep Sea Research II**, v. 53, p. 250–269, 2006.

PALMA, E. D.; MATANO, R. P.; PIOLA, A. R. A numerical study of the Southwestern Atlantic Shelf circulation: Stratified ocean response to local and offshore forcing. **Journal of Geophysical Research: Oceans**, v. 113, n. 11, p. 1–22, 2008.

PAULY, D.; ZELLER, D. Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. **Nature Communications**, v. 7, p. 1–9, 2016.

PERES, M. B. **Síntese das informações da pesca de tainha no Rio Grande do Sul.** Itajaí: CEPSUL, 2007. I Relatório de reunião técnica para o ordenamento da pesca da tainha (Mugil platanus, M. liza) na região Sudeste/Sul do Brasil.

PINA, J. V.; CHAVES, P. T. A pesca de tainha e parati na Baía de Guaratuba, Paraná, Brasil. **Acta Biológica Paranaense**, v. 34, p. 103–113, 2005.

PINHEIRO, L.; LANA, P. C.; ANDRIGUETTO-FILHO, J.M. HANAZAKI, N. A pesca do arrastão de praia no litoral do Paraná : reflexões sobre o método etnoecológico. In: ARAÚJO, T. A. S.; ALBUQUERQUE, U. P. (Eds.). . **Encontros e Desencontros na Pesquisa Etnobiológicas e Etnoecológicas: os Desafios do Trabalho em Campo**. Recife: NUPPEA, 2009. p. 135–151.

PIOLA, A. R.; MÖLLER, O. O.; GUERRERO, R. A.; CAMPOS, E. J. D. Variability of the subtropical shelf front off eastern South America: Winter 2003 and summer 2004. **Continental Shelf Research**, v. 28, n. 13, p. 1639–1648, jul. 2008.

PIOLA, R.; CAMPOS, E. J. D.; MÖLLER JR, O. O.; CHARO, M.; MARTINEZ, C. Subtropical Shelf Front off eastern South America. **Journal of geophysical research**, v. 105, p. 6565–6578, 2000.

PLANQUE, B.; LOOTS, C.; PETITGAS, P.; LINDSTRØM, U.; VAZ, S. Understanding what controls the spatial distribution of fish populations using a multi-model approach. **Fisheries oceanography**, v. 20, n. 1, p. 1–17, 2010.

POMEROY, R. S.; BERKES, F. Two to tango : the role of government in fisheries. **Marine Policy**, v. 21, n. 5, p. 465–480, 1997.

REIS, E. G.; D'INCAO, F. The present status of artisanal fisheries of extreme Southern Brazil : an effort towards community-based management. **Ocean and Coastal Management**, v. 43, p. 585–595, 2000.

RICE, J. Managing fisheries well: delivering the promises of an ecosystem approach. **Fish and Fisheries**, v. 12, n. 2, p. 209–231, 13 jun. 2011.

RODRIGUES, F. L.; VIEIRA, J. P. Surf zone fish abundance and diversity at two sandy beaches separated by long rocky jetties. **Journal of the Marine Biological Association of the United Kingdom**, v. 93, n. 4, p. 867–875, 2013.

ROPELEWSKI, C. F.; HALPERT, M. S. Global and Regional Scale Precipitation Patterns Associated with the El Niño/Southern Oscillation. **Monthly Weather Review**, v. 115, n. 8, p. 1606–1626, 1987.

ROUYER, T.; FROMENTIN, J.; STENSETH, N. C.; CAZELLES, B. Analysing multiple time series and extending significance testing in wavelet analysis. **Marine Ecology Progress Series**, v. 359, p. 11–23, 2008.

SANT'ANA, R.; KINAS, P. G. **Avaliação do Estoque de Tainha (Mugil liza): ampliação dos modelos Bayesianos de Dinâmica de Biomassa para múltiplas séries de CPUE, com adição de temperatura superficial do mar e capturabilidade autocorrelacionada**. Brasília: Oceana, 2016. 31 p. Relatório técnico.

SANTANA, R.; KINAS, P. G.; VIL, L.; SCHWINGEL, P. R.; CASTELLO, J. P.; VIEIRA, J. P. Bayesian state-space models with multiple CPUE data : the case of a mullet fishery. **Scientia Marina**, v. 81, n. September, p. 361–370, 2017.

