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JOSÉ RENATO MENDES DE BARROS CORREIA

RECRUTAMENTO DE PEIXES NO ATLÂNTICO SUL:

experimentação com estruturas de agregação e fatores oceanográficos

Recife

2020

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Tese apresentada ao Programa de Pós-Graduação em Oceanografia da Universidade Federal de Pernambuco, como requisito parcial para a obtenção do título de Doutor em Oceanografia.

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Para Clarissa e Maria Manoela

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RESUMO

O recrutamento é uma fase do ciclo de vida do peixe importante e de difícil estudo pois muitos métodos amostragem são pouco eficazes na captura ou contagem de recrutas, especialmente em ambientes profundos. O presente estudo objetivou avaliar, pela primeira vez, a abundância e diversidade de recrutas de peixes em naufrágios de Pernambuco (Brasil) testando estruturas de agregação de peixes (FAD) e verificar influências de parâmetros oceanográficos no seu recrutamento. Testou-se dois modelos de FADs empregados em pesquisas de recrutamento: unidade de padrão de monitoramento de recrutamento de peixes recifais (SMURF) e recifes artificiais ancorados (ARM). O estudo realizou-se entre 09/2016 a 02/2019 (30 expedições) e comparou a abundância total de recrutas de peixes amostrados nos naufrágios Taurus e Virgo. Considerou-se dois modelos, duas profundidades (fundo e meia-água - 6 metros do fundo) e tempo de imersão do FAD. Testou-se a influência das correntes marinhas na inclinação das estruturas de ancoragem dos FADs. Averigou-se a influência das estações chuvosa e seca, das profundidades, do hidrodinamismo (na região boreste e bombordo do complexo de naufrágios Taurus-Virgo) e de parâmetros físicos e químicos da água sobre a estrutura da assembleia de recrutas enfatizando as espécies mais abundantes. SMURFs amostraram sete vezes mais recrutas de peixes do que ARMs, sem diferença entre as profundidades. Correntes marinhas locais inclinaram as estruturas de ancoragem com SMURFs cerca de 24º, reduzindo em 0,5 m a altura em relação ao fundo. O tempo de imersão avaliado, entre 14 e 28 dias, não influenciou na abundância de recrutas. Não houve diferença no número de recrutas amostrados entre SMURFs de ambas profundidades, entretanto o tamanho dos peixes foi significativamente maior naqueles localizados no fundo. Identificou-se 25 espécies, entre elas sete novos registros em naufrágios no estado: *Decapterus tabl*, *Astrapogon* sp., *Lutjanus buccanella*, *Doratonotus megalepis*, *Stephanolepis hispidus* e *Stephanolepis setifer*. Houve um novo registro para a costa de Pernambuco: *Apogon robbyi*. Cinco espécies contribuíram com 84% de todos os espécimes amostrados. A estrutura da assembleia diferenciou-se entre as estações, onde a abundância total foi maior na estação chuvosa. No entanto, o recrutamento de *Alphestes afer*, *Ste. hispidus* e *Ste. setifer* foi maior nos meses da estação seca, enquanto *Lutjanus chrysurus* e *Sparisoma* sp. recrutaram em picos durante o período chuvoso. *A. afer* e *Sparisoma* sp. foram mais abundantes no fundo, enquanto *S. hispidus* e *S. setifer* preferiram SMURFs a meia-água. A região boreste do complexo de naufrágios Taurus-Virgo mostrou o dobro de velocidades de correntes em relação a bombordo, entretanto sem influência sobre o recrutamento de peixes. As temperaturas médias, registradas com sensores *in loco*, mostraram-se significantemente relacionadas ao recrutamento dos peixes. *L. chrysurus*, *S. hispidus* e *S. setifer* recrutaram mais durante as maiores temperaturas, enquanto *A. afer* e *Sparisoma* sp. recrutaram mais nas menores temperaturas. FADs, principalmente SMURFs, mostraram ser boas ferramentas no monitoramento do recrutamento de peixes e espécies pequenas e crípticas em naufrágios do Atlântico Sul. Esse monitoramento é condição essencial para se determinar, com base ecológica, o afundamento ou não de novas estruturas.

Palavras-chave: FAD. SMURF. ARM. Assentamento. Fatores abióticos. Fatores denso-independentes.

ABSTRACT

Recruitment is an important phase of the fish's life cycle but difficult to study because many sampling methods, are less effective for catching or counting recruits, especially in deep environments. The present study aimed to evaluate, for the first time, the abundance and diversity of fish recruits in shipwrecks in Pernambuco (Brazil). by testing fish aggregation devices (FAD), and to verify influences of oceanographic parameters on your recruitment. Two models of FADs used in recruitment research were tested: standard monitoring unit for the recruitment of reef fish (SMURF) and anchored artificial reefs (ARM). The study was conducted from 09/2016 to 02/2019 (30 expeditions) and compared the total abundance of fish recruits sampled in the Taurus and Virgo shipwrecks. In addition to the models, two depths (bottom and mid-water - 6 meters from the bottom) and immersion time of the FAD were tested. Influence of marine currents on the inclination of the anchoring structures of the FADs was also tested. Influence of rainy and dry seasons, depths, hydrodynamics (at port and starboard sides of the Taurus-Virgo shipwreck complex) and as well as physical and chemical parameters of the seawater were tested on the assemblage structure of recruits emphasizing the most abundant species. SMURFs aggregated seven times more fish recruits than ARMs, with no difference between depths. Local marine currents tilted SMURFs anchorage structures about 24º, reducing by 0.5 m the height in relation to the bottom. Immersion time, between 14 and 28 days, did not influence the abundance of recruits. There was no difference in the number of recruits sampled between the SMURFs of both depths, however the size of the fish was significantly higher in those located at the bottom. Twenty-five species were identified, including seven new records in shipwrecks in the state: *Decapterus tabl*, *Astrapogon* sp., *Lutjanus buccanella*, *Doratonotus megalepis*, *Stephanolepis hispidus* and *Stephanolepis setifer*. There was is a new record for the coast of Pernambuco: *Apogon robbyi*. Five species contributed 84% of all specimens sampled. Recruit assemblage structure was different between the seasons, and the total recruits' abundance was higher in the rainy season. Despite this, recruitment of *Alphestes afer, S. hispidus* and *S. setifer* was higher in dry season months, while *Lutjanus chrysurus* and *Sparisoma* sp. recruited in peaks during rainy season. *A. afer* and *Sparisoma* sp. were more abundant at the bottom, while *S. hispidus* and *S. setifer* preferred mid-water SMURFs. Starboard side of Taurus-Virgo shipwreck complex showed twice the current velocities in relation to Port side, however there was no influence on fish recruitment. Average temperatures, recorded with dataloggers in loco, were significantly related to fish recruitment. *L. chrysurus*, *S. hispidus* and *S. setifer* recruited more at highest temperatures, while recruits of *A. afer* and *Sparisoma* sp. recruited more at lowest temperatures. FADs, especially SMURFs, proved to be good tools in monitoring the recruitment of fish and small and cryptic species in south Atlantic shipwrecks. This monitoring is an essential condition for determining, on an ecological basis, the sinking or not of artificial structures.

Keywords: FAD. SMURF. ARM. Larval settlement. Abiotic factors. Density-independent factors.

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1 INTRODUÇÃO

Os estudos de recrutamento de organismos marinhos demonstraram seu papel fundamental para determinação da estrutura das populações adultas (BOOTH; BROSNAN, 1995), bem como nos demais aspectos ecológicos da sua vida (VICTOR, 1991). Uma vez que um dos principais objetivos dos recifes artificiais é compensar impactos antrópicos causados aos habitats naturais e consequentemente as populações de peixes (CARR; HIXON, 1997), a conceituação dos estágios de vida até recrutamento além dos processos que regulam a chegada e permanência dos recrutas no ambiente recifal pode auxiliar na compreensão da participação ecológica de ambientes artificiais, como os naufrágios, nos ecossistemas marinhos.

1.1 ESTÁGIOS INICIAIS DO CICLO DE VIDA DOS PEIXES E FATORES REGULADORES

A transição do ambiente pelágico para o ambiente recifal, que ocorre no fim do estágio pelágico dos peixes recifais, marca uma importante e arriscada etapa da história de vida do peixe (KAUFMAN *et al.*, 1992). A maioria dos peixes recifais tem um estágio pelágico, normalmente larval, que dura entre 9 e 100 dias, e o estágio considerado bentônico, associado ao substrato recifal, que começa após o assentamento larval durante o recrutamento (LEIS, 1991). O termo assentamento para peixes refere-se à transição entre o fim estágio larval pelágico para um estágio intimamente relacionado à estrutura recifal, no qual a maioria passa por uma distinta metamorfose, com seus corpos desenvolvendo opacidade e cor, formação de escamas e exibindo mudanças comportamentais (VICTOR, 1991). Uma vez que os recifes são os hábitats mais fragmentados e isolados do planeta, o período larval é muito importante pois corresponde à fase de dispersão dos peixes dos ambientes recifais (VICTOR, 1991).

Então, é seguro dizer que o tempo de assentamento (*i.e*. duração do estágio larval, ou “PLD” *Pelagic Larval Duration*) é um dos fatores determinantes para a distribuição geográfica dos peixes recifais. A duração do estágio larval não se diferencia apenas entre táxons, mas também entre diferentes localidades e estações ao longo do ano (LEIS, 1991; VICTOR; WELLINGTON, 2000). Há evidências de que as larvas de alguns peixes da família Haemulidae podem permanecer nos arredores do recife natal, possivelmente por estarem associadas ao seu substrato (LINDEMAN *et al.*, 2001). Algumas espécies das famílias Labridae e Pomacentridae do Pacífico Tropical, apesar de possuírem PLDs superiores a 30 dias, têm faixas de dispersão menor que 6 km (VICTOR; WELLINGTON, 2000).

Muitas espécies são dispersas por transporte larval passivo, influenciado por grandes correntes superficiais, enquanto outras são melhores explicadas devido ao seu comportamento larval atrelado à dinâmica das massas d´água locais (COWEN, 2002). No Hawaii, por exemplo, vórtices foram responsáveis por manter larvas próximas aos recifes (LOBEL; ROBINSON, 1986). Regiões próximas raramente trocam larvas, se localizadas em lados diferentes de uma frente oceânica (GILG; HILBISH, 2003), no entanto dois locais distantes podem ser bem conectados se ligados por uma forte corrente entre eles (MITARAI et al., 2009). Dessa forma, a simples distancia métrica pode não ser um bom fator preditivo para a estruturação gênica pelas trocas larvais (WHITE *et al.*, 2010). Apesar da dinâmica de massas d’água ser um importante fator na dispersão larval, as respostas aos estímulos sensoriais – bem como natação ativa – constituem fatores para definição do local de assentamento. Por exemplo, larvas podem controlar sua posição na coluna por natação ativa (LEIS; CARSON-EWART, 2003) e serem atraídas por estímulos olfativos, auditivos e visuais oferecidos pelos recifes (LEIS; CARSON-EWART; WEBLEY, 2002; MYRBERG; FUIMAN, 2002; WRIGHT *et al.*, 2010).

Em ambientes costeiros, a intensidade do recrutamento de larvas pelágicas de peixes pode ser dependente de um conjunto de variáveis. Os processos biológicos podem incluir migrações nictemerais (LEIS, 1991) e ontogenéticas (SILVA-FALCÃO, 2012), enquanto os físicos abrangem variações nas condições hidrológicas, correntes e marés, que atuam em escalas temporais e espaciais distintas (COWEN, 2002). Além disso, processos denso-dependentes, como a mortalidade, competição e predação regulam a densidade de recrutas nesses ambientes (SHULMAN *et al.*, 1983; SHULMAN, 1985; SHULMAN; OGDEN, 1987).

A variação no sucesso pós recrutamento de peixes pode ser determinante para o tamanho das populações de adultos (JONES, 1990; LEWIS, 1997). Nos recifes do Panamá, a densidade dos adultos da espécie de labrídeo *Thalassoma bifasciatum* refletiu diretamente na densidade de recrutas. O recrutamento dessa espécie correlacionou-se positivamente com as capturas ictioplanctônicas noturnas nos recifes (VICTOR, 1986). A mortalidade pós-assentamento é alta e frequentemente dependente da idade que a larva possuía ao assentar (i.e. assentante tardio ou não) e da quantidade de organismos que assentaram (DOHERTY; SALE, 1986; SCHMITT; HOLBROOK 1999), podendo chegar a 99% (JONES, 1991).

1.2 RECIFES ARTIFICIAIS E A HIPÓTESE “ATRAÇÃO VS. PRODUÇÃO”

Por definição, recifes artificiais são estruturas de origens diversas, posicionadas intencionalmente no fundo do mar para influenciar os processos físicos, biológicos, geológicos ou socioeconômicos dos recursos marinhos (SEAMAN; JENSEN, 2000). Contudo, o uso da palavra “recife” é questionável uma vez que a mesma é utilizada para definir uma estrutura marinha tridimensional de carbonato de cálcio e origem biológica e/ou geológica (PANDOLFI, 2011). Portanto, o uso do termo “hábitat artificial” é mais indicado, pois este define um ambiente artificial povoado por espécies associadas a recifes (SEAMAN; SPRAGUE, 1991; PRATT, 1994). No presente estudo, entretanto, o termo recife artificial será empregado, uma vez que esta terminologia é comumente utilizada na maioria das publicações consultadas. Convém também esclarecer que os recifes artificiais podem ser igualmente classificados como estruturas de agregação de peixes (ou FAD, sigla em inglês para *Fish Agregating Device*), conforme pode se constatar por evidências apresentadas no tópico seguinte desta introdução. Entretanto, o uso do termo estruturas de agregação de peixes ou FAD, será empregado durante o presente trabalho para estruturas ancoradas no fundo do mar, mantidas flutuantes na coluna d’água com auxílio de cordas e boias ou mantidas rente ao fundo.

Por algum tempo, os recifes artificiais foram defendidos como locais de aumento de sobrevivência larval e crescimento de peixes jovens em vista a depleção dos ambientes recifais naturais (BOHNSACK; SUTHERLAND, 1985; BORTONE; SAMOILYS; FRANCOUR, 2000; CONSOLI et al., 2014). No entanto estudos comparativos mostraram que a assembleia de peixes em recifes artificiais é menos diversa em relação aos recifes naturais (CARR; HIXON, 1997), e que naufrágios modificam tanto a fauna de invertebrados bentônicos quanto de peixes recifais no seu entorno (DAVIS; CARLSON; CASELLE, 2018).

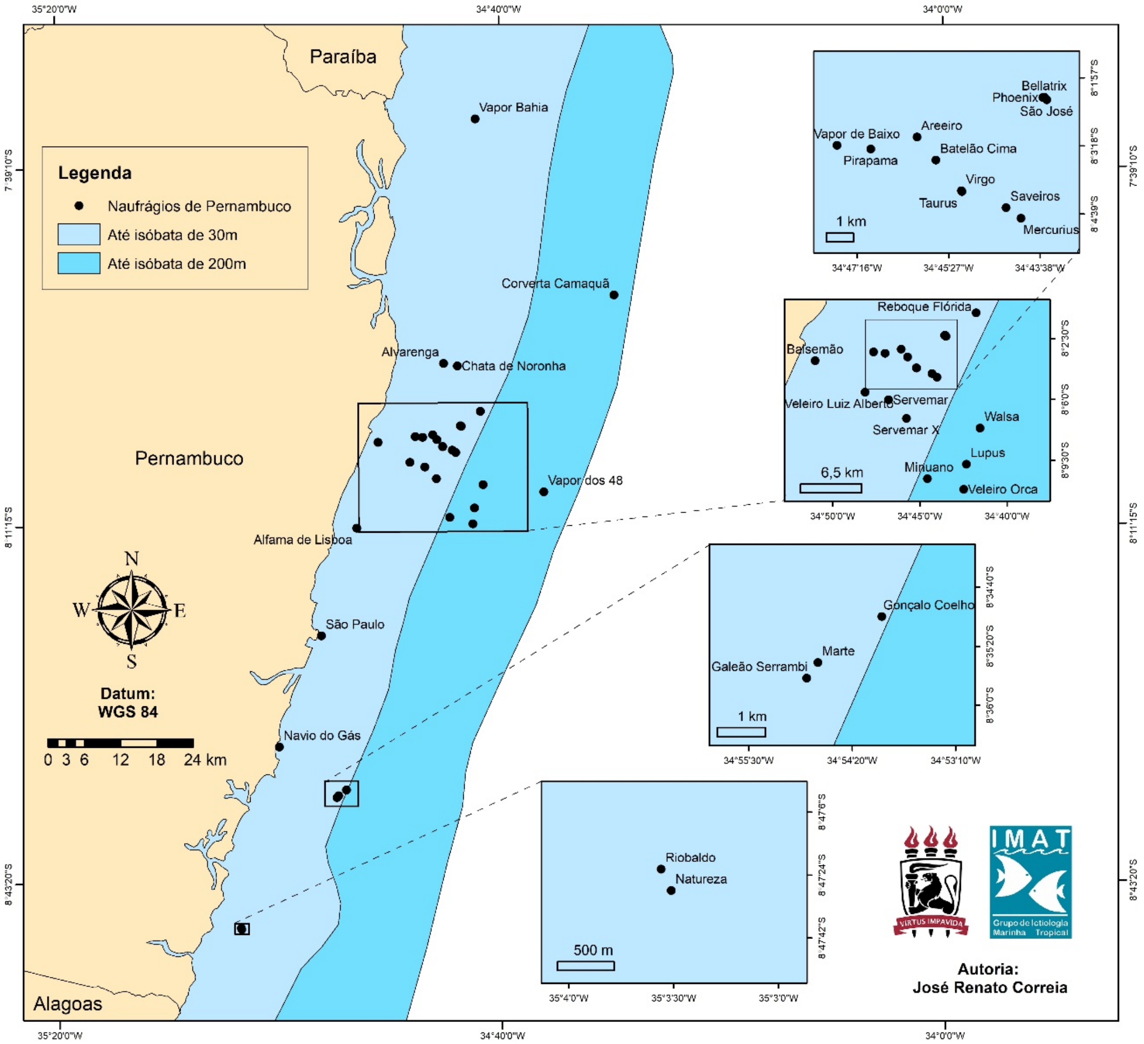
Embora a estrutura trófica das assembleias de peixes em naufrágios no Pacifico Central se assemelhasse a estrutura dos recifes naturais próximos (FOWLER; BOOTH, 2012), na região sudeste do Brasil, recifes de concreto e naufrágios apresentaram maior abundância de carnívoros e predadores de invertebrados móveis em relação aos recifes naturais das ilhas oceânicas, onde foram encontrados maior número de herbívoros (HACKRADT; FÉLIX-HACKRADT; GARCÍA-CHARTON, 2011; SIMON; JOYEUX; PINHEIRO, 2013). A idade dos recifes também mostrou ser um fator de influência na estrutura trófica da comunidade íctia. Quando analisadas as densidades das guildas tróficas, um naufrágio mais velho apontou maior dissimilaridade quando comparados ao naufrágio mais novo (SIMON; JOYEUX; PINHEIRO, 2013).