SANTOS, A. M. P. Fisheries oceanography using satellite and airborne remote sensing methods : a review. **Fisheries Research**, v. 49, p. 1–20, 2000.

SECKENDORFF, R. W.; AZEVEDO, V. G. Abordagem histórica da pesca da tainha Mugil platanus e do parati Mugil curema (Perciformes: Mugilidae) no litoral norte do estado de São Paulo. **Série Relatórios Técnicos**, v. 28, p. 1–8, 2007.

SEELIGER, U. The Patos Lagoon Estuary, Brazil. In: SEELIGER, U.; KJERFVE, B. (Eds.). **Coastal Marine Ecosystems of Latin America**. Berlin: Springer, 2001. p. 167–183.

SILVA, C. N. S.; BROADHURST, M. K.; MEDEIROS, R. P.; DIAS, J. H. Resolving environmental issues in the southern Brazilian artisanal penaeid-trawl fishery through adaptive co-management. **Marine Policy**, v. 42, p. 133–141, 2013.

STEFFEN, E.; CRUTZEN, P. J.; MCNEILL, J. R. The Anthropocene: are humans now overwhelming the great forces of nature? **Ambio**, v. 36, p. 614–621, 2007.

STENSETH, N. C.; OTTERSEN, G.; HURRELL, J. W.; MYSTERUD, A.; LIMA, M.; CHAN, K.-S.; YOCCOZ, N. G.; ADLANDSVIK, B. Studying climate effects on ecology through the use of climate indices: the North Oscillation, El Niño Southern Oscillation and beyond. **Proceedings of the Royal Society B: Biological Sciences**, v. 270, p. 2087–2096, 2003.

STEPHENS, D. W.; KREBS, J. D. **Foraging Theory.** Princeton: Princeton University Press., 1986.

SUMAILA, U. R.; CHEUNG, W. W. L.; LAM, V. W. Y.; PAULY, D.; HERRICK, S. Climate change impacts on the biophysics and economics of world fisheries. **Nature Climate Change**, v. 1, n. 9, p. 449–456, 2011.

TORRENCE, C.; COMPO, G. P. A Practical Guide to Wavelet Analysis. **Bulletin of the American Meteorological Society**, v. 79, p. 61–78, 1998.

TORRENCE, C.; WEBSTER, P. J. Interdecadal Changes in the ENSO–Monsoon System. **Journal of Climate**, v. 12, n. 8, p. 2679–2690, 1999.

TRENBERTH, K. E. The Definition of El Niño. **Bulletin of the American Meteorological Society**, v. 78, n. 12, p. 2771–2777, 1997.

TRENBERTH, K. E.; HOAR, T. J. The 1990-1995 El Niño Southern Oscillation Event: longest on record. **Geophysical Research Letters**, v. 23, p. 57–60, 1996.

VIEIRA, J. P. Juveniles mullets (Pisces: Mugilidae) in the estuary of Lagoa dos

Patos, RS, Brazil. **Copeia**, v. 2, p. 409–418, 1991.
VIEIRA, J. P.; GARCIA, A. M.; GRIMM, A. M. Evidences of El Niño Effects on the Mullet Fishery of the Patos Lagoon Estuary. **Brazilian Archives of Biology and Technology**, v. 51, p. 433–440, 2008.

VIEIRA, J. P.; SCALABRIN, C. Migração reprodutiva da tainha (Mugil platanus Günther, 1980) no Sul do Brasil. **Atlântica, Rio Grande**, v. 13, p. 131–141, 1991a.

VIEIRA, J. P.; SCALABRIN, C. Migração reprodutiva da “tainha” (Mugil platanus Gunther,1980) no sul do Brasil. **Atlântica**, v. 12, p. 131–141, 1991b.

WALKER, B.; HOLLING, C. S.; CARPENTER, S. R.; KINZIG, A. Resilience, adaptability and transformability in social– ecological systems. **Ecology and Society**, v. 9, n. 2, p. 5, 2004.

WALUDA, C. M.; RODHOUSE, P. G.; TRATHAN, P. N.; PIERCE, G. J. Remotely sensed mesoscale oceanography and the distribution of Illex argentinus in the South Atlantic. **Fisheries Oceanography**, v. 10, n. 2, p. 207–216, 2001.

WICKHAM, H.; CHANG, W. **Devtools: Tools to Make Developing R Packages Easier**. Disponível em: <https://cran.r-project.org/package=devtools>.