As dúvidas sobre a função dos recifes artificias permeiam a pesquisa marinha há anos: eles produzem nova biomassa de peixes ou atraem e agregam peixes das áreas adjacentes aos recifes sem aumentar sua biomassa (BOHNSACK, 1989; GROSSMAN; JONES; SEAMAN, 1997)? O problema "atração vs. produção", como ficou conhecido afirma que, na hipótese da atração, os peixes migram ativamente vindos dos recifes naturais, enquanto a hipótese da produção afirma que os recifes artificiais provêm novos hábitats que promovem a sobrevivência de larvas não advindas aos recifes naturais (WILSON *et al.*, 2001).

No Brasil, as informações sobre os estágios de vida iniciais dos peixes nessas regiões são inexistentes, pois os dados ictiológicos em naufrágios são de indivíduos juvenis tardios e adultos (por exemplo, BROTTO; KROHLING; ZALMON, 2006; COXEY, 2008; FISCHER, 2009; HONÓRIO; RAMOS; FEITOZA, 2010; FAGUNDES-NETTO *et al.*, 2011; MARANHÃO, 2011; SIMON, *et al.*, 2013 e BARROS, 2017).

O estado de Pernambuco possui dezenas de naufrágios ao longo de sua costa (Figura 1), concentrados principalmente na isóbata de 20 m (CORREIA *et al.*, 2018). Segundo estudo realizado por Maranhão (2011), os dois naufrágios mais diversos em ictiofauna na costa do estado são o Taurus (95 espécies) e o Pirapama, (92 espécies). Entre eles, as famílias Carangidae, Epinephelidae, Labridae e Pomacentridae foram mais representativas na assembleia de peixes do Taurus, enquanto Haemulidae, Lutjanidae e Scaridae nas assembleias do Pirapama. Entretanto, o mesmo estudo não indicou diferenças entre densidades de categorias tróficas.

Figura 1 – Principais naufrágios do Estado de Pernambuco



Fonte: O Autor (2020).

A região onde a maioria dos naufrágios ocorrem, possui condições ambientais favoráveis na maior parte do ano, com águas que possuem visibilidade horizontal chegando a > 30 m (SANTOS *et al.*, 2010; MARANHÃO, 2011) e águas quentes com temperatura média > 27ºC (SANTOS *et al.*, 2010). Essas condições ambientais, além da existência da lei estadual 23.394/2001 que proíbe a caça submarina e pesca de linha e anzol nas áreas próximas a esses recifes artificiais (PERNAMBUCO, 2001), tornam a costa deste estado um local adequado para pesquisas ecológicas em naufrágios (COXEY, 2008).

Carr e Hixon (1997) esclarecem que, para se compreender a função de ambientes artificiais, é preciso investigar sobre o transporte larval, assentamento, as diferentes fases do crescimento e mortalidade de indivíduos. Dessa forma, o uso de estruturas de agregação de recrutas, como mostrado acima tem dado bons resultados em estudos, particularmente sobre as fases de assentamento e recrutamento. Entretanto, por questões logísticas e de segurança contra mares agitados, os FADs têm sido colocados em regiões rasas (LEIS; CARSON-EWART; WEBLEY, 2002).

1.3 O USO DE ESTRUTURAS DE AGREGAÇÃO NA BUSCA DE PADRÕES DE RECRUTAMENTO DOS PEIXES

Por muito tempo, o uso de redes de arrasto e de cerco, além de armadilhas de luz foram os métodos mais utilizados no estudo das fases iniciais do ciclo vida dos peixes para amostragem de larvas em estágios iniciais e tardios (CHOAT *et al.*, 1993). Essas técnicas, utilizadas ainda nos dias atuais, identificam com bastante precisão padrões de ocorrência para esses intervalos de idade larval (SILVA-FALCÃO; SEVERI; ARAÚJO, 2013; GRANDE *et al.*, 2019). Entretanto, as diversas fases que passam os peixes, entre a vida larval pelágica até o completo recrutamento (revisado em ADAMS *et al.*, 2006), estão sujeitas a processos regulatórios denso-independentes e denso-dependentes (LEIS; MCCORMICK, 2002), que fazem com que o número final de recrutas seja bem menor que o aporte de estágios larvais iniciais e tardios para cada ambiente (DOHERTY *et al.*, 2004).

Estruturas artificiais podem também atrair e agregar peixes em estágios iniciais (WALSH, 1985; KINGSFORD, 1993). Estes se valem da proteção e novos hábitats formados pelas estruturas, que atenuam processos denso-dependentes que ocorrem pós-assentamento (AMMAMM, 2004). A partir dessa constatação, surgem os primeiros FADs voltados para estudo desses estágios, sendo os primeiros desenvolvidos por Schroeder (1987) para o ambiente bentônico e Beets (1989) para a coluna d'água. Posteriormente, aglutinações de ambos modelos surgiram para uso suspenso na coluna d'água por Leis, Carson-Ewart e Webley (2002) e Paiva *et al.* (2015). Um modelo, com semelhanças estruturais aos FADs de Schroeder (1987) e de Beets (1989), foi desenvolvido por AMMANN (2004), que aumentou a complexidade estrutural e criou o SMURF (*Standard Monitoring Units for Reef Fishes*). Este se tornou amplamente utilizado em diversos estudos pelo mundo, por exemplo: BEN-DAVID; KRITZER, 2005 em Belize; SIDDON; SIDDON; STEKOLL, 2008 no sudeste do Alaska; WHITE; CASELLE, 2008 no sudoeste dos EUA; SHIMA; SWEARER, 2009 na Nova Zelândia; KLEIN *et al.*, 2018 em Portugal. Outros modelos foram desenvolvidos para o uso bentônico fixo ao fundo (STEELE *et al.*, 2002; VALLÈS; KRAMER; HUNTE, 2006), que foram relacionados com comunidades de recrutas distintas das observadas a modelos suspensos (KLEIN *et al.*, 2018).

Por meio do uso dos FADs, padrões de recrutamento foram estimados em diversas espécies de peixes (AMMANN, 2004; VALLÈS; KRAMER; HUNTE, 2008) e estes foram relacionados ao aporte larval (WHITE; CASELLE, 2008), eventos de ressurgência (WILSON *et al.*, 2008; KLEIN *et al.*, 2018; OTTMAN *et al.*, 2018), fases lunares (VALLÈS; KRAMER; HUNTE, 2006 e 2008; VALLÈS; HUNTE; KRAMER, 2009), amplitudes de marés (VALLÈS; HUNTE; KRAMER, 2009) e correntes e vórtices marinhos (SELKOE *et al.*, 2006; SHULZITSKI, K. *et al.*, 2018).

Nos estudos para se verificar a participação dos naufrágios na ecologia da ictiofauna marinha há necessidade de utilização de novos parâmetros biológicos, dessa forma o uso de FADs em naufrágios poderá aliar a frequência e facilidade metodológica proporcionada pelos censos visuais com as vantagens de coletas de indivíduos existentes nas práticas com redes de arrasto uma vez que o uso destas nesses ambientes necessitaria de equipamentos motorizados para manter velocidades relativamente altas e constantes de modo a impedir a fuga dos organismos-alvo, neste caso recrutas de peixes. Para isso a presente pesquisa testará as hipóteses a seguir.

1.4 HIPÓTESES

a) Há diferença na abundância de recrutas de peixes amostrados por modelos de FADs.
b) Há diferença na diversidade e abundância de recrutas de peixes relativos à profundidade; coluna d’água e fundo.
c) Há sazonalidade no recrutamento de peixes.
d) Há influência de fatores oceanográficos no recrutamento de peixes.

1.5 OBJETIVOS

Os objetivos desta tese visam pavimentar o conhecimento sobre recrutamento de peixes em ambientes marinhos de naufrágios profundos no Atlântico Sul, aplicando técnicas mais recentes de amostragem para essa fase de vida dos peixes relacionando-a com fatores oceanográficos, além de sugerir protocolos para aplicação dessas técnicas nesses ambientes.

1.5.1 Geral

Avaliar a abundância e diversidade de recrutamento de peixes utilizando estruturas de agregação de peixes (FAD) em recifes artificiais da costa do Brasil (Atlântico Sul) e relacioná-las com fatores biótico e abióticos.

1.5.2 Específicos

a) Testar e comparar a eficiência de modelos diferentes de FADs na abundância de recrutas amostrados;
b) Testar e comparar a abundância e tamanho de recrutas amostrados com FADs em diferentes profundidades da coluna d'água;
c) Comparar a abundância de recrutas amostrados em diferentes tempos de imersão de FADs;
d) Determinar a composição e abundância de recrutas amostrados em FADs próximos a naufrágios do estado de Pernambuco;
e) Determinar as características, batimétricas, hidrodinâmicas e hidrológicas no entorno dos naufrágios estudados;
f) Testar e comparar a composição e abundância da comunidade de recrutas nos dois bordos do complexo de naufrágios Taurus-Virgo;
g) Testar e comparar a composição e abundância da comunidade de recrutas nas estações de estiagem e chuvosa;
h) Comparar composição e abundância da comunidade de recrutas nas estações de estiagem e chuvosa;
i) Testar e comparar a influência de variáveis oceanográficas na composição e abundância da comunidade de recrutas.

1.6 ESTRUTURA ORGANIZACIONAL DA TESE

Esta tese está organizada em Capítulo 1 referente a Introdução Geral que aborda os principais conceitos necessários à sua compreensão referentes a temática das fases iniciais de vida dos peixes de recifes. Ela também faz uma revisão sobre o uso das estruturas de agregação de peixes nas pesquisas de recrutamento e também avalia as vantagens e desvantagens no uso de recifes artificiais na ecologia marinha. A Introdução Geral é finalizada com os Objetivos Gerais e Específicos desta tese.

O capítulo 2, intitulado “Using aggregating devices to sample fish recruits around deep shipwrecks: experiments and suggestions”, é um artigo aceito pela Revista do Laboratório de Ciências do Mar, com publicação prevista para o próximo mês. Nesta pesquisa, testa-se as estruturas de agregação de peixes (FAD) na amostragem de recrutas pela primeira vez tanto em ambientes tropicais no Atlântico Sul, quanto em locais profundos de mar aberto.

O capítulo 2 traz ainda sugestões - por meio de extensa pesquisa bibliográfica e experimentação - acerca de uso de FADs na pesquisa dos estágios iniciais de vida dos peixes. É apresentado um histórico metodológico das pesquisas mundiais envolvendo FADs na amostragem de recrutas de peixes, a fim de se conhecer as variações estruturais dos equipamentos e das profundidades de implementação da técnica. Também estão indicados os procedimentos operacionais padronizados para a sua instalação em regiões próximas a naufrágios da plataforma continental do nordeste do Brasil.

O capítulo 2 também apresenta a modelagem numérica decorrente dos experimentos que foram realizados em uma piscina para indicar as possíveis influências oceanográficas sobre as estruturas implementadas no mar. Além desses testes, é demonstrada a experimentação realizada *in loco*, tendo sido testandas as estruturas de agregação, suas diferentes posições em termos de profundidades e tempos de permanência na água diferentes, criando-se um arcabouço para o capítulo seguinte.

O capítulo 3, intitulado “Spatio-temporal variation of fish recruitment in the south Atlantic: implications of oceanographic conditions”, é um artigo e tem finalidade ecológica, listando as espécies dos recrutas coletados e identificando-se as relações entre a diversidade e abundância encontradas, incluindo os variados parâmetros oceanográficos coletados utilizando CTD, correntômetros e datallogers instalados *in situ*.

Através de experimentos de longa-duração, utilizando FADs do tipo SMURF, e da identificação das espécies coletadas, o capítulo 3 buscou responder se a comunidade de recrutas está estruturada por profundidade e/ou sazonalidade de estações e quais espécies foram responsáveis que causaram esses estruturação. Também se investiga a influência dos parâmetros oceanográficos (temperatura, salinidade, concentração de clorofila, saturação de oxigênio, turbidez e hidrodinamismo) na comunidade de recrutas. Por fim, o padrão de recrutamento entre as espécies mais abundantes foi traçado, indicando se houve relação com sazonalidade de estações e entre os parâmetros oceanográficos mais significantes para a comunidade.

2 USING AGGREGATING DEVICES TO SAMPLE FISH RECRUITS AROUND DEEP SHIPWRECKS: EXPERIMENTS AND SUGGESTIONS

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Situação: artigo aceito pela revista “Arquivos de Ciências do Mar”

ABSTRACT

Fish aggregating devices (FAD) are an ancient fishery technique that benefits from the gregarious behavior of many species. They represent alternatives to usual census approach to study fish recruits. Based on this, we test two FAD models built for fish recruitment research, Standard monitoring unit for the recruitment of reef fishes (SMURF) and Artificial Reef Mooring (ARM) moored for the first time close to deep shipwrecks in Brazil Northeastern coast. We compared fish recruits' abundance sampled by both models at two depths, bottom and mid-water (6 meters from the bottom). SMURFs sampled seven times more fish recruits than ARM with no difference between depth. We discovered that SMURFs mooring tilted 24º in mean with local marine currents. A long-term study with SMURFs tested immersion time influence in recruit's sampling, and explored recruit's abundance and standard length at two depth from the bottom. Increasing immersion time from 14-28 days did not influence recruit's abundance. Bottom and Mid-water SMURFs sampled equal recruit's number and fish sizes were significantly larger at the bottom. FADs, specially SMURFs, showed good tool to sample fish recruits in deeper shipwrecks, however standardization of FAD deployment is indicated to maximize work time and security in unstable sea conditions.

Keywords: SMURF; ARM; artificial reefs; reef fish; fish recruitment

INTRODUCTION

Fish Aggregating Devices (FADs) are instruments used for centuries by artisanal fishermen to attract fish and facilitate your capture (NATIONAL RESEARCH COUNCIL, 1988). A historical review of these devices found that the earliest known use of FADs dates back to 200 AD in the Mediterranean, and that it has also been used for hundreds of years by traditional fishermen in Japan, Indonesia, Malaysia and the Philippines (DEMPSTER; TAQUET, 2004) This fishery is known for names such as "kannizzati", "capcer" and "'cannizzi" in Mediterranean (GALEA, 1961; MORALES-NIN *et al.*, 2000), and the FADs known as "tsuke" in Japan (FRANCOIS, 1991), "rumpon" in Indonesia and "unjang" in Malaysia (BERGSTROM, 1983) and "payao" in Philippines (MURDY, 1980). Their constructions were (and still are) basically made by vegetal material such as trunks and trees, bamboo, palm leaves, cork, grass (GOODING; MAGNUSON, 1967; NATIONAL RESEARCH COUNCIL, 1988; DEMPSTER; TAQUET, 2004).

This technique makes use of the behavior of many species that remain aggregated and seek shelter, protection, and places for reproduction or feeding (SOEMARTO, 1960; GOODING; MAGNUSON, 1967; HUNTER; MITCHELL, 1967), although the food is not necessarily obtained from fouling organisms in the FAD (IBRAHIM *et al.*, 1996). This characteristic of fish attraction to floating objects was called "thigmotropism" in fish (IBRAHIM *et al.*, 1996).

The use of FADs on the mature fish ecology became common (ALEVIZON; GORHAM, 1989; DEUDERO *et al.* 1999), but to study fish early stages, FADs provided a much larger advance given the difficulty of capturing small individuals (WALSH, 1985). Schroeder (1987) used FADs for the first time in research focusing exclusively for young fish. Your system allowed select individuals' sizes, as well as facilitate your collection.