WILLIAMS, B. K.; BROWN, E. D. Adaptive Management: From More Talk to Real Action. **Environmental Management**, v. 53, n. 2, p. 465–479, 2014.

WOLTER, K.; TIMLIN, M. S. Measuring the strength of ENSO events - how does 1997/98 rank? **Weather**, v. 53, p. 315–324, 1998.

WOOD, S. N. **Generalized additive models: an introduction with R.** Boca Raton: CRC Press, 2006.

WORLD BANK. **Hidden harvest : the global contribution of capture fisheries.** Disponível em: <http://documents.worldbank.org/curated/en/515701468152718292/Hidden-harvest-the-global-contribution-of-capture-fisheries>. Acesso em: 29 out. 2017.

ZUUR, A. F.; IENO, E. N.; WALKER, N. J.; SAVELIEV, A. A.; SMITH, G. M.

Mixed Effects Models and Extensions in Ecology with R. New York: Springer Science Business Media, 2009.

ANEXOS

Anexo 1: Parâmetros da análise de ondaletas da temperatura da superfície do mar (TSM), velocidade do vento, concentração de clorofila-a, do índice multivariado do El Niño Oscilação Sul (MEI) e da captura por unidade de esforço (CPUE).

	TSM	Velocidade do vento	Clorofila-a	MEI	CPUE
Dj	0,0625	0,0625	0,0625	0,0625	0,0625
S0	0,5	0,5	0,5	0,5	0,5
G	0,55	-0,01	0,67	0,92	0,49
A	0,83	0,99	0,74	0,38	0,86

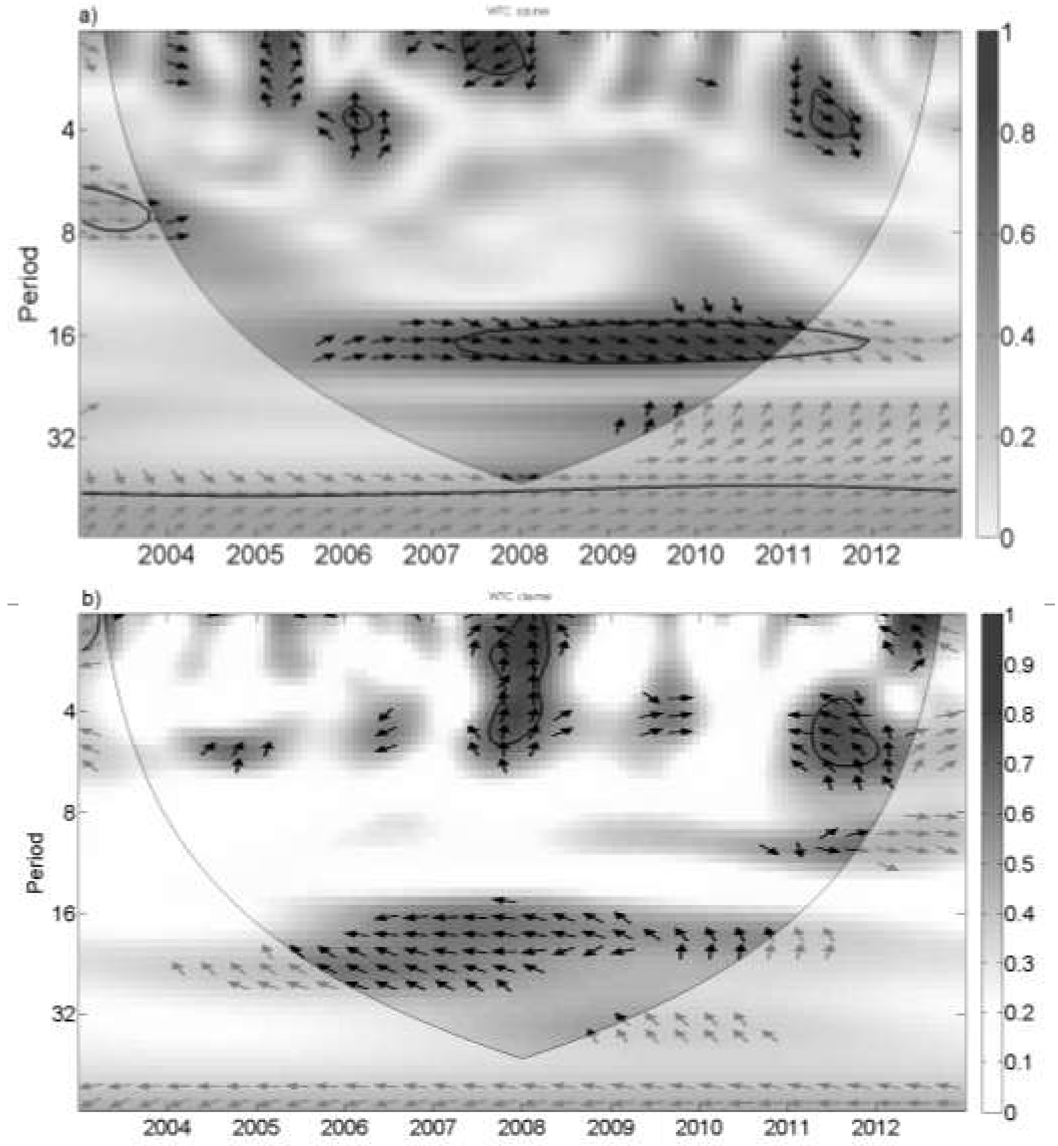
*DJ: espaçamento entre escalas discretas; *S0: a menor escala da ondaleta; *G: estimativa da autocorrelação de lag 1; *A: estimativa da variância do ruído.