The "Schroeder's basket", as it was called, was used for the first time as moored and floating devices to characterize the different young fish communities at different depths (LEIS; CARSON-EWART; WEBLEY, 2002). Ammann (2004) developed the Standard Monitoring Units for Reef Fishes (SMURFs) that resembled the Schroeder's basket, but with your interior composed of randomly folded nets, enabling greater complexity than the previous FAD model. The SMURF model followed being used from temperate to tropical environments (for example CASELLE; WARNER, 1996; BEN-DAVID; KRITZER, 2005; CASELLE; KINLAN; WARNER, 2010). Also, with the purpose of studying the recruitment of coral reef fish, were developed versions of the SMURFs fixed to the bottom and composed by fragments of corals and/or rocks, known as "benthic collectors" (STEELE *et al.*, 2002; VALLES; KRAMER; HUNTE, 2006).

Differences in post recruitment success of fish may be due to own species characteristics, and also due to geographic location, water mass displacement carrying eggs and larvae and inherent characteristics of the species (SHULMAN, 1985; SHULMAN; OGDEN, 1987; SHULMAN et al., 1983). Those factors determine the size of adult populations (JONES, 1990; LEWIS, 1997).

On the exposed, the goals of this study were to optimize FAD deployment at deeper depths on open waters and to compile published data around fish recruitment using FADs. It was done, also, an experimental (*in loco*) designs to identify 1) the efficiency of different FADs models to sample fish recruits, 2) the abundance of fish recruits and recruit sizes sampled by the most efficient FAD model between two depths, 3) the influence of FAD immersion time in recruits sampling and 4) the influence of ocean currents hydrodynamics on the FADs moorings.

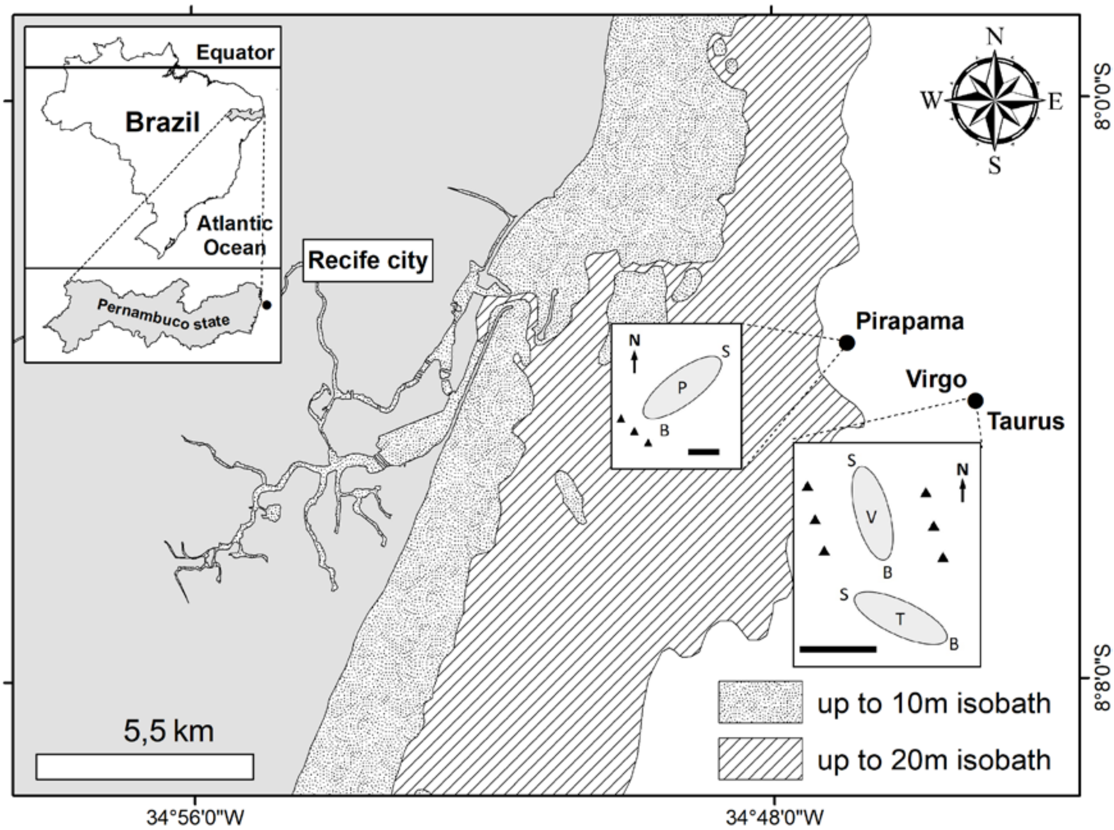
MATERIALS AND METHODS

Study area

The study took place in shipwrecks in the coastal area from Pernambuco State (Northeastern Brazil), located between 9-13 km away from the port of Recife city (Figura 1). The shipwreck Pirapama (8°3'23.00"S and 34°46'58.00"W), sunk in 1889, incidentally, measures 60 m total length, is located 21 m depth and is oriented with the bow facing Southwest (SANTOS *et al.*, 2010) (Figura 1, inset). The shipwrecks Taurus and Virgo (8°4'11.58"S and 34°45'11.76"W) with approximately 25 m total length were sunk deliberately to 25 m depth, in 2006 (SANTOS *et al.*, 2008) and 2017 (CORREIA *et al.*, 2018), respectively. They form a complex of artificial reefs, with the wrecks separated each other by 9 m. This distance was measured in situ using measuring tape in December 2017. In December 2018, a bathymetric model using single-beam echo sounder data was built and confirmed this measurement (CORREIA *et al.*, *in prep.*, also Chapter 3). The bow of the Taurus faces East-Southeast (E-SE) and the bow of the Virgo faces South-Southeast (S-SE) (Figura 1, inset).

Regional tides are semi-diurnal, ranging from 1.5 to 3 m at neap and spring periods, respectively. Shelf currents are mainly driven by winds. Wind is predominantly easterly, being strongest between August to October, when the currents are strongest and northwards. Between January and March, the wind relaxes, and the shelf currents are sluggish southwards. Shelf waters are dominated by Tropical Water, with salinity >36.5 psu and temperature >26 °C (SCHETTINI *et al.*, 2017).

Figura 1 - Location of studied shipwrecks regions and 10 to 20 m isobaths and positioning of the three FADs supporting structures (triangles) related to bow (B) and stern (S) of shipwrecks Pirapama (P), Virgo (V) and Taurus (T).



Fonte: O Autor (2020)

Compilation of fish recruitment researches using FAD

To access published information on the use of FADs in the study of fish recruitment it was conducted surveys in online databases. These surveys were gathered in spreadsheets to visualize the following information: FADs models, dimensions of FADs, volume of FADs (informed or calculated by dimensions), depth of study area, maximum and minimum sampling depths with the FAD and the diving method used in the samplings.

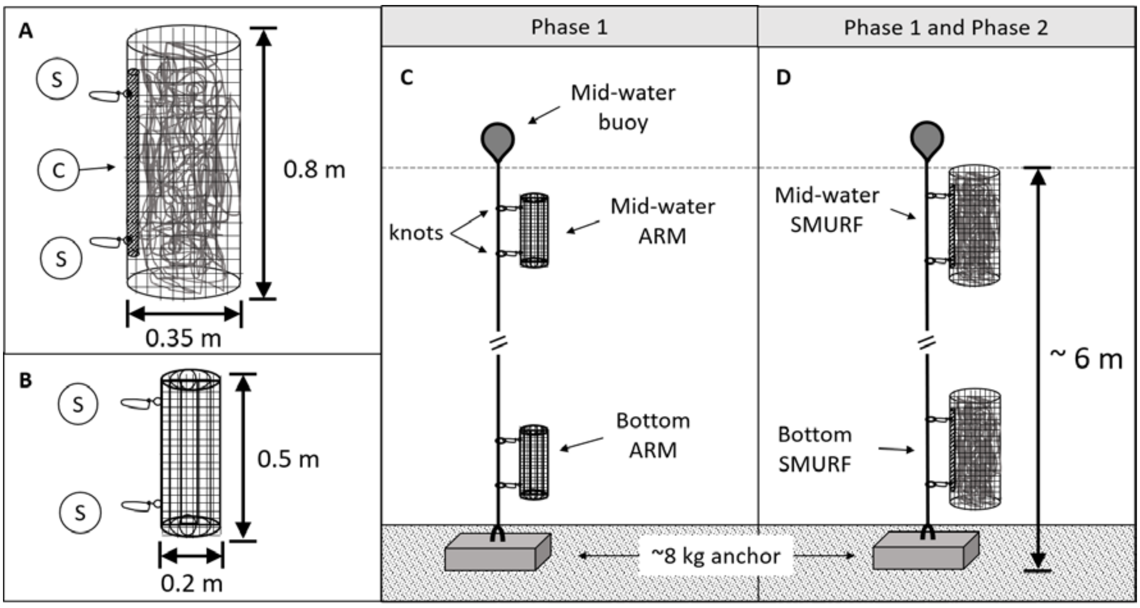
FAD structures and mooring set-ups

This research was conducted using two FAD models: ARM (Artificial Reef Mooring) and SMURF. ARM model was modified from Schroeder (1987). It was successfully used by Leis, Carson-Ewart e Webley (2002) and its name created by Paiva *et al.* (2015). The structure of the ARMs was composed of a spiral cylindrical frame (0.6 m length x 0.20 m diameter) of black fencing plastic net with mesh size of 2 x 2 cm and stainless-steel snap-clips tied to frame (Figura 2B and 2C. SMURFs model was modified from Ammann (2004). It was composed of a closed cylindrical frame (0.8 m length x 0.35 m diameter) of black plastic fencing net with mesh size of 2 x 2 cm and filled with a, randomly folded, piece of 9.0 x 1.2 m of a malleable and orange plastic net with mesh size 5 x 7 cm (Figura 2A and 2D) with a neutral buoyancy.

The SMURFs models in this study were constructed with a spinal cord made of a 20 mm PVC pipe where stainless-steel snap-clips were tied, to maintain format and volume of the frame against local marine currents.

In the field, the ARMs and SMURFs were moored with a structure composed of anchor, rope and mid-water buoy to ensure that they remained mid-water suspended at a maximum of 6 meters above the sandy bottoms (Figura 2C and 2D, respectively). Two SMURFs were fastened per mooring, being one on the bottom and one 6 meters above. Three moorings were positioned near the shipwrecks: the bow of the wreck Pirapama, port side and starboard of the wreck Virgo.

Figura 2 – FADs models' schematic drawing. (A) SMURF showing the spinal cord (circled C) made of 20 mm PVC pipe and the two stainless steel snap-clips (circled S) used to clip in mooring rope. (B) ARM showing two stainless steel snap-clips (circled S) also used to clip in mooring rope. (C) ARMs and (D) SMURFs mooring (anchor, rope and mid-water buoys) used in experiments of Phase 1, comparison between the ARMs and SMURFs from Mid-water and Bottom, and Phase 2 immersion time experiment.

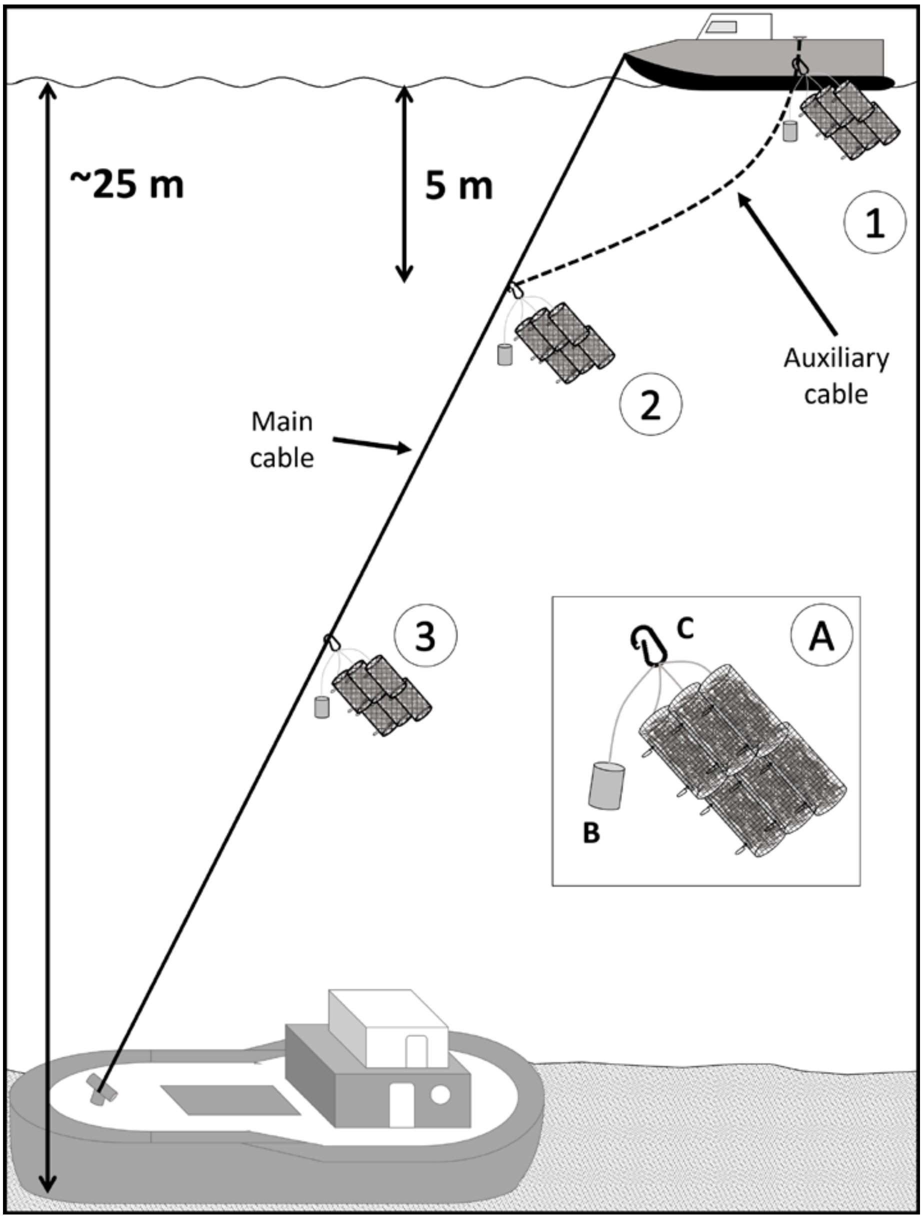


Fonte: O Autor (2020)

Depending on winds, Pernambuco coastal waters can change from calm and clear to turbulent and turbid. To prevent drag and loss of FAD's structures, the moorings were connected by 10m coated steel cables attached to the anchors, separated 10 meters from each other and 10 meters from shipwreck.

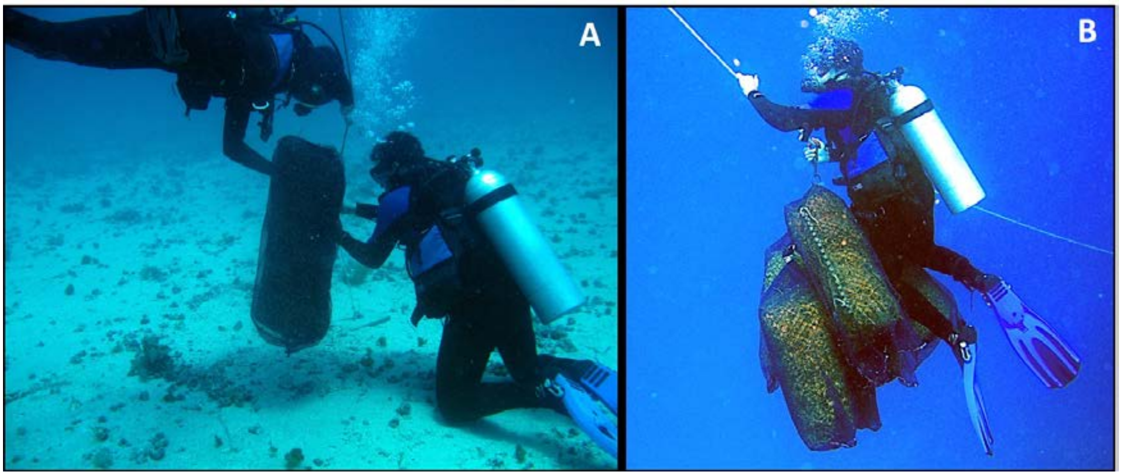
To deploy the FADs on the moorings close to the shipwrecks, FADs were packed into six-FADs-group that was clipped to an auxiliary cable, positioned at the side of support boat (Figura 3). With an attached diving ballast aid, the group sunk until the connection of the auxiliary cable to the main cable (where which support boat was tied to shipwreck) 5 m below surface, and a diving security stop zone as well. There, the set of FADs waited until three divers where in the water. Then divers conducted the arrange by the main cable to shipwreck deck. Arriving at wreck deck, six-FADs-group was unclipped from main cable, divided two FADs per diver and all divers swam to the same mooring position to proceed FADs collection and changing (Figura 3A). After FADs collection divers returned with a collected six-FADs-group trough the main cable (Figura 4B), executed a security stop at 5 m, switched to auxiliary cable and proceed to support boat. This methodology was used to increase security of divers and to prevent drifting from the boat due sudden wind driven superficial currents formed by climatic instability in the region.

Figura 3 – FADs deployment in water. (1) A six-FADs-group clipped to an auxiliary cable, positioned at the side of support boat, and then (2) sunk until 5 m. (3) six-FADs-group being conduct by the main cable, which connected support boat to shipwreck deck. FADs lifting occurred in reverse order (3) to (2) to (1). *SMURF used for example. ARMs deployment occurred similarly. Figure inset (A): A six-FADs-group (arranged 2 by 2) and tied in a (C) 1-ton carabiner and a (B) 3 kg diving ballast.



Fonte: O Autor (2020)

Figura 4 – Divers involving and collecting SMURFs with cylindrical net with 5 mm of mesh size (A). Divers returning to surface by the main cable with collected six-FADs-group (B).



Fonte: O Autor (2020)

Pilot experiment

To test the handling feasibility, durability of structures and ability to sample specimens at deeper regions, a pilot test was run with the FAD model SMURF. This run also served to deploy all the moorings used in subsequent experiments. Three moorings were positioned in three regions near the shipwrecks: bow of the wreck Pirapama, port side and starboard of the shipwreck complex Taurus-Virgo (Figura 1, inset triangles), 10 meters separated each other. Immersion intervals ranged 14 to 109 days, from September 2016 to March 2017. SMURFs were collected individually with a cylindrical net with 5 mm of mesh size and specimens were counted, measured and preserved in alcohol 70%.

FADs model comparison - Phase 1

In this first phase, the objective was to compare the efficiency to sample the recruits between SMURFs and ARMs. At sea, the support structures mounted for pilot experiments were used to position two SMURFs (Figura 2B) and two ARMs (Figura 2C). Each model of FAD was positioned: one in bottom and other in 6 m from the bottom in the same areas of pilot study. The immersion time until the collection ranged between 13 and 32 days and occurred between the months of March and June 2017. SMURFs and ARMs were collected individually with a cylindrical net with 5 mm of mesh size and specimens were counted, measured and preserved in alcohol 70%.

Long-term experiments – Phase 2

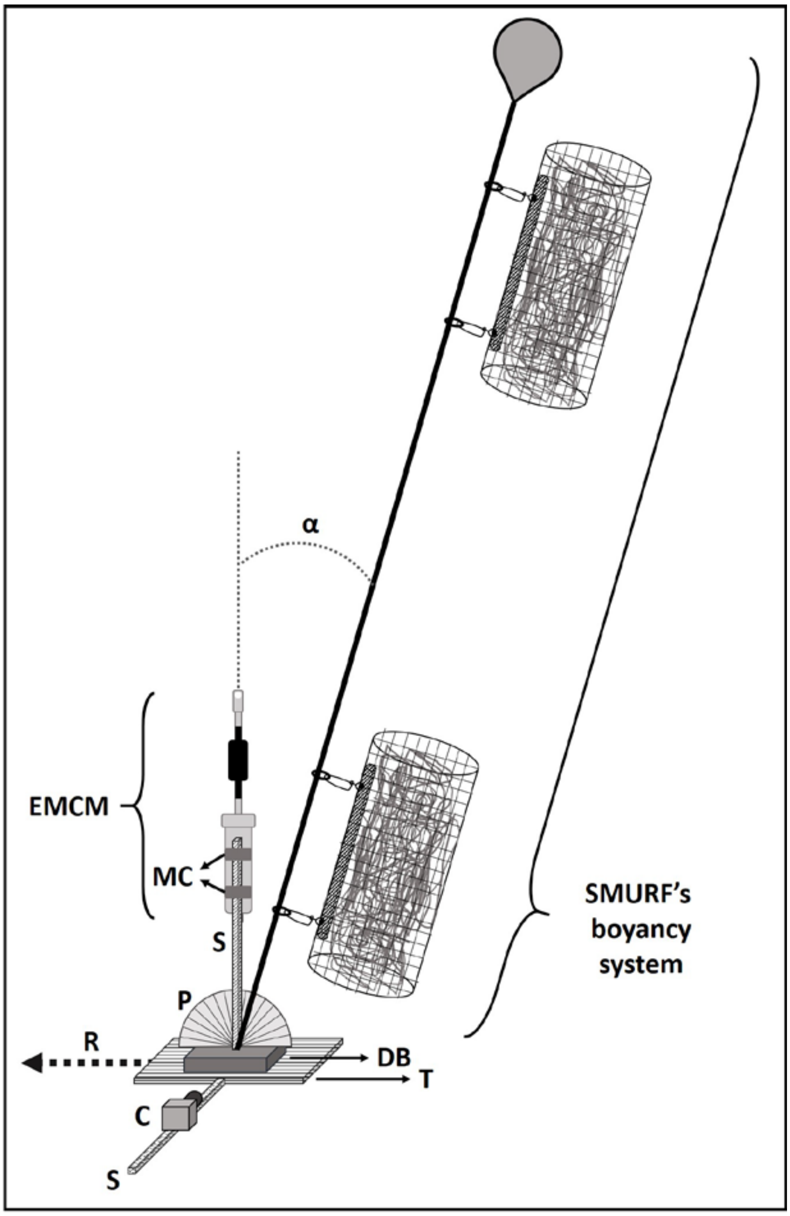
In phase 2, the objective was to perform long-term study in the Taurus-Virgo shipwreck complex to identify the relation between SMURF immersion time and recruit abundance per SMURF. We also identify the influences of depth (bottom and mid-water, see Figura 2) over fish recruit abundance and sizes. The immersion time until the collection ranged between 14 and 28 days and occurred from October 2017 to February 2019. The SMURFs collections and specimen's processing were exactly the same as Phase 1.

Hydrodynamic measurements and flow effects on the SMURFs

The FADs structures, especially SMURFs, produced drag and the mooring tilted with currents. To investigate the effects of the flow on the mooring and its efficiency regarding the level of each trap, an experiment was performed to measure how the mooring tilt with currents (Figura 5). A SMURF mooring was set up in a diving pool with ~5.5 m at the deepest part, and ~12 m wide (we tested only SMURFs because they produce more drag than ARMs). The mooring was on a sled, where there was also an electromagnetic current meter (EMCM) recording at 1 s interval, at ~0.5 m above the bed, a protractor aligned with the mooring rope, and an underwater video recording camera. The sled was trawled across the pool at nearly constant speed each time, in a total of 8 trawls. The mean angle and mean velocity were averaged for each trawl. The data was plotted on a polynomial regression.

To assess the temporal efficiency, it was used a data set of currents recorded at 25 m deep nearly 18 km south from the wrecks. These data were recorded with an acoustic Doppler current profiler (by Nortek A/S model Aquadopp Current Profiler of 1,000 kHz) at hourly intervals between 2 June and 19 October 2011, and with 1 m of vertical resolution (SCHETTINI *et al.*, 2018). The lowest 5 beans were depth-averaged to give the frequency of current velocities at the bottom layer where the SMURFs were positioned. Bottom currents frequency were related with tilt angle polynomial equation to find mooring tilt angle frequency with local currents.

Figura 5 – SMURF buoyancy system tilt angle (α) experiments on diving pool. SMURF's set up mounted on non-magnetic frame constructed with a wooden tray (T), protractor (P) and sticks (S) holding electromagnetic current meter (EMCM) fixed by non-magnetic metal clamps (MC) and a video camera (C). Diving ballast (DB) maintained frame on pool bottom and a rope (R) was used to push the frame and create a flow.



Fonte: O Autor (2020)

Data analysis

We analyzed the data from Phase 1 experiments (FADs model comparison) considering the abundance of recruits per FAD. Although data from Phase 1 passed in Levene's test (p=0.117) they were not normal in Kolmogorov Smirnov's test (p<0.05) so we compared data through Multifactorial GLM analysis to test FAD models, Depth and interactions (α = 0.05).

Phase 2 data, recruits sampling and recruits' sizes per depth, were not normal in Kolmogorov Smirnov's test (p<0.05), so we tested then through Mann-Whitney Rank Sum Test (α = 0.05). We performed a linear regression of the log10 transformed recruit samples per FAD and immersion time to investigate if increasing FAD time in water would affect recruit sampling. All statistical analysis and graphs were created in Sigmaplot 11 (Systat Sofware).

RESULTS

Compilation of fish recruitment researches using FAD

Comparing the 31 studies that collected fish recruits with FAD's methods (Tabela 1), approximately 71% used SMURF, 19% Benthic collector, 10% ARM, and 39% did not give the information about the FADs used. Only 10% installed FADs at depths below the basic dive limits of 18 m. Concerning the dive method used in the FAD collections, only 10 of them reported it, and 60% of these studies using Scuba.

Tabela 1 – Characteristics of devices and studied areas, and device collection methods used in fish recruitment research with FAD. FADs models (ARM, Benthic collector and SMURF) were used to devices with construction similar to Schroeder (1987), Valles, Krammer and Hunte (2006) and Ammann (2004), respectively. Symbols legends: (?) unclear information; (-) nonexistent information. The complete reference is in literature cited.

Study	FAD model[a]	Radius (m)	Height (m)	Informed or calculated FAD volume (m³)	Area depth (m)	Sampling depth (m)		Diving method
						Min	Max	
SCHROEDER, 1987	ARM	0.10	0.30	0.01	10	3	6	-
LEIS; CARSON-EWART; WEBLEY, 2002	ARM	0.10	0.30	0.01	15	7	13	-
PAIVA *et al.*, 2015	ARM	0.10	0.30	0.01	6 to 9	2	7	-
STEELE *et al.*, 2002	Benthic collector	-	-	0.49	7 to 15	7	15	-
VALLES; KRAMER; HUNTE, 2006	Benthic collector	0.30	0.13	0.04	7 to 12	7	12	Scuba diving
VALLES; KRAMER; HUNTE, 2008	Benthic collector	0.30	0.13	0.04	~8.7	~8.7	~8.7	?
VALLES; HUNTE; KRAMER, 2009	Benthic collector	0.30	0.13	0.04	-	-	-	?
ARNEY; FROEHLICH; KLINE, 2017	Benthic collector	-	-	0.03	20	0	20	Scuba diving
MILLER; VALLÈS; OXENFORD, 2014	Benthic collector	0.30	0.13	0.04	3 to 20	3	20	Scuba diving
STEELE *et al.*, 2002	SMURF	0.15	0.90	0.06	7 to 30	5	5	-
AMMANN, 2004	SMURF	0.18	1.00	0.10	18 to 19	1	19	Snorkelling and Scuba diving
LUZIER; WILSON JR, 2004	SMURF	-	-	-	-	-	-	-
BEN-DAVID; KRITZER, 2005	SMURF	-	-	-	2 to 5	?	?	-
SELKOE *et al.*, 2006	SMURF	-	-	-	-	-	-	-
STEPHENS *et al*., 2006	SMURF	0.18	1.00	0.10	-	-	-	-
SIDDON; SIDDON; STEKOLL, 2008	SMURF	-	-	-	6 to 8	1	7	Scuba diving
WHITE; CASELLE, 2008	SMURF	-	-	-	15	3	3	-
SHIMA; SWEARER, 2009	SMURF	0.18	1.00	0.10	~6	?	4	-
CASELLE; KINLAN; WARNER, 2010	SMURF	0.18	1.00	0.10	4.5	1.5	1.5	-
TAVERNETTI; MORGAN; YU, 2009	SMURF	0.18	1.00	0.10	4.5	1.5	1.5	-
CREAN; SWEARER; PATTERSON, 2010	SMURF	-	-	-	-	-	-	?
KOHN; CLEMENTS, 2011	SMURF	-	-	-	-	-	-	-
LOTTERHOS; MARKEL, 2012	SMURF	0.18[b]	1.00[b]	0.10[b]	6 to 18[b]	1	2	-
SHIMA *et al.*, 2012	SMURF	-	-	-	3 to 6	1	4	-
JONES; ANDERSON; EDWARDS, 2013	SMURF	-	-	-	-	-	-	?
MORTON; SHIMA, 2013	SMURF	-	-	-	4 to 6	2	4	Scuba diving
JONES; MULLIGAN, 2014	SMURF	-	-	-	12	1	1	Snorkelling
HAGGARTY; LOTTERHOS; SHURIN, 2017	SMURF	0.18	1.00	0.10	6 to 18	1[c]	2[c]	-
OTTMAN *et al.*, 2016; 2018	SMURF	0.15	1.00	0.07	15	1	1	Snorkelling
OTTMANN; GROROD-COLVERT; SPONAUGLE, 2019	SMURF	0.15	1.00	0.07	15	1	1	Snorkelling
KLEIN et al., 2018	SMURF	0.18	1.00	0.10	12 to 14	1	14	Scuba diving
BAETSCHER et al., 2019	SMURF	-	-	-	-	-	-	Scuba diving

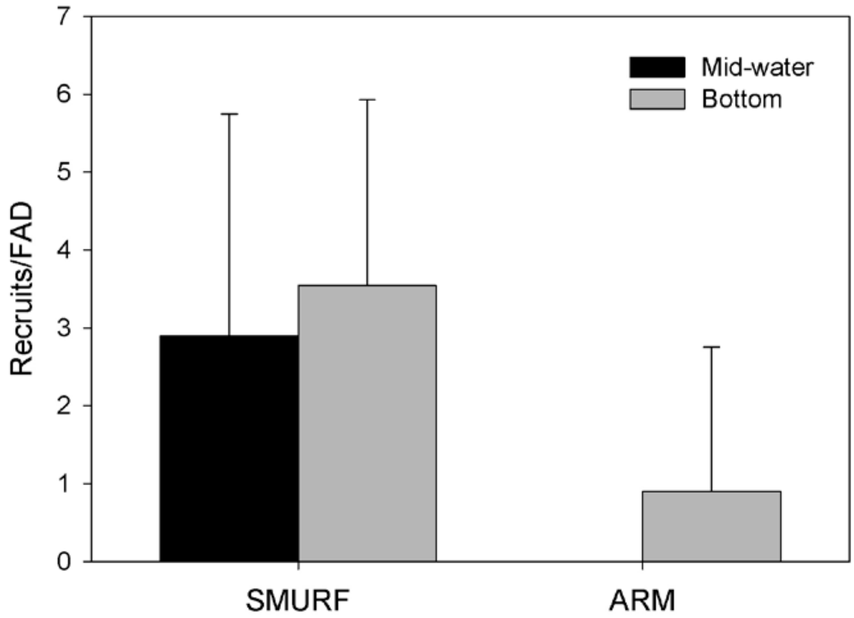
[a]models names given after analysis of device construction inside study methodology
[b]obtained in Haggarty, Lotterhos and Shurion (2017)
[c]obtained in Lotterhos and Markel (2012)

Fonte: O Autor (2020)

FADs model comparison - Phase 1

The FAD model SMURF sampled significantly more recruits (119) compared to ARM which sampled in total only 9 individuals. There were no differences in abundances of recruits sampled at the depths tested for both FADs and no interaction between model and depth (Tabela 2, Figura 6).

Figura 6 – Mean abundance (+standard deviation) of recruits caught with FADs models SMURF and ARM at Mid-water and Bottom depths. No recruits were sampled by mid-water ARMs.



Fonte: O Autor (2020)

Tabela 2 – Multifactorial GLM test of FAD models and depths of deployment and interactions.

Source of Variation	DF	SS	MS	F	*p*
FAD model	1	76.494	76.494	17.155	<0.001
Depth	1	5.941	5.941	1.332	0.256
FAD model x Depth	1	0.161	0.161	0.036	0.850
Residual	36	160.527	4.459		
Total	39	242.775	6.225		

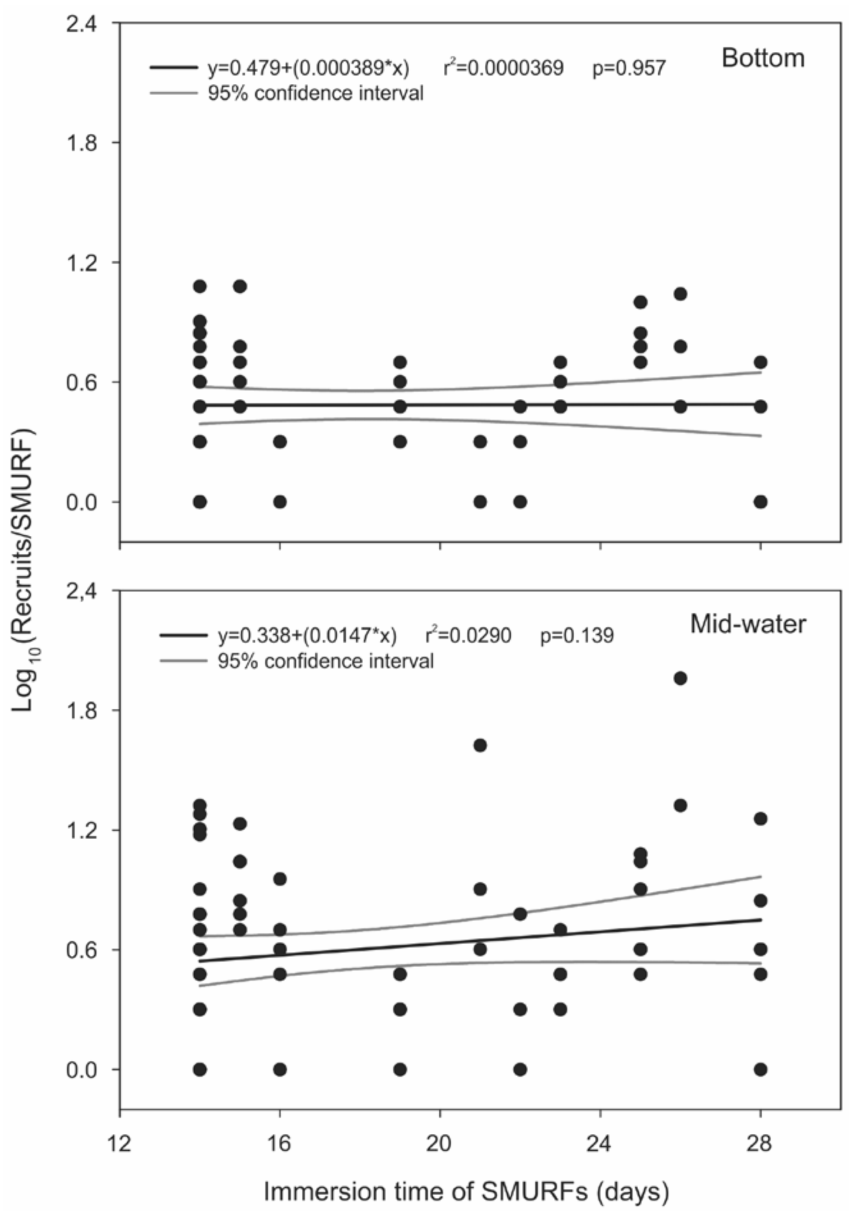
Fonte: O Autor (2020)

Long-term Experiments – Phase 2

Immersion time influence and abundance and sizes of recruits sampled by SMURFs

There was no relation between immersion time of SMURFs and the number of recruits sampled per SMURFs, despite the slight positive angle in linear regression of both depths data (Figura 7).