Anexo 2: dados brutos de temperatura da superfície do mar (TSM), velocidade do vento, concentração de clorofila-*a*, índice multivariado do El Niño Oscilação Sul (MEI) e da captura por unidade de esforço (CPUE).

Data	TSM (° C)		Velocidade do vento (m/s)		Clorofila-*a* (mg/m^3)		MEI	CPUE (ton/barco)
	Mensal	Anomalia	Mensal	Anomalia	Mensal	Anomalia		
Jan/03	26,14	0,68	2,59	-1,43	0,51	-0,04	1,22	528,30
Fev/03	26,76	0,65	3,49	-0,06	0,45	0,00	0,94	78,67
Mar/03	26,74	0,84	2,71	-0,27	0,38	0,06	0,83	650,75
Abr/03	24,56	-0,28	2,04	-0,13	0,40	0,06	0,42	12040,00
Mai/03	22,22	-0,39	1,94	-0,20	0,44	0,10	0,11	26273,78
Jun/03	20,62	-0,13	1,18	-1,04	0,47	0,12	0,10	16045,26
Jul/03	19,77	0,19	2,53	-0,20	0,46	0,13	0,14	4497,50
Ago/03	19,11	-0,02	2,25	-0,34	0,53	0,11	0,32	1887,50
Set/03	18,91	-0,61	1,92	-0,89	0,84	0,17	0,48	6000,00
Out/03	20,81	0,00	3,30	0,06	1,18	0,19	0,52	3403,28
Nov/03	22,58	0,13	3,17	-0,35	1,34	0,09	0,57	720,00
Dez/03	23,73	-0,34	3,03	-0,61	1,17	0,07	0,35	1526,67
Jan/04	24,68	-0,78	5,01	0,99	0,62	0,04	0,33	875,00
Fev/04	25,40	-0,71	2,39	-1,17	0,33	-0,03	0,36	775,00
Mar/04	25,14	-0,77	3,08	0,10	0,31	-0,11	-0,04	2628,00
Abr/04	24,85	0,01	3,00	0,83	0,31	-0,10	0,37	43,27
Mai/04	22,39	-0,22	2,20	0,06	0,32	-0,09	0,54	15981,66
Jun/04	20,41	-0,34	2,13	-0,09	0,38	-0,12	0,27	29398,96
Jul/04	19,38	-0,20	2,82	0,10	0,46	-0,09	0,54	10968,72
Ago/04	19,97	0,84	2,08	-0,50	0,52	-0,21	0,63	11046,54
Set/04	19,85	0,32	3,20	0,38	0,62	-0,14	0,57	11198,14
Out/04	20,78	-0,03	2,00	-1,23	0,64	-0,12	0,51	11597,71
Nov/04	21,92	-0,53	2,85	-0,67	0,48	-0,04	0,81	17744,00
Dez/04	23,55	-0,52	3,93	0,28	0,37	-0,06	0,67	4947,64
Jan/05	25,34	-0,13	4,17	0,15	0,32	-0,08	0,32	540,00
Fev/05	25,26	-0,85	3,39	-0,17	0,25	-0,11	0,81	2600,00
Mar/05	26,06	0,16	3,13	0,15	0,27	-0,10	1,07	1700,00
Abr/05	25,06	0,22	2,25	0,08	0,31	-0,05	0,64	3000,00
Mai/05	23,29	0,68	2,81	0,67	0,40	-0,06	0,84	19928,85
Jun/05	22,23	1,47	2,80	0,58	0,38	-0,14	0,59	31266,64
Jul/05	20,53	0,95	2,47	-0,26	0,42	-0,11	0,49	14415,08
Ago/05	19,97	0,84	2,52	-0,06	0,57	-0,09	0,35	3200,00
Set/05	19,67	0,14	2,72	-0,09	0,71	0,03	0,32	1600,00
Out/05	20,82	0,01	2,62	-0,61	0,65	0,10	-0,17	1105,49
Nov/05	22,58	0,14	3,84	0,33	0,56	0,14	-0,39	594,51
Dez/05	23,88	-0,18	3,58	-0,06	0,45	0,01	-0,57	100,00
Jan/06	25,48	0,02	3,84	-0,18	0,40	0,02	-0,44	1200,00
Fev/06	26,47	0,36	2,38	-1,18	0,28	-0,06	-0,42	841,78
Mar/06	26,40	0,50	2,94	-0,03	0,28	-0,02	-0,53	680,00
Abr/06	24,76	-0,08	1,64	-0,53	0,31	0,03	-0,58	400,00
Mai/06	22,06	-0,56	2,50	0,36	0,40	0,05	0,01	15250,17
Jun/06	20,83	0,08	2,34	0,11	0,38	-0,05	0,53	13524,96
Jul/06	20,44	0,86	2,70	-0,03	0,43	-0,17	0,69	23153,33
Ago/06	19,81	0,68	2,78	0,20	0,47	-0,08	0,76	7753,33
Set/06	19,05	-0,47	1,93	-0,89	0,79	0,06	0,82	6816,97
Out/06	20,82	0,01	3,96	0,72	0,73	0,00	0,96	1380,00
Nov/06	22,19	-0,26	3,37	-0,15	0,63	-0,07	1,29	2292,36
Dez/06	23,99	-0,08	4,58	0,93	0,37	-0,03	0,95	3175,28
Jan/07	25,21	-0,26	3,19	-0,83	0,45	-0,07	0,99	4087,64
Fev/07	26,20	0,09	4,41	0,85	0,32	-0,12	0,53	5000,00
Mar/07	26,27	0,37	3,29	0,31	0,36	-0,09	0,12	7633,33
Abr/07	25,67	0,84	2,52	0,35	0,35	-0,10	0,02	857,50