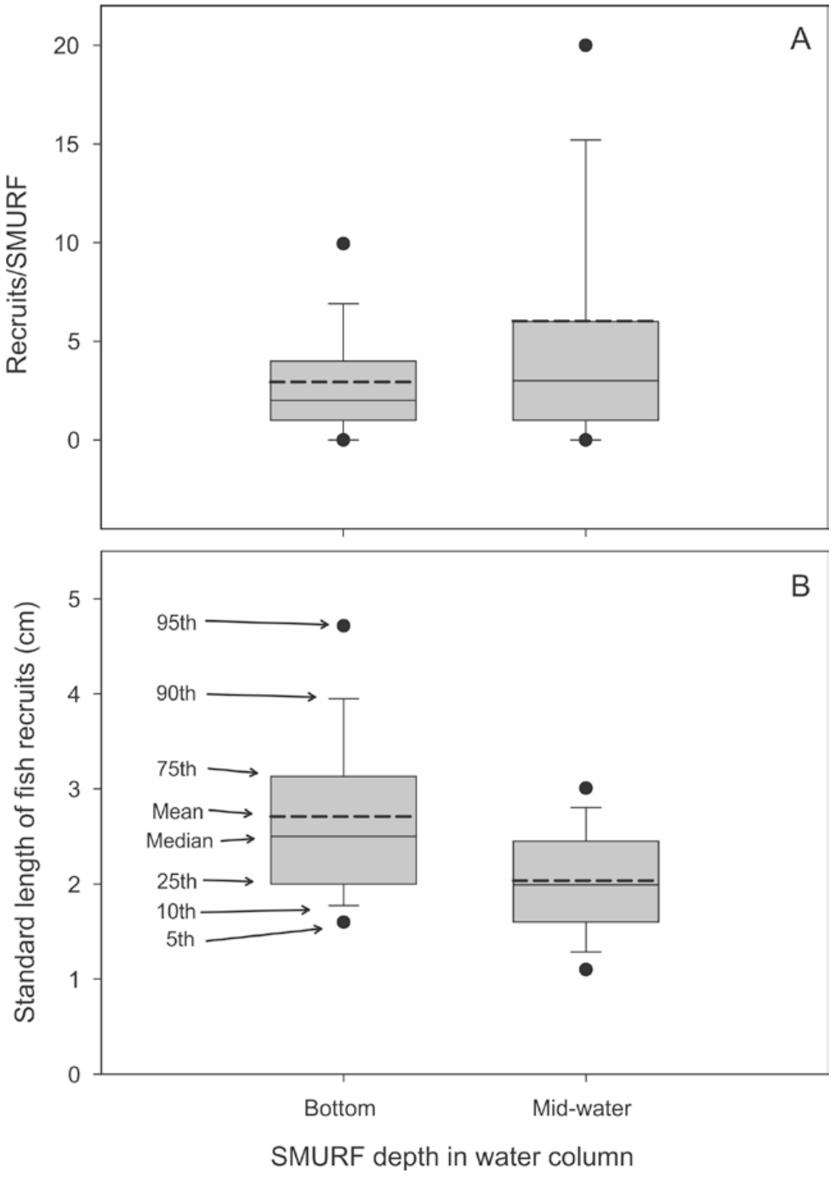
Figura 7 – Log_{10} transformed of recruits catches per SMURF as a function of immersion time of Bottom and Mid-water SMURFs



Fonte: O Autor (2020)

Within Phase 2, using only SMURFs, 699 specimens were sampled, 464 on mid-water and 233 on Bottom ones. The Bottom and Mid-water sampled statistically equal numbers of fish recruits per FAD (Mann-Whitney's Test, U = 2652.5, $p = 0.299$) with medians of 2.0 and 3.0, respectively (Figura 8, A). Recruits sizes were bigger at the Bottom compared to Mid-water ones (Mann-Whitney's Test, U = 29583,5, $p < 0.001$). Recruits sampled had total lengths median of 2.5 cm on the bottom and 1.9 cm on Mid-water (Figura 8, B), with variation between 0.8 and 6.1 cm. All individuals were newly settlers and young juveniles.

Figura 8 – Boxplot of Recruits abundance per SMURF and Standard lengths at two depth in water column. Boxplot elements: percentiles, median and mean are described in the plot.

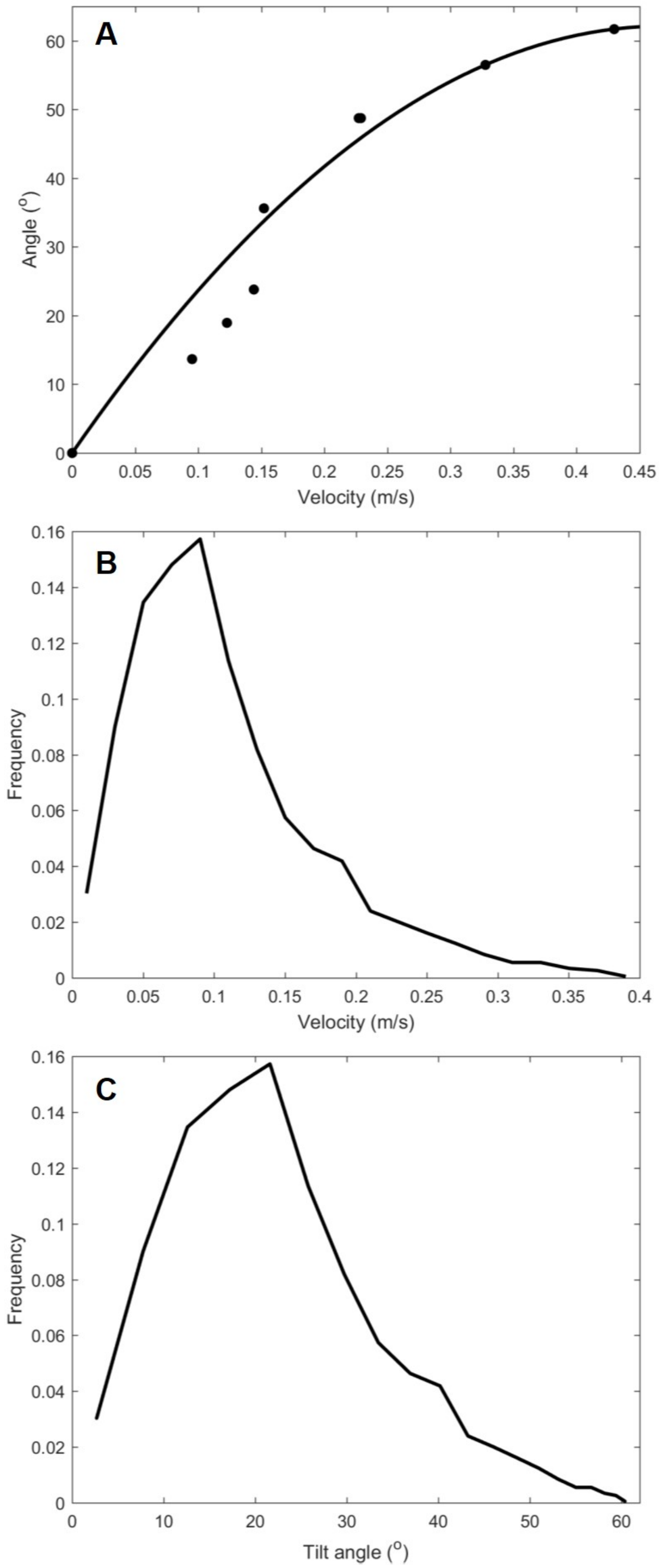


Fonte: O Autor (2020)

Hydrodynamic measurements and flow effects on the SMURFs

The relationship of the tilt angle to the velocity can be described by tilt angle = a*velocity^2 + b*velocity + c (a = -282.7, b = 265.1 and c = -8.76 x 10^{-6}, with r^2 = 0.93) (Figura 9A). The Figura 9B shows the accumulative frequency of current velocity, from ~3,800 temporal samples. The mean current during this period was 0.11 m/s, and the 50% and 90% percentiles were 0.08 and 0.19 m/s, respectively. With these flow conditions, the mean tilt angle was 24°, and at 90% of the time the tilt angle was < 40° (Figura 9C). Considering the planned height above the bed of 6 m, the mean height predicted for local currents was 5.5 m, and higher than minimum height of 4,5 m on 90% of the time obtained with the predictions.

Figure 9 – Relationship of the tilt angle (α) of SMURF mooring structure to the current velocities. Regression obtained with SMURFs trawls experiments in a diving pool (A). Accumulative frequency of current velocities (measured by ADCP) for Recife city coast between 2 June and 19 October 2011* (B). SMURF tilt angle predictions for the local current velocities (C). * Schettini (unpublished data).



Fonte: O Autor (2020)

DISCUSSION

Experiment deployment at sea more specifically in open sea, require some level of skills both out of water and especially when there is need to enter the water. In this way, information about the method used for activities within the water is of essential value to clarify about the challenges that future researchers may face. Therefore, it is reckless when 70% of the studies surveyed do not make it clear about the method used to perform the experiments in the field. This represents an evident technical scientific gap. The information about dive method used is important, especially when sites sampled have great depths where a free dive does not reach. In the present study, for the first time, experiments with aggregation of recruits were implemented at depths below 20 m, with implied extra caution for the researchers and the experiments (harder to access).

Among all FADs studies, ARM model were the least used despite its simple and inexpensive construction and rapid implementation in water, compared to benthic collectors that were composed of more complex constructions, take more time to implement in water (KLEIN, 2016) and require the use of anesthetics before involvement with the collection net (VALLÈS; KRAMMER; HUNTE, 2006). SMURFs models were the most used among the 31 studies compiled. Its construction despite being simple and compared to the ARMs, aggregates the structural complexity found in the benthic collectors. Compared to SMURFs, Benthic collectors apparently were more effective sampling fish young stages, but the SMURF model sampled more the recruits (KLEIN, 2016).

The low efficiency of ARM model, compared to the SMURF, was unexpected, since several studies with ARM achieved relatively high recruits' catches (SCHROEDER, 1987; LEIS; CARSON-EWART; WEBLEY, 2002; PAIVA *et al.*, 2015). These studies used sampling intervals smaller than the present study: 4 to 10 days (SCHROEDER, 1987), 2 days (LEIS; CARSON-EWART; WEBLEY, 2002) and 7 days (PAIVA *et al.*, 2015), in addition to different positioning arrays and abundance calculations. Leis, Carson-Ewart and Webley (2002) computes the sample mean just for the FADs in which individuals of were found, while Schroeder (1987) calculates the abundance in recruits/FAD/day. On the other hand, authors like Paiva *et al.* (2015) do not report catches by FADs, just the total number of individuals per species per treatments. Our study registered a sample mean of 0.02 recruits/ARM/day (n = 19, [data not shown]), well below the minimum number found by Schroeder (1987), which was 0.21 recruits/ARM/day (n = 160) in a coral reefs environment, which was similar to the sample mean of SMURFs model in this study, 0.2 recruits/SMURF/day (n = 21). Despite the varied sampling times in this study, between 13 and 32 days, both (SMURFs and ARMs) were always collected at the same the same intervals. This showed that SMURF model was more effective in deep artificial reefs environment.

Overall results demonstrate that there is a difference in the recruit communities in Mid-water and Bottom SMURFs, with the latter having high number of species than the former. In your study developing the model SMURF, Ammann (2004) showed that SMURFS positioned at the bottom had similar abundances from those deployed in Mid-water.

Depth apparently did not have any influence in number of fish recruits per FAD, excluding the ARMs, where the few sampled fishes were found in devices placed on the bottom. FADs positioned closer to the bottom tend to aggregate similar total numbers of recruits, while significant differences between the samples usually occur between FADs positioned close the bottom to those from subsurface (LEIS; CARSON-EWART; WEBLEY, 2002; Ammann, 2004), the latter tend to be preferred in studies focusing on only one species or in groups of similar species in view its high aggregation rates for these species (e.g. BEN-DAVID; KRITZER, 2005; CASELLE; KINLAN; WARNER, 2010). The long-term experiments (phase 2) were able to validate those of phase 1 showing similar sampling rates around 3 recruits per SMURF.

The differences between positioning of FADs are more evident when analyzing species by species data due to their behavioral and biological characteristics that may or might not have preference for certain depths (LEIS; CARSON-EWART; WEBLEY, 2002; AMMANN, 2004). Analyses already performed showed that there is a difference between the recruits' assemblages between the depths evaluated in this study (CORREIA *et al.*, *in prep.*). These intrinsic characteristics of the species may also have influenced the similarity of samplings by immersion time.

Although most studies use two weeks as standard immersion time to sample fish recruits (for example LUZIER; WILSON JR, 2004; CASELLE; KINLAN; WARNER, 2010; KLEIN *et al.*, 2018; OTTMAN *et al.*, 2017, 2018, 2019), some studies performed daily sampling (VALLÈS, KRAMMER; HUNTE, 2006) to more than two months of immersion time (SHIMA *et al.*, 2012). This variation of sampling intervals often obeys the ecological and biological characteristics inherent to the species something already noted in literature (AMMANN, 2004; VALLÈS, KRAMMER; HUNTE, 2006). Here, two weeks were not responsible for higher samples numbers although were the immersion time most tested. Probably, the uninfluenced fish recruits' samplings by SMURF's Immersion time showed here reflect a pool of different species recruitment times that could only be tested species by species

The size of individuals sampled were according to the lengths found in several studies that used FADs for recruitment and less than the maximum recruitment size of reef fishes, aprox. 6 cm (VICTOR, 1991) indicating that the fishes sampled in your study were mostly newly settlers to and young juveniles. The differences found by depths in the size ranges also show intrinsic characteristics of the species since some settle on FADs with higher sizes than the averages found in reef fish (BEN-DAVID; KRITZER, 2005).

When developing study with FADs it should be considered wave, currents and forces related to the structure (ÖZGÜL; LÖK; DÜZBASTILAR, 2011). The pool experiments with local marine currents relation could prove that mid-water FADs remained less than 0.5 m from the planned depths. Thus, the abundance data obtained for this position did not have influence by bottom FADs. This concern should be greater in experiments that use FADs held suspended by mid-water buoys (e.g. LEIS; CARSON-EWART; WEBLEY, 2002; AMMANN, 2004; PAIVA *et al.*, 2015.

The data of the present research indicate that the FADs, more specifically the SMURFs, can serve as useful tools to the study of fish recruits and smaller specimens in artificial environments such as shipwrecks. The SMURFs can sample fish recruits difficult to be perceived at visual censuses, and represent an efficient alternative for ecological research of fish early stages.

Ac*knowledgementes*

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Marenga. All samples were collected under environmental licenses SISBIO nº 55133-1, issued on 29/09/2016 and nº 55133-2, issued on 02/10/2017.

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3 SPATIO-TEMPORAL VARIATION OF FISH RECRUITMENT IN SHIPWRECKS FROM SOUTH ATLANTIC: IMPLICATIONS OF OCEANOGRAPHIC CONDITIONS

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ABSTRACT

The recruitment of fish is a sensitive phase that directly impacts the supply of juveniles and adults to reef populations. At this stage, oceanographic and ecological factors can influence the survival of settling fishes. Fish aggregating devices (FAD) represent alternative methods for studying fish recruitment and the occurrence of small and cryptic species especially in deeper places such as artificial reefs formed by shipwrecks. To verify fish recruitment near shipwrecks, sets of SMURFs (Standard monitoring unit for recruitment of reef fish) were deployed on the sea bottom and mid-water (6 meters from the bottom), 10-15 meters away from the Taurus-Virgo shipwreck complex in the northeastern coast of Brazil between November 2017 and February 2019. CTD (Conductivity, Temperature, Depth) surveys and temperature loggers were used to sample environmental data combined with electromagnetic current meters placed at starboard and port side in the shipwreck complex. The SMURFs attracted 23 species and two others fish taxons identified in this study, seven of them new occurrences for shipwrecks in Pernambuco state including a new record of *Apogon robbyi*. There was no difference in total abundance between the depths tested in this study. Five species were responsible for more than 84% of similarity among samples. The assemblage structure was different between seasons and total abundance was higher in the rainy season. However, recruitment of *Alphestes afer*, *Stephanolepis hispidus* and *Stephanolepis setifer* were higher in the dry months, while *Lutjanus chrysurus* and *Sparisoma* sp. had recruitment peaks during the rainy season. The species *Sparisoma* sp. and *A. afer* were more present in bottom SMURFs, while *S. hispidus* and *S. setifer* were more abundant in mid-water SMURFs. Flow velocity on the Starboard region of the Virgo-Taurus shipwreck complex was two times faster than on the Port side, but there was no influence registered on fish recruitment. Mean water temperature was significantly correlated with fish recruitment. *Lutjanus chrysurus*, *S. hispidus*, and *S. setifer* had higher recruitment values during months with higher temperatures, while the recruits of *A. afer* and *Sparisoma* sp. were more abundant at lower temperatures. These pioneer data showed that SMURFs are important tools in monitoring the recruitment of fish species, including small and cryptic species in shipwrecks in the South Atlantic.

Keywords: FAD; artificial reefs; reef fish; juvenile fish; seawater temperature

INTRODUCTION

Recruitment is a phase in the life cycle of fish closely associated with reef structure and biota, in which they have to survive through a period of time after settlement (LEVIN, 1994; LEIS; MCCORMICK, 2002). The settlement phase is characterized by a rapid change from pelagic larval life to a benthic habitat (VICTOR, 1991), which involves the perception of auditory, olfactory, and visual cues offered by the reefs (LEIS; CARSON-EWART; WEBLEY, 2002; MYRBERG; FUIMAN, 2002; WRIGHT *et al*., 2010), At this phase, bottleneck events occur, impacting the number of adult individuals in the population.(DOHERTY *et al*., 2004).

These events, which regulate larvae recruitment, are environmental and biological factors that operate on temporal and spatial scales (COWEN, 2002, WILSON *et al*. 2008). Interannual and seasonal scales contribute to most of the recruitment variation (SPONAUGLE; COWEN, 1997; ABESAMIS; RUSS, 2011). Considering spatial scales, settlement may be a result of regional processes like current eddies (SPONAUGLE *et al*., 2005) or local processes such as varying current flow around marine reliefs (WOLANSKI; HAMNER, 1988) and current velocity (SCHMITT; HOLBROOK, 2002). Large-scale environmental processes are known to influence and even change patterns generated by smaller-scale processes (LEVIN, 1992, DOWNES; KEOUGH, 1998; JENKINS, 2005). Those factors can modify larval supply to benthic habitats by differential larval dispersal and mortality (CASELLE; WARNER, 1996).

Small-scale environments such as artificial reefs can be used as laboratories for density dependence and independence studies, considering factors such as oceanographic processes and ecological interactions that influence post-recruitment survival (LEIS; MCCORMICK, 2002). They are used in all oceans as a strategy to mitigate the decline of fish stocks caused by increased exploitation and other human-induced impacts, in addition to providing environments for underwater tourism practice (BOHNSACK; SUTHERLAND 1985, BOHNSACK; 1989, CARR; HIXON 1997). However, there is still a debate whether artificial reefs, such as shipwrecks, contribute to the survival of larvae that would not reach natural reefs or if they act only by "stealing" larvae that would otherwise have dispersed to natural reefs (WILSON *et al*., 2001). This uncertainty is enhanced by the fact that most studies have shown that species composition often differs between artificial and natural reefs (CLARK; EDWARDS 1994; 1999; FOWLER; BOOTH, 2012; SIMON; JOYEUX; PINHEIRO, 2013).

The Artificial Shipwreck's Park of Pernambuco (PNAPE) (SANTOS *et al*., 2008), Northeast Brazil, harbors great diversity of fish (CORREIA *et al*. 2018), although the knowledge of the ichthyofauna at these sites is restricted to juveniles and adults (COXEY, pers. Comm.; MARANHÃO, pers. Comm.). Due to the increasing number of purposely sunken ships to promote tourism in the region (SANTOS *et al*., 2008; CASTANHARI; TOMÁS; ELLIFF, 2012; CORREIA *et al*., 2018), it is necessary to apply practical and trusted techniques in fish early stages studies on shipwrecks. This could help to understand if these artificial structures act as attractors or producers of fish populations, contributing to larvae survival (CARR; HIXON, 1997; GROSSMAN; JONES; SEAMAN, 1997) and which environmental factors could influence this recruitment.

It is often difficult to directly evaluate the mechanisms that determine interannual variations in recruitment intensity (HAMILTON *et al*., 2006). Therefore, the use of fish aggregation devices (FADs) has been one of the most popular techniques for studying fish recruitment (AMMANN, 2004; VALLES; KRAMER; HUNTE, 2006), enabling more regular studies even in difficult-to-access habitats (see CORREIA *et al*., 2020, also Chapter 2, for more information). FADs have enabled researchers to study the influence of oceanographic factors at small scale (KLEIN *et al*., 2018) to meso and large scale (WHITE; CASELLE, 2008; WILSON *et al*., 2008) in fish recruitment and behavior patterns in settlers and recruits of marine fish (LEIS; CARSON-EWART; WEBLEY, 2002).

On the exposed, the goals of this study were 1) to identify fish species that recruit on FADs installed near shipwrecks, 2) to investigate if recruits assemblages as a whole or any species, in particular, respond to spatial or temporal patterns, and 3) to evaluate if hydrological and hydrodynamics processes influence recruits assemblages around shipwrecks, and thus, infer if the oceanographic conditions surrounding the shipwrecks provide favorable environments for the recruitment of reef fish.

MATERIALS AND METHODS

Study area

This research was conducted on three shipwrecks distributed in two regions, ranging from 9 to 13 km away from the Port of Recife (Figura 1), in the coastal area of Pernambuco State. The climate in the area is humid tropical with two main seasons: wet season (September to February) and dry season (March to August). During the dry season, precipitation levels are usually below 100 mm; diversely, the rainy season receives more than 75% of the region's annual rainfall (HONORATO-DA-SILVA *et al*., 2009). The tidal regime is semi-diurnal, with tides ranging from 1.5 to 3 m at neap and spring periods, respectively. Shelf currents are mainly driven by easterly winds, which are strongest between August and October, when the currents are strongest and northwards. Between January and March, the wind relaxes, and the shelf currents are sluggish southwards. Shelf waters are dominated by Tropical Water, with salinity >36.5 PSU and temperature >26 °C (SCHETTINI *et al*., 2017).

Figura 1 – Location (★) of the studied wrecks and positioning of the SMURF' supporting structures. Circles show the location of structures during Pilot and Long-term monitoring experiments and "X" mark the positions of supporting structures of electromagnetic current meters. The red color refers to the bow of the wreck Pirapama, and green and yellow refer to starboard and port side of the Taurus-Virgo shipwreck complex, respectively.

Fonte: O Autor (2020)

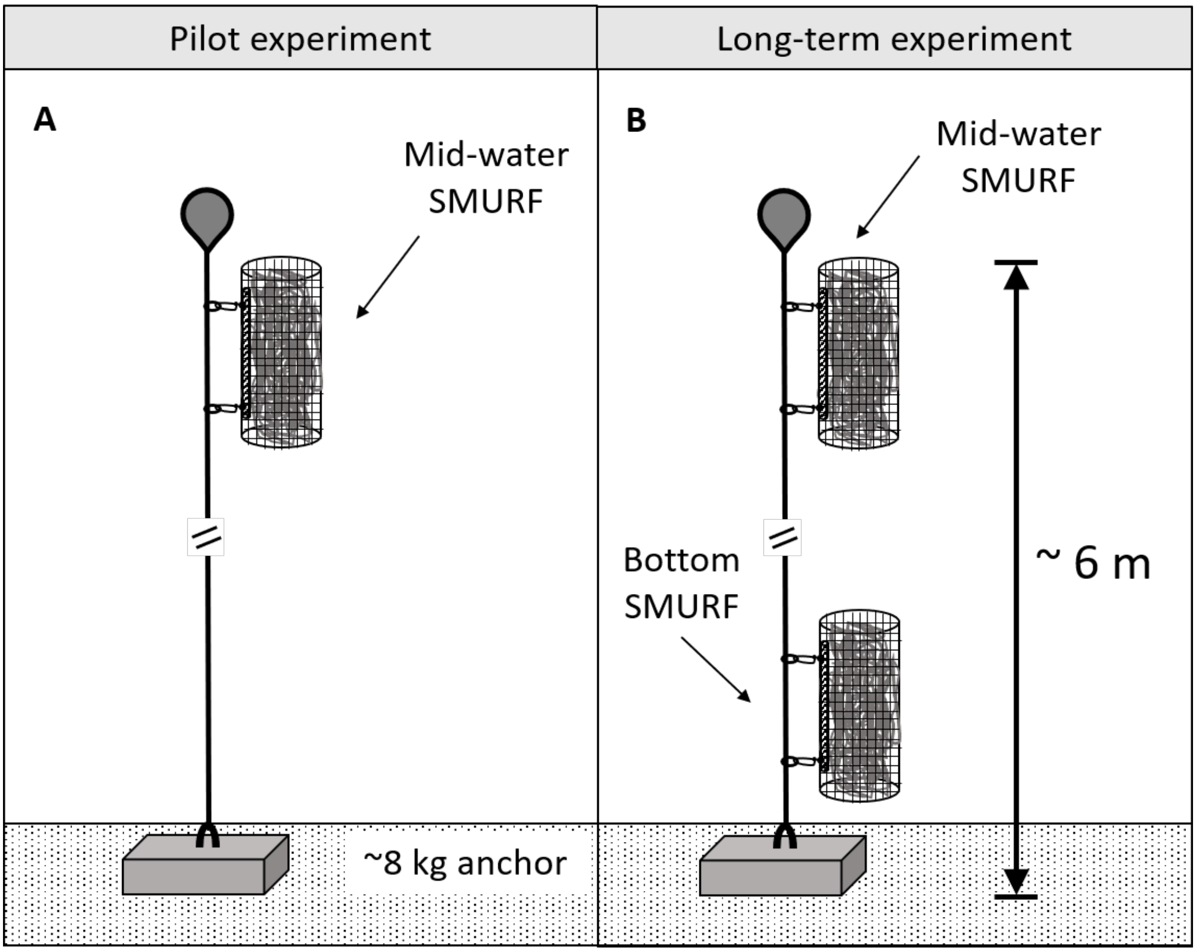
The shipwreck Pirapama (8°3'23.00" S and 34°46'58.00" W), sunk incidentally in 1889, measures 60 m in total length, is located at a 21 m depth and is oriented with the bow facing Southwest (SOUZA, 2010). The shipwrecks Taurus and Virgo (8°4'11.58 S and 34°45'11.76" W) with approximately 25 m total length were sunk deliberately to a depth of 25 m, in 2006 (SANTOS *et al*., 2008) and 2017 (CORREIA *et al*., 2018), respectively. They form a complex of artificial reefs and they are located 9 m away from each other, with their bows facing East-Southeast (E-SE, Taurus) and South-Southeast (Virgo) (Figura 1, also see bathymetry data in results). The conformation and hydrodynamic characteristics in the region allow the speculation that in the Taurus-Virgo complex, the Port side may function as a protected environment from local currents, and the Starboard side forms a more exposed region.

Fish recruits' collection

Pilot experiment

To test the handling feasibility, the durability of structures and the ability to capture specimens a pilot test was carried out with the FAD model SMURF (AMMANN, 2004). The SMURF is composed by a closed cylindrical frame (1.0 m length x 0.35 m diameter) made of black plastic fencing net with a mesh size of 2 x 2 cm. It was filled with a randomly folded piece (9.0 x 1.2 m) of a malleable orange plastic net with a mesh size of 5 x 7 cm (Figura 2A) and neutral buoyancy.

Figura 2 – Mid-water and Bottom SMURFs used during pilot experiments (A) and Long-term monitoring experiments (B). More information on SMURFs and supporting structures are reported in Correia *et al*. (2020). The anchors and buoys are representative and not to scale.



Fonte: O Autor (2020)

In the field, the SMURFs were moored with a structure composed of anchor, rope and a mid-water buoy to keep them suspended in the water column, approximately 6 m above sea bottom. Three moorings were positioned in the following regions near the shipwrecks: the bow of the Pirapama wreck, the port side, and starboard of Virgo wreck (Figura 1, red, yellow and green circles), separated from each other by approximately 10 m. Each group of three SMURFs remained in the water for periods that ranged from 14 to 109 days between September 2016 and March 2017. This large variation in submerged periods was due to climatic instability that compromised the safety of the divers during the operation causing a delay. During the procedure of recovery of the SMURFs, each one was enclosed in cylindrical nets with 5 mm mesh size, and all six SMURFs were brought together to the boat where the fish were sacrificed (collections held under environmental license SISBIO No. 55133-2, issued on 02/10/2017).

Subsequently, the fish were kept in a freezer until measurement and identification could be carried out.

In order to identify specimens at the lowest taxonomic level, several sources had to be examined. Guides were consulted for the description of larval stages (RICHARDS, 2006) and early stage descriptions were made according to Cervigón (1993) Thresher (1984), Carpenter (2002) and the Fishbase database (FROESE; PAULY, 2018). Species were classified according to Richards (2006), except for Epinephelidae species that were classified according to Craig and Hastings (2007), and the species Lutjanus chrysurus (Bloch, 1971), classified according to Gold, Voelker e Renshaw (2011). In this study, individuals were considered as recruits if their sizes were smaller than half the sizes of adults indicated in identification guides and specific literature.

Fish recruitment monitoring

A long-term monitoring was performed to identify seasonal recruitment using previous moorings of pilot experiments. The monitoring occurred between March 2017 and February 2019, with immersion time varying from 13 to 32 days. The structure of fish recruit's assemblage at different depths was investigated using three SMURF moorings with two SMURFs per mooring, one positioned at the bottom and one at 6 m from the bottom (mid-water) in the same areas of the pilot study (Figura 1). The differences between bottom and mid-water recruitment at the starboard side of the Taurus-Virgo shipwreck complex, (considered the less hydrodynamic), and the port side of the same complex (considered more hydrodynamic) were also tested. SMURFs were collected individually with a cylindrical net with a 5 mm mesh size and specimens were preserved and identified, exactly as in the pilot experiment.

Bathymetric mapping of Taurus-Virgo shipwreck complex

To better understand the hydrodynamic results around the Taurus-Virgo complex a bathymetric mapping was carried out using an echo sounder (Fishfinder Humminbird 798ci HD). A total of 4780 depth points were recorded with latitude and longitude. These data were interpolated by Kriging method to generate a Digital Bathymetric Model (DBM). Data were acquired on December 4th 2018, at 10:00-11:00 am.

Hydrodynamics around shipwrecks and oceanographic parameters measurements

Both sides of the Taurus-Virgo were investigated to verify the existence of a possible attenuation zone of local currents on the port side of the complex and a more exposed location on the starboard. Current velocity and direction were recorded on each side of the complex with electromagnetic current meters (EMCM) by JFE Advantech. The EMCMs were moored on a frame of non-magnetic steel, with the sensors leveled ~ 1 m above sea bottom and 10 m away from FADs (Figura 1). The EMCMs recorded at 30' intervals, averaging over 2' at 1 Hz sampling rate. The EMCMs were deployed on June 7th 2018 and recovered on July 5th 2018. However, the synoptic data comprised the first 13 days, when both EMCMs were recording. The directions were corrected for the local magnetic declination of -22°.

The oceanographic parameters, temperature (ºC), salinity (PSU), dissolved oxygen saturation (%), chlorophyll concentration (µg/L) and turbidity (FTU) were recorded with a CTD probe by JFE Advantech (Rinko-Profiler model, with 10 Hz acquisition rate). Vertical profiles were recorded at every ~1 km of navigation (9-12 profiles) in each of 12 transects executed between November 2017 and February 2019 from Recife' port to Taurus-Virgo shipwreck complex. Salinity was converted from conductivity and temperature using PSS-78 (Practical Salinity Scale, UNESCO, 1981) and Turbidity was log -transformed to facilitate data visualization in profile graphs.

Water temperature was also recorded in loco with a datalogger (UA-002-64, HOBO, ONSET) positioned on a supporting rope between the bottom and mid-water SMURFs, in four surveys (November to December 2017; January, March to July and December 2018; and January to February 2019). The lack of continuity in the HOBO's records was due to leaking, that damaged circuits of some equipment.

Data Analysis

Biological data

The data from the long-term experiments were analyzed and processed considering the abundance of each species per SMURF. The time in the water did not influence recruit's abundance in this research (CORREIA *et al*., 2020. These data were Ln (x+1) transformed and a similarity matrix of Bray-Curtis (with 1 dummy variable added) was used to compare fish assemblage structure of the factors season (dry and rainy) and depth (mid-water and bottom) through two-way Permutational Anova (PERMANOVA) test ($\alpha = 0.05$, with the type III sums of squares (partial), and 9999 Permutation of residuals under the full model). These tests were carried out using samples from Pirapama and Taurus-Virgo complex from April 2017 to February 2019.

A one -way PERMANOVA test ($\alpha = 0.05$, type III partial sums of squares, 9999 unrestricted permutations of raw data) was also performed to compare the fish assemblage structures on the Port side and on the Starboard of the Taurus-Virgo shipwreck complex using only samples from Taurus-Virgo complex from April 2017 to February 2019.