Mai/07	22,67	0,05	2,27	0,13	0,43	-0,01	0,25	46951,91
Jun/07	19,82	-0,93	3,11	0,88	0,42	0,09	-0,22	45845,10
Jul/07	18,20	-1,38	3,03	0,30	0,42	0,16	-0,29	8254,80
Ago/07	17,44	-1,69	2,22	-0,36	0,53	0,26	-0,44	6496,29
Set/07	19,40	-0,13	3,96	1,15	0,80	0,21	-1,18	2100,00
Out/07	21,03	0,23	4,19	0,95	0,63	0,04	-1,22	3337,30
Nov/07	22,41	-0,04	2,37	-1,15	0,47	-0,03	-1,17	4251,39
Dez/07	24,61	0,54	3,62	-0,03	0,54	-0,03	-1,19	4914,85
Jan/08	25,66	0,20	5,06	1,04	0,44	0,04	-1,02	5448,35
Fev/08	25,63	-0,48	3,34	-0,22	0,35	0,17	-1,39	5873,75
Mar/08	25,68	-0,22	3,07	0,09	0,27	0,03	-1,58	398,60
Abr/08	24,75	-0,09	2,11	-0,06	0,45	-0,05	-0,88	583,00
Mai/08	22,41	-0,21	1,48	-0,66	0,60	0,00	-0,37	19026,12
Jun/08	21,11	0,35	2,36	0,14	0,40	-0,01	0,13	20543,38
Jul/08	19,49	-0,09	1,97	-0,75	0,70	0,00	0,05	7354,21
Ago/08	19,70	0,57	2,12	-0,46	0,42	-0,18	-0,27	200,00
Set/08	19,49	-0,04	2,37	-0,44	0,63	-0,12	-0,55	72,00
Out/08	20,51	-0,29	3,69	0,45	0,72	-0,02	-0,69	49,17
Nov/08	22,45	0,00	5,71	2,19	0,63	-0,02	-0,60	2,00
Dez/08	23,48	-0,59	3,72	0,07	0,46	0,02	-0,66	174,50
Jan/09	24,83	-0,63	3,84	-0,18	0,32	0,01	-0,73	356,00
Fev/09	25,73	-0,38	3,22	-0,34	0,34	0,02	-0,71	967,67
Mar/09	25,94	0,03	2,54	-0,44	0,29	-0,02	-0,72	256,00
Abr/09	24,80	-0,04	1,65	-0,53	0,38	-0,01	-0,11	980,67
Mai/09	23,15	0,54	2,12	-0,01	0,42	-0,07	0,36	18192,15
Jun/09	20,63	-0,12	1,73	-0,49	0,46	0,00	0,82	36098,30
Jul/09	19,75	0,17	3,00	0,28	0,36	-0,11	1,04	1938,56
Ago/09	19,25	0,12	3,12	0,54	0,46	-0,09	1,07	61,33
Set/09	20,26	0,73	2,46	-0,35	0,70	-0,22	0,74	90,00
Out/09	20,98	0,18	3,05	-0,19	0,88	-0,08	0,91	45,00
Nov/09	23,53	1,09	3,68	0,16	0,93	0,03	1,12	231,34
Dez/09	24,88	0,82	3,99	0,34	0,59	-0,02	1,05	321,50
Jan/10	26,55	1,09	3,56	-0,46	0,46	0,01	1,07	303,50
Fev/10	27,87	1,76	4,16	0,61	0,70	0,05	1,52	350,00
Mar/10	26,25	0,35	2,63	-0,35	0,59	0,15	1,47	253,00
Abr/10	24,80	-0,03	2,50	0,32	0,67	0,19	0,99	1436,67
Mai/10	23,00	0,39	2,26	0,12	0,74	0,08	0,64	17294,29
Jun/10	20,92	0,16	2,17	-0,06	0,66	0,08	-0,33	29733,10
Jul/10	19,84	0,26	4,10	1,38	0,74	0,04	-1,16	26823,90
Ago/10	18,32	-0,81	2,12	-0,46	0,66	0,13	-1,68	60,00
Set/10	19,30	-0,23	3,77	0,96	0,76	0,05	-1,87	1110,00
Out/10	20,81	0,00	2,18	-1,06	0,70	-0,08	-1,90	1017,39
Nov/10	22,24	-0,21	2,68	-0,83	0,48	0,04	-1,49	826,00
Dez/10	24,13	0,06	3,56	-0,09	0,48	0,05	-1,58	1395,00
Jan/11	26,12	0,66	5,12	1,10	0,31	0,01	-1,74	964,67
Fev/11	26,42	0,31	4,99	1,43	0,45	0,04	-1,56	472,33
Mar/11	24,91	-0,99	4,63	1,65	0,44	0,05	-1,58	7276,77
Abr/11	24,55	-0,29	2,38	0,21	0,48	0,01	-1,40	18577,00
Mai/11	22,64	0,03	1,76	-0,38	0,48	-0,05	-0,29	22437,20
Jun/11	20,31	-0,45	2,31	0,08	0,58	-0,03	-0,08	48353,48
Jul/11	18,49	-1,09	2,48	-0,24	0,70	0,14	-0,23	10275,17
Ago/11	18,36	-0,77	2,34	-0,24	0,63	0,04	-0,52	2,43
Set/11	18,88	-0,65	3,41	0,60	0,79	0,09	-0,77	11700,00
Out/11	20,65	-0,16	3,33	0,10	0,95	-0,01	-0,93	480,00
Nov/11	21,59	-0,85	3,84	0,33	0,74	-0,06	-0,95	581,00
Dez/11	23,62	-0,45	3,40	-0,24	0,47	0,02	-0,96	254,00
Jan/12	24,62	-0,84	3,82	-0,20	0,34	0,05	-0,99	128,25
Fev/12	25,37	-0,74	3,80	0,24	0,32	0,03	-0,70	120,00
Mar/12	25,63	-0,27	1,78	-1,20	0,27	0,04	-0,40	2278,00