Total recruit abundances were compared in relation to seasons and depth using pooled species data Ln (x+1) transformed with a Euclidean distance matrix (FAIRCLOUGH *et al*., 2008) through two-way PERMANOVA test ($\alpha = 0.05$, type III partial sums of squares, 9999 unrestricted permutations of raw data). The Similarity Percentages (SIMPER) test was executed to determine the species that contributed the most to the similarity of the fish assemblage structures, assuming a cut off at 90%. To evaluate recruits' abundance in relation to depth and vessel side, the values were Ln (x+1) transformed and a Euclidian distance matrix was calculated. A PERMANOVA test ($\alpha = 0.05$, type III partial sums of squares, 9999 unrestricted permutations of raw data) was also performed. The structure of fish assemblages was graphically displayed with a non-metric multidimensional scaling plot (nMDS) (CLARKE; WARWICK 2001).

Statistical analysis of biological data was executed using Primer V6 & PERMANOVA+® (ANDERSON; GORLEY; CLARKE, 2008) software.

Oceanographic Parameters visualization

Hydrodynamic data from EMCM were plotted in polar frequency graphs and data from each CTD profile from each measured parameter was interpolated using kriging method and plotted in a depth x distance graph.

For the purpose of visual comparison, temperature data obtained with HOBO datallogers were plotted with the time series data obtained from a 20-m deep sensor of PIRATA's (Prediction and Research Moored Array in the Tropical Atlantic) Project's buoy (8S30W). Temperature data from PIRATA's buoys were collected daily between 11/02/2017 and 11/02/2019. There was no information on temperature from the 20 m deep sensor between April and June 2017.

Exploring relationships between biological data and oceanographic parameters

For a comparison of fish recruitment and oceanographic parameters data from coincident months (Nov-2017; Dec-2017; Jan-2018; Mar-2018; Apr-2018; Jul-2018; Dec-2018; Jan-2019 and Feb-2019) for biological data, CTD measurements and HOBO data were used. Species determined by the SIMPER test were selected, and their recruitment in the aforementioned months was calculated and expressed as mean abundance per sample (bottom and mid-water samples were considered equally). CTD data of the closest profiles from Taurus-Virgo complex were averaged from 18 m to seafloor for each parameter referring to coincident months. Temperature and thermal amplitude (maximum temperature - minimum temperature) means from HOBO hourly data were also calculated.

A total of eight environmental variables were checked for collinearity by Spearman correlation: mean temperature (CTD), salinity, turbidity, chlorophyll concentration, dissolved oxygen, temperature (HOBO), thermal amplitude (HOBO). A conservative Spearman correlation of $R^2 = 0.6$ was used as threshold. Mean temperature (CTD) was correlated with temperature (HOBO) (Spearman $R^2 = 0.67$) and turbidity was correlated with salinity (Spearman $R^2 = 0.70$) and with chlorophyll concentration (Spearman $R^2 = 0.90$). Temperature (CTD) was excluded due to its lower resolution when compared with HOBO data. Turbidity was also excluded due to low correlation and no significance with salinity and chlorophyll concentration and significance values (Spearman $R^2=0.65$, $p=0.06$).

After the selection of biological and environmental data, a model of the best environmental variables (or combination of variables) that accounted for the variation in the fish assemblages was constructed with the Bray-Curtis matrix of biological data and with the Euclidian distance matrix. Environmental data were normalized by the Distance-based linear modeling (DistLM) analysis with a selection of the Akaike information criterion for small samples (AICc). AICc is recommended when the ratio between the sample size (n) and the number of parameters (p) in the largest candidate model is small (< 40) (BURNHAM; ANDERSON, 2004) Distance-based redundancy analysis (dbRDA) was used to plot the data according to this model.

Permutation tests for linear models (lmPerm package for R) were executed to check the interference of the best environmental variable or combination of variables indicated by DistLM on the recruitment of each fish species selected by the SIMPER test.

Recruitment ofthe selected fish species and temperature time series plotting was performed using SigmaPlot 11 (Systat) software. Analysis of relationship between biological and environmental data was executed and plotted using Primer 6 & PERMANOVA+ (PRIMER-E) software. Correlations and regression analysis were executed with the R 3.6 (R-CORE-TEAM, 2020) and plotted using Past 3 (HAMMER; HARPER; RYAN, 2001) software.

RESULTS

Pilot experiment

In Pilot tests, SMURFs were submerged for periods ranging from 14 to 109 days and sampled a total of 90 individuals belonging to 7 families. The families Carangidae, Lutjanidae and Monacanthidae were responsible for 85% of all collected individuals.

Long-term monitoring experiment

During the long-term monitoring experiments, a total of 768 specimens belonging to 25 taxons from 13 families were collected (Tabela 1). All individuals were recruits, except from 6 adult specimens of *Apogon robbyi* (ranging between 2.6-3.0 cm SL) according to Baldwin *et al*. (2011). In general, the mean size of the recruits was around 2.6 cm ± 0.3 SD, ranging between 0.9 and 6.1 cm (Tabela 1).

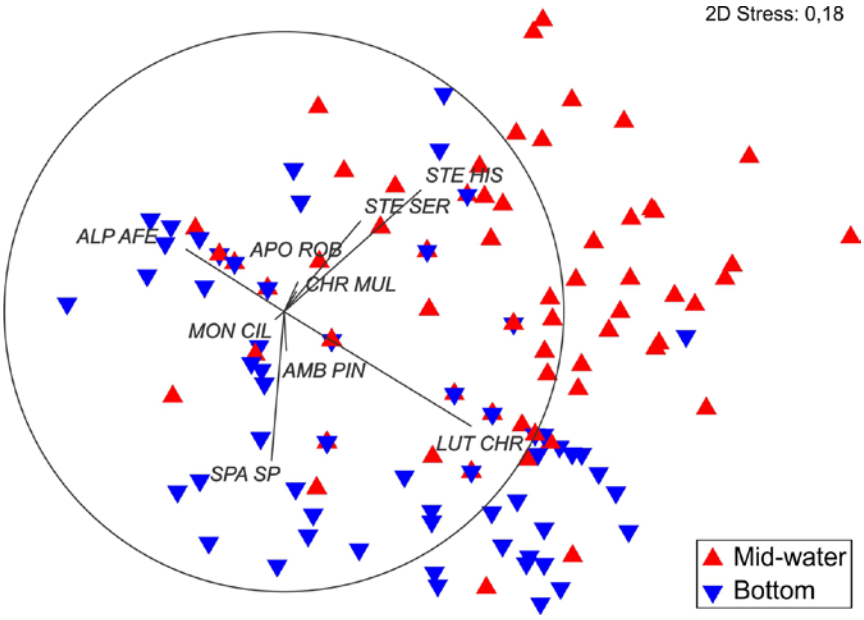
Depth highly influenced the recruit assemblage structure (PERMANOVA Pseudo-F = 12.203, p(perm) = 0.0001). This was also clearly revealed by the nMDS graphic (Figura 3). SIMPER analysis showed that nine species contributed to more than 90% of an average dissimilarity of 88.31. The mid-water group was formed by a high contribution of *Stephanolepis hispidus* (39%) and *Lutjanus chrysurus* (36%), and low contribution of *S. setifer* (16%). The sea bottom group was formed by a high contribution of *L. chrysurus* (39%) and *Sparisoma* sp. (39%) and a low contribution of *Alphestes afer* (18%).

Tabela 1 – Recruit species sampled by SMURF with the corresponding mid-water, bottom and total abundance, and Standard Length (SL) mean and range. SD = Standard Deviation. Standard length values are in cm.

Common name	Scientific name	Family	Mid-water	Bottom	Total	Mean SL (SD)	SL range
Pilot experiment							
Yellowtail snapper	*Lutjanus chrysurus* (Bloch, 1791)	Lutjanidae	31	-	31	1.8 (0.3)	1.5 - 2.6
Mackerel scad	*Decapterus macarellus* (Cuvier, 1833)	Carangidae	22	-	22	3.4 (0.2)	2.9 - 3.9
Planehead filefish	*Stephanolepis hispidus* (Linnaeus, 1766)	Monacanthidae	22	-	22	1.8 (0.3)	1.3 - 2.7
Mutton hamlet	*Alphestes afer* (Bloch, 1793)	Epinephelidae	9	-	9	4.3 (0.4)	4.0 - 5.2
Parrotfish	*Sparisoma* sp.	Scaridae	2	-	2	2.7 (0.2)	2.5 - 2.8
Ocean surgeon	*Acanthurus bahianus* Castelnau, 1855	Acanthuridae	1	-	1	3.6	3.6
Brown chromis	*Chromis multilineata* (Guichenot, 1853)	Pomacentridae	1	-	1	1.8	1.8
Roughear scad	*Decapterus tabl* Berry, 1968	Carangidae	1	-	1	4.0	4.0
Snappers	*Lutjanus* sp.	Lutjanidae	1	-	1	1.5	1.5
			90	0	90	2.5 (1.0)	1.3 - 5.2
Long-term monitoring							
Yellowtail snapper	*Lutjanus chrysurus*	Lutjanidae	126	100	226	2.3 (0.6)	1 .0- 4.8
Planehead filefish	*Stephanolepis hispidus*	Monacanthidae	206	12	218	2.0 (0.5)	1 .0- 3.3
Pygmy filefish	*Stephanolepis setifer* (Bennett, 1831)	Monacanthidae	110	2	112	1.6 (0.4)	0.9 - 2.9
Parrotfish	*Sparisoma* sp.	Scaridae	20	68	88	2.6 (0.9)	1.1 - 5.7
Mutton hamlet	*Alphestes afer*	Epinephelidae	17	39	56	3.5 (0.8)	2.7 - 6.1
Striped cardinalfish	*Apogon robbyi* Gilbert & Tyler, 1997	Apogonidae	-	14	14	2.4 (0.4)	1.8 - 3.0
Coney	*Cephalopholis fulva* (Linnaeus, 1758)	Epinephelidae	-	7	7	3.5 (0.3)	3.2 - 4.1
Redspotted hawkfish	*Amblycirrhitus pinos* (Mowbray, 1927)	Cirrhitidae	2	4	6	2.6 (0.2)	2.4 - 2.9
Brown chromis	*Chromis multilineata*	Pomacentridae	5	-	5	2.4 (0.4)	2.0 - 3.0
Fringed filefish	*Monacanthus ciliatus* (Mitchill, 1818)	Monacanthidae	1	4	5	2.4 (0.2)	2.2 - 2.7
Rock beauty	*Holacanthus tricolor* (Bloch, 1795)	Pomacanthidae	3	1	4	1.9 (0.2)	1.7 - 2.1
Ocean surgeon	*Acanthurus bahianus*	Acanthuridae	-	3	3	3.2 (0.2)	3.1 - 3.4
Dwarf wrasse	*Doratonotus megalepis* Günther, 1862	Labridae	-	3	3	2.4 (0.4)	2.0 - 2.9
Lantern bass	*Serranus baldwini* (Evermann & Marsh, 1899)	Serranidae	-	3	3	2.8 (0.1)	2.8 - 2.9
Doctorfish	*Acanthurus chirurgus* (Bloch, 1787)	Acanthuridae	-	2	2	3.1 (0.1)	3.0 - 3.2
Blue tang surgeonfish	*Acanthurus coeruleus* Bloch & Schneider, 1801	Acanthuridae	2	-	2	3.5 (0.4)	3.2 - 3.8
Southern Atlantic sharpnose-puffer	*Canthigaster figueiredoi* Moura & Castro, 2002	Tetraodontidae	1	1	2	2.2 (0.3)	2.0 - 2.4
Tomtate grunt	*Haemulon aurolineatum* Cuvier, 1830	Haemulidae	-	2	2	4.9 (0.6)	4.4 - 5.3
Yellowmouth grouper	*Mycteroperca interstitialis* (Poey, 1860)	Epinephelidae	-	2	2	4.1 (1.3)	3.2 - 5.0
Surgeonfishes	*Acanthurus* sp.	Acanthuridae	1	-	1	3.1	3.1 - 3.1
Longlure frogfish	*Antennarius multiocellatus* (Valenciennes, 1837)	Antennariidae	-	1	1	2.2	2.2 - 2.2
Cardinalfishes	*Apogon* sp.	Apogonidae	-	1	1	1.3	1.3 - 1.3
Cardinalfishes	*Astrapogon* sp.	Apogonidae	-	1	1	2.9	2.9 - 2.9
Rock hind	*Epinephelus adscensionis* (Osbeck, 1765)	Epinephelidae	-	1	1	2.7	2.7 - 2.7
Blackfin snapper	*Lutjanus buccanella* (Cuvier, 1828)	Lutjanidae	-	1	1	2.5	2.5 - 2.5
Filefishes	Monacanthidae*	Monacanthidae	1	-	1	-	-
Parrotfishes	Scaridae	Scaridae	1	-	1	2.6	2.6 - 2.6
			496	272	768	2.3 (0.8)	0.9 - 6.1

Fonte: O Autor (2020)

Figura 3 – nMDS of the structure of recruits' assemblage from Pirapama, Taurus and Virgo wrecks collected by mid-water and bottom SMURFs between April 2017 and February 2019. Vectors are based on nine species responsible for more than 90% of contribution on SIMPER analysis: *Stephanolepis hispidus* (STE HIS), *Stephanolepis setifer* (STE SET), *Lutjanus chrysurus* (LUT CHR), *Alphestes afer* (ALP AFE), *Sparisoma* sp. (SPA SP), *Apogon robbyi* (APO ROB), *Chromis multilineata* (CHR MUL), *Monacathus ciliatus* (MON CIL) and *Amblycirrhitus pinos* (AMB PIN).

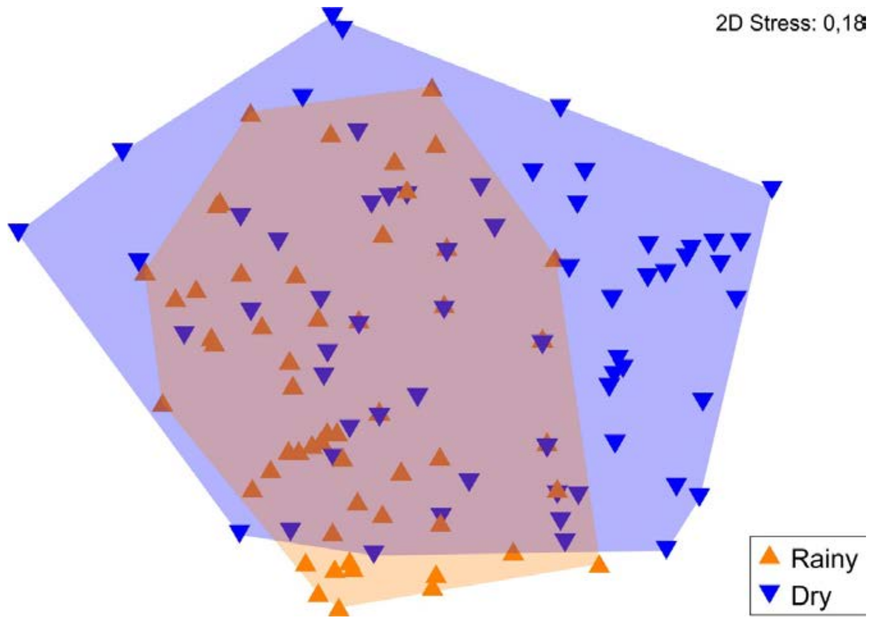


Fonte: O Autor (2020)

Thirteen taxons were found exclusively in the bottom SMURFs: *Apogon robbyi*, *Apogon* sp. and *Astrapogon* sp. (Apogonidae), *Cephalopholis fulva*, *Mycteroperca interstitialis* and (Epinephelidae), *Acanthurus bahianus*, *A. chirurgus* (Acanthuridae), *Doratonotus megalepis* (Labridae), *Serranus baldwini* (Serranidae), *Haemulon aurolineatum* (Haemulidae), *Antennarius multiocellatus* (Antennaridae) and *Lutjanus buccanella* (Lutjanidae). Among these, only five families occurred exclusively at this depth: Apogonidae, Serranidae, Labridae, Antennaridae and Haemulidae. Three taxons were restricted to mid-water SMURFs*: Chromis multilineata*, *Acanthurus coeruleus* and *Acanthurus* sp. SIMPER analysis showed that five taxons accounted for approximately 83% of dissimilarity between bottom and mid-water assemblages: *Lutjanus chrysurus* (25%), *Stephanolepis hispidus* (18%), *Sparisoma* sp. (17%), *Alphestes afer* (13%) and *Stephanolepis setifer* (11%).

Fish assemblages' structures were significantly different in dry and rainy seasons (Two-way PERMANOVA Pseudo-F= p(perm) = 0.0001; Figura 4). SIMPER analysis showed that assemblages observed during the rainy season were composed almost entirely by *L. chrusurus* (69%) followed by *Sparisoma sp.* (14%) and *S. hispidus* (13%). Assemblages sampled during the dry season were formed by contributions of *A. afer* (36%), *Sparisoma* sp. (24%), *L. chysurus* (16%) and *S. hispidus* (15%).