Abr/12	24,58	-0,26	1,62	-0,55	0,35	0,01	0,11	19715,88
Mai/12	22,31	-0,30	2,04	-0,10	0,44	0,04	0,75	22528,44
Jun/12	20,66	-0,10	2,13	-0,09	0,43	0,06	0,84	22174,56
Jul/12	19,91	0,33	2,14	-0,58	0,37	0,01	1,10	8079,30
Ago/12	19,39	0,26	4,27	1,68	0,49	0,10	0,62	253,00
Set/12	20,47	0,94	2,37	-0,44	0,72	-0,14	0,34	247,93
Out/12	20,85	0,04	4,03	0,80	0,70	-0,02	0,08	240,60
Nov/12	22,97	0,53	3,65	0,13	0,73	-0,07	0,13	228,00
Dez/12	24,81	0,74	3,06	-0,59	0,53	-0,04	0,09	203,81

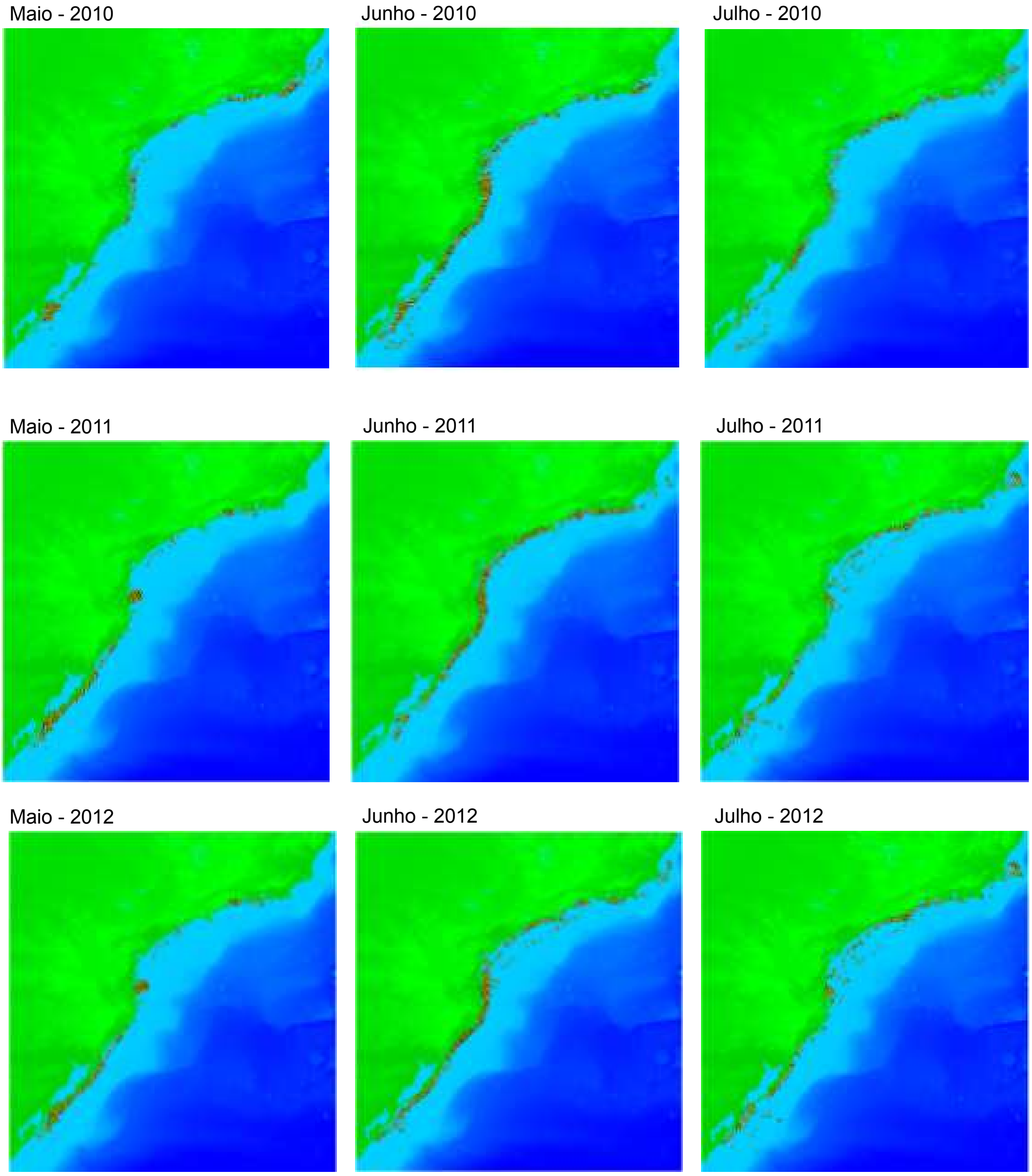


Anexo 3: Ondaleta cruzada entre a) Temperatura da Superfície do Mar (série 1) e Índice Multivariado do ENSO (série 2); e b) Clorofila-*a* (série 1) e Índice Multivariado do ENSO (série 2).

Anexo 4: dados de atividade de pesca das traineiras, localização dos pontos de pesca e componentes u e v do vento no dia 15 de junho de 2010.

Código do navio	Latitude decimal	Longitude decimal	Data	Horas de pesca	Vento: comp. u	Vento: comp. v
1278	-27.02	-48.24	15/06/2010	5	-0.09	-7.01
1829	-34.14	-52.71	15/06/2010	22	3.62	-4.22
1202	-22.61	-41.58	15/06/2010	18	-3.58	-3.03
1288	-28.26	-48.61	15/06/2010	1	-1.34	-8.43
1476	-25.94	-48.42	15/06/2010	19	-0.32	-3.57
1429	-32.16	-52.10	15/06/2010	1	1.14	-3.17
1709	-30.23	-50.12	15/06/2010	17	-1.98	-5.78
1369	-29.82	-49.91	15/06/2010	13	-2.48	-7.00
2222	-26.95	-48.29	15/06/2010	8	0.04	-5.87
550	-27.25	-48.30	15/06/2010	9	0.02	-7.39
2197	-26.99	-48.26	15/06/2010	8	0.04	-5.87
1619	-30.25	-50.14	15/06/2010	19	-1.98	-5.78
1377	-25.95	-48.44	15/06/2010	24	-0.32	-3.57
1271	-29.71	-49.83	15/06/2010	9	-2.12	-6.62
2090	-22.68	-41.60	15/06/2010	6	-3.58	-3.03
1299	-22.71	-41.72	15/06/2010	4	-3.58	-3.03
1688	-30.12	-50.03	15/06/2010	6	-1.98	-5.78
881	-22.64	-41.53	15/06/2010	18	-3.58	-3.03
1729	-26.16	-48.51	15/06/2010	4	0.26	-2.96
1204	-27.02	-48.38	15/06/2010	6	0.11	-6.58
1788	-27.30	-48.25	15/06/2010	6	-0.15	-7.82
1289	-25.96	-48.41	15/06/2010	23	-0.32	-3.57
1296	-30.21	-50.12	15/06/2010	23	-1.98	-5.78
794	-26.95	-48.29	15/06/2010	11	0.04	-5.87
1921	-30.21	-50.12	15/06/2010	26	-1.98	-5.78

1911	-27.34	-48.27	15/06/2010	7	0.02	-7.39
2043	-30.20	-50.12	15/06/2010	21	-1.98	-5.78
1345	-25.95	-48.43	15/06/2010	16	-0.32	-3.57
1371	-30.29	-50.14	15/06/2010	12	-2.18	-6.43
1686	-30.33	-50.19	15/06/2010	12	-2.18	-6.43
1678	-22.66	-41.61	15/06/2010	6	-3.58	-3.03
2202	-23.18	-44.35	15/06/2010	24	-2.89	-2.16
2054	-22.62	-41.55	15/06/2010	13	-3.58	-3.03
1524	-27.39	-48.39	15/06/2010	1	0.02	-7.39
1999	-30.36	-50.16	15/06/2010	9	-2.18	-6.43
1298	-30.21	-50.12	15/06/2010	20	-1.98	-5.78
1990	-22.66	-41.59	15/06/2010	12	-3.58	-3.03
1690	-27.14	-48.36	15/06/2010	5	0.11	-6.58
2064	-24.00	-46.32	15/06/2010	2	-1.67	-2.16



Anexo 5: mapas de distribuição mensal da frota de traineira em atividade de pesca durante a safra de tainha (maio, junho e julho) de 2010 a 2012