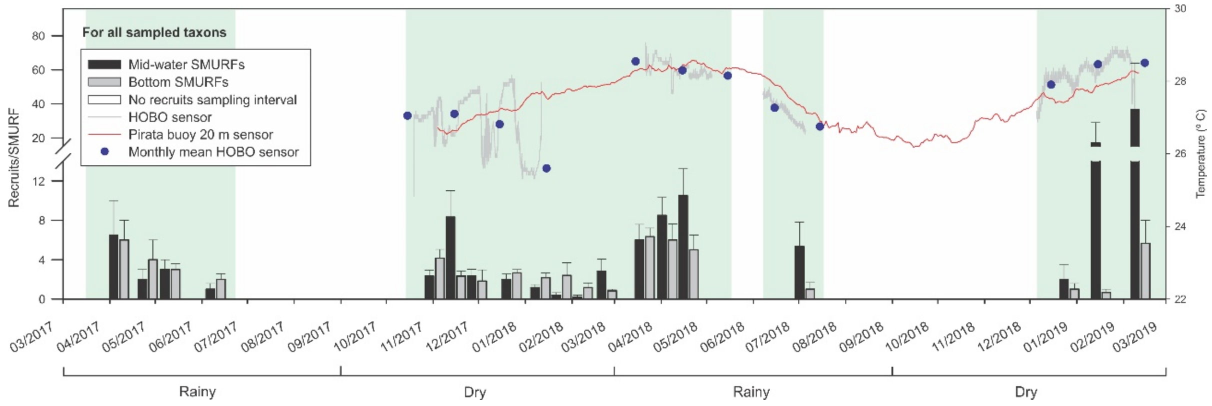
Figura 4 – nMDS of assemblage structure of recruits from Pirapama, Taurus and Virgo wrecks collected by SMURFs in rainy and dry seasons between April 2017 and February 2019.



Fonte: O Autor (2020)

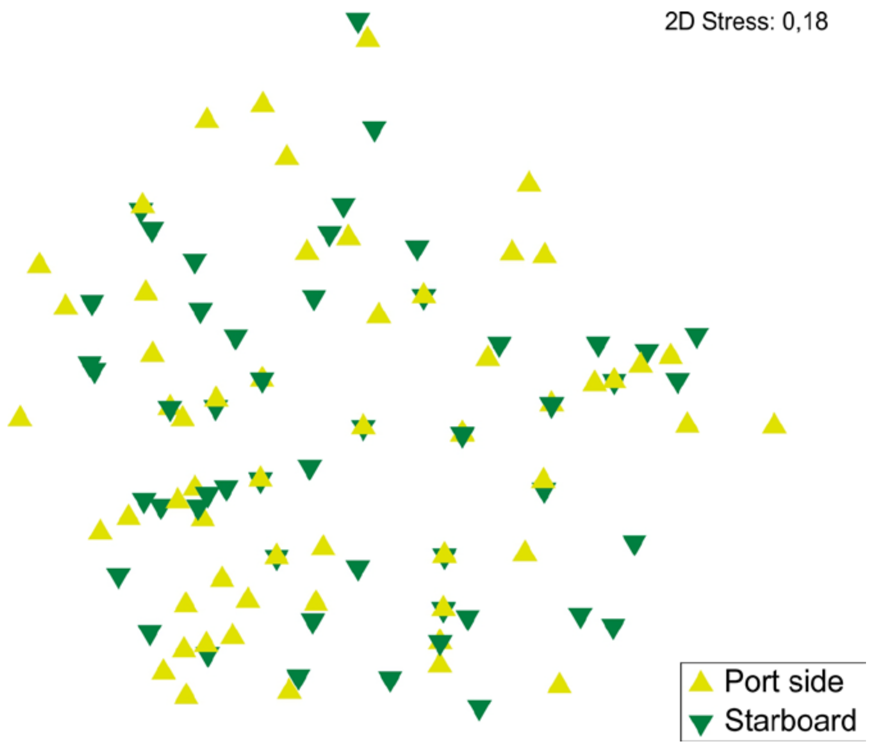
Despite the difference in assemblage structure, depth did not cause variation in general recruit abundances (Univariate two-way PERMANOVA Pseudo-F=2.9828, p(perm)= 0.0864). On average, recruitment values for all fish species sampled in this study were not significantly different between mid-water and bottom SMURFs. On the other hand, the parameter “seasons” was found to influence on total recruit abundances (Univariate two-way PERMANOVA Pseudo-F= 17.184, p(perm)= 0.0001). Recruitment was nearly 60% higher in the rainy season when compared to the dry season (Figura 5). Recruits’ assemblage structures were not different between Port Side and Starboard regions of the Taurus-Virgo complex (Pseudo-F = 0.65488, p(perm) = 0.6329) (Figura 6).

Figura 5 – Mean abundances (+standard error) of pooled data of recruits sampled during the long-term monitoring experiments plotted together with 20 m depth temperatures recorded from HOBO dataloggers sensor (*in situ*) and PIRATA 8S30W buoy. Date: month-year.



Fonte: O Autor (2020)

Figura 6 – nMDS of assemblage structure of recruits on each side (Port and Starboard) of the Taurus-Virgo shipwreck complex collected by SMURF between April 2017 and February 2019



Fonte: O Autor (2020)

Recruitment analysis of the five most abundant species showed that *A. afer and L. chrysurus* have inverse seasonal patterns. (Figura 7). Recruitment of *A. afer* was higher during the dry season in the last months of 2017 and decreased gradually until March 2018, while recruitment of *L. chrysurus* increased from late 2017 to April 2018. No recruit of *A. afer* was sampled in the last months of 2018 or early 2019. Surprisingly, *L. chrysurus* recruits were sampled during this same period. *A. afer* had a significant relation with bottom SMURFs but no relation with the sides of the shipwreck complex. *L. chrysurus* had no relation with neither of these parameters (Tabela 2).

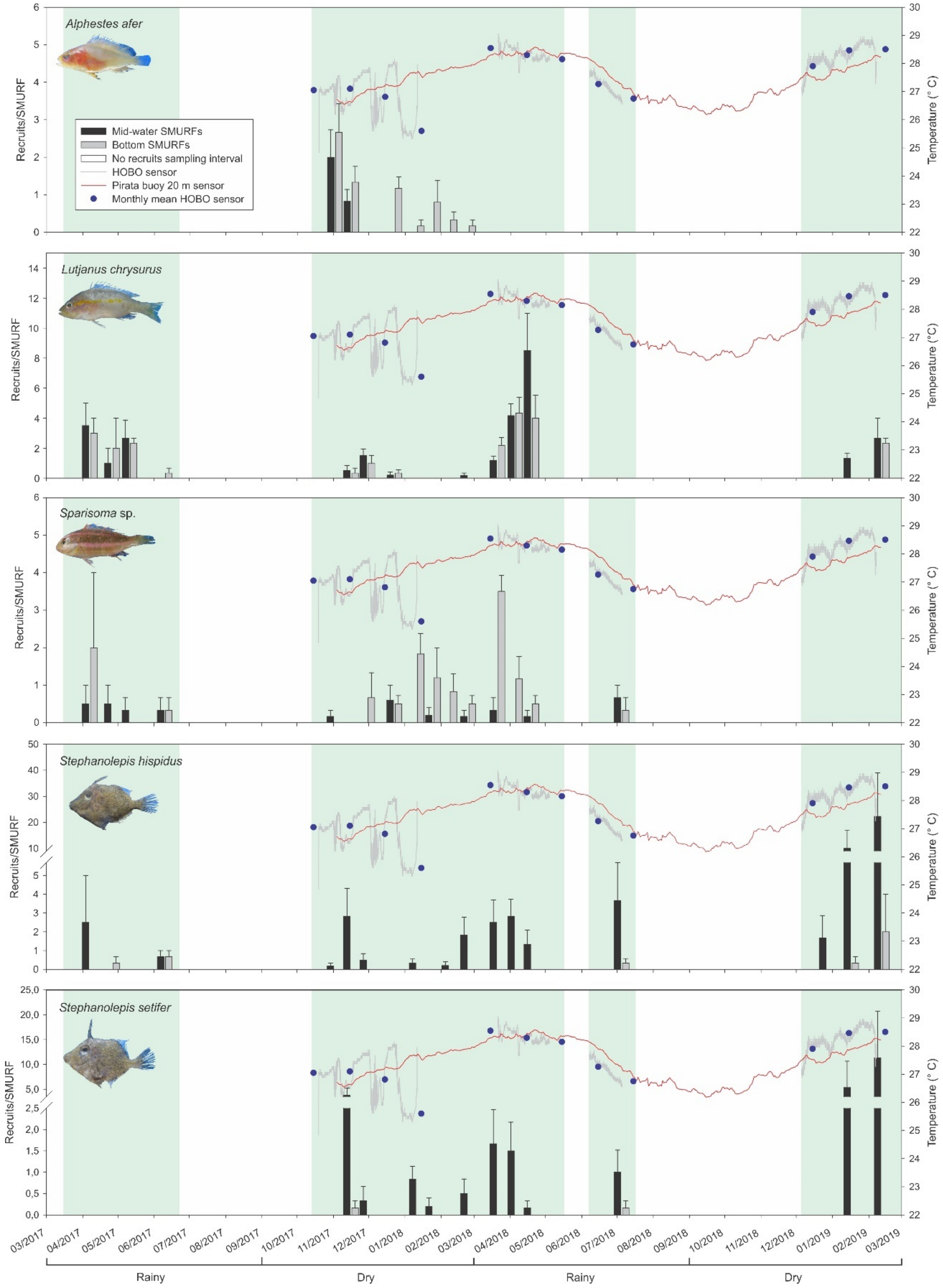
Sparisoma sp., *Stephanolepis hispidus* and *S. setifer* recruitment showed an inverse relationship with depth. While *Sparisoma* sp. recruited significantly in bottom SMURFs, *Stephanolepis* species were found in mid-water ones (Figura 7, Tabela 2). However, no significant relation between recruit abundance and the side of the shipwreck complex was found for the three species. *Sparisoma* sp recruitment was noted toward April in 2017 and 2018 when higher peaks occurred. Recruits of *Sparisoma* sp. were significantly more abundant in bottom SMURFs (Figura 7). Recruitment values for both *Stephanolepis* species showed no significant relation with time of year and were observed in both seasons. Despite the statistical results, higher numbers of recruits were sampled in the first months of 2019.

Tabela 2 – Results of Two-way PERMANOVA for the five taxons that contributed the most to the dissimilarity between samples.

Factor	*Alphestes afer*		*Lutjanus chrusurus*		*Sparisoma* sp.		*Stephanolepis hispidus*		*Stephanolepis setifer*	
	Pseudo-F	*p* (perm)	Pseudo-F	*p* (perm)	Pseudo-F	*p* (perm)	Pseudo-F	*p* (perm)	Pseudo-F	*p* (perm)
Depth	4.6045	**0.0332**	0.2988	0.5892	14.9070	**0.0004**	36.0150	**0.0001**	25.5040	**0.0001**
Side	0.0004	0.9834	0.0472	0.8258	1.5476	0.2185	0.6155	0.4340	0.0127	0.9145
Depth x Side	0.0527	0.8186	0.6888	0.4127	0.4437	0.5103	1.5235	0.2211	0.1437	0.7131

Fonte: O Autor (2020)

Figura 7 – Mean abundances (+standard error) of recruits of the five most abundant species during long-term monitoring experiments plotted together with depth temperatures recorded from HOBO dataloggers sensor and PIRATA 8S30W buoy.

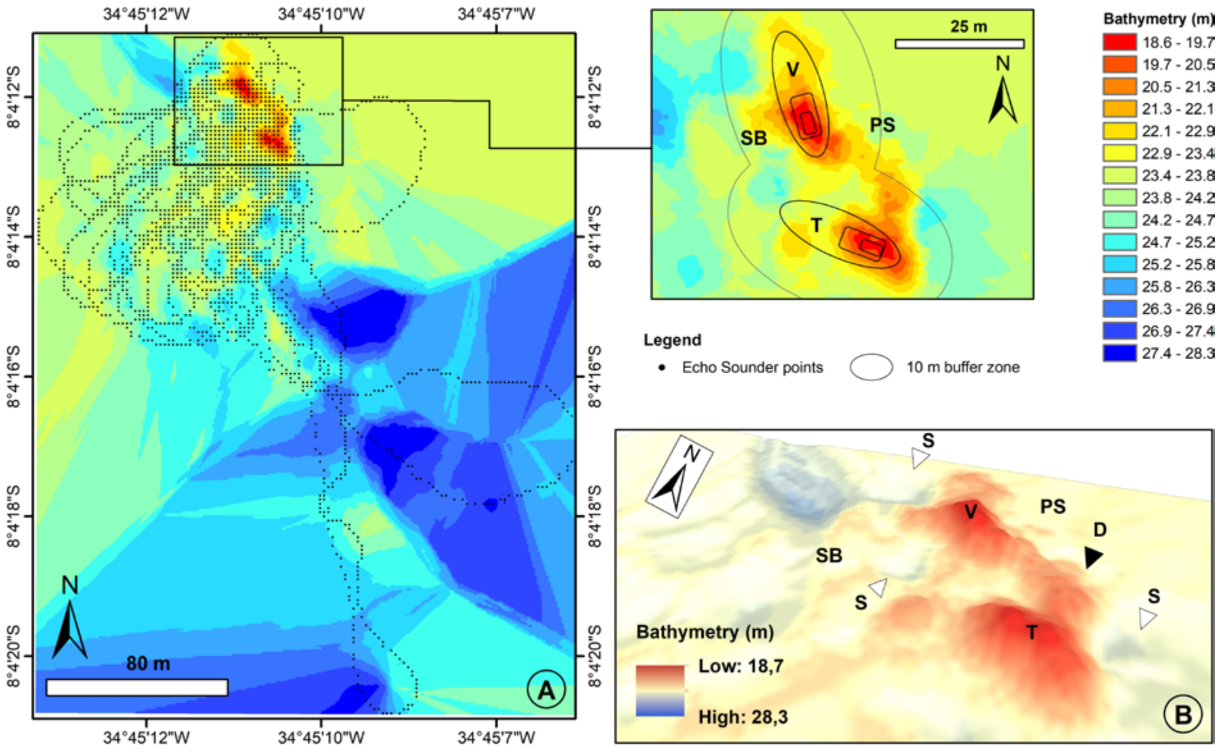


Fonte: O Autor (2020)

Bathymetric mapping of Taurus-Virgo shipwreck complex

Digital Bathymetric Model (DBM) results showed that Virgo's bow faces South-Southeast (S-SE) while Taurus's bow faces East-Southeast (E-SE). The Captain bridge from both vessels are at 18.6 m depth. Sea bottom depth in a 10 m radius around vessels' structures ranges between 25.2 to 19.7 m. DBM also showed that the Port side of the complex is shallower than the Starboard (Figura 8). The 3D DBM showed two formation features at the wrecks' site: scour and depositional zones.

Figura 8 – 2D (A) and 3D (B) Digital Bathymetric Model of Taurus-Virgo shipwreck complex detailing vessels Virgo (V) and Taurus (T) positions and Port side (PS) and Starboard (SB) sides. Scour zones (S) and Depositional zones (D) around a 10 m buffer are also identified.

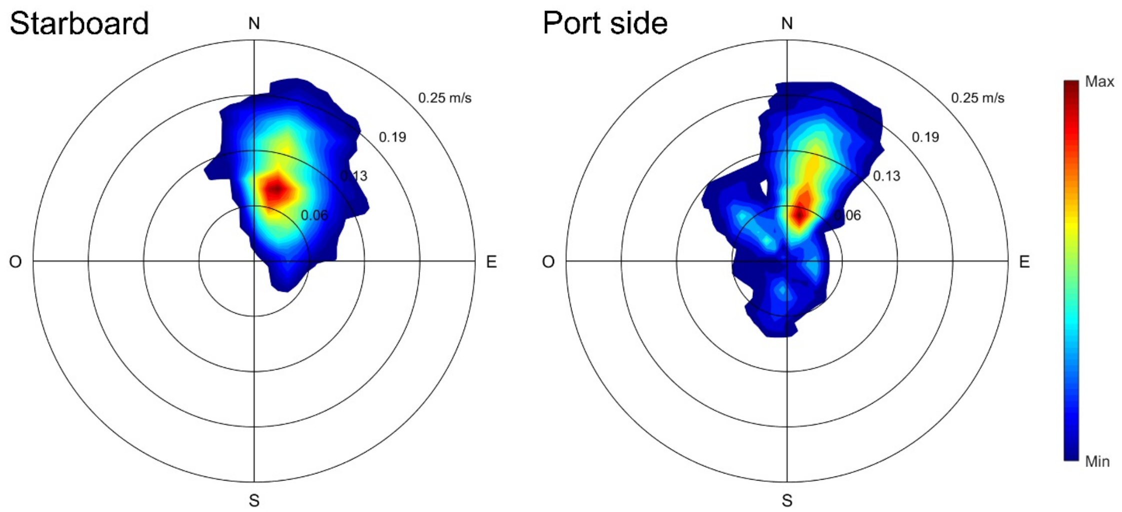


Fonte: O Autor (2020)

Hydrodynamics around shipwrecks and measurement of oceanographic parameters

During the short experiment at the wrecks, the mean current velocities registered were 0.06 m/s on the port side and 0.10 m/s in the starboard side of the Taurus-Virgo complex (Figura 9). The currents on starboard were more stable with a predominance of the N-NE direction. On the other hand, the currents to on the port side were more complex, showing the occurrence of opposite vectors (countercurrents), with directions N-NE, and S-SW.

Figura 9 – Polar frequency distributions of currents registered with two electromagnetic current meters from 7 June 2018 to 20 June 2018. Each current meter was positioned on each side (Starboard and Port side) of the Taurus-Virgo shipwreck complex.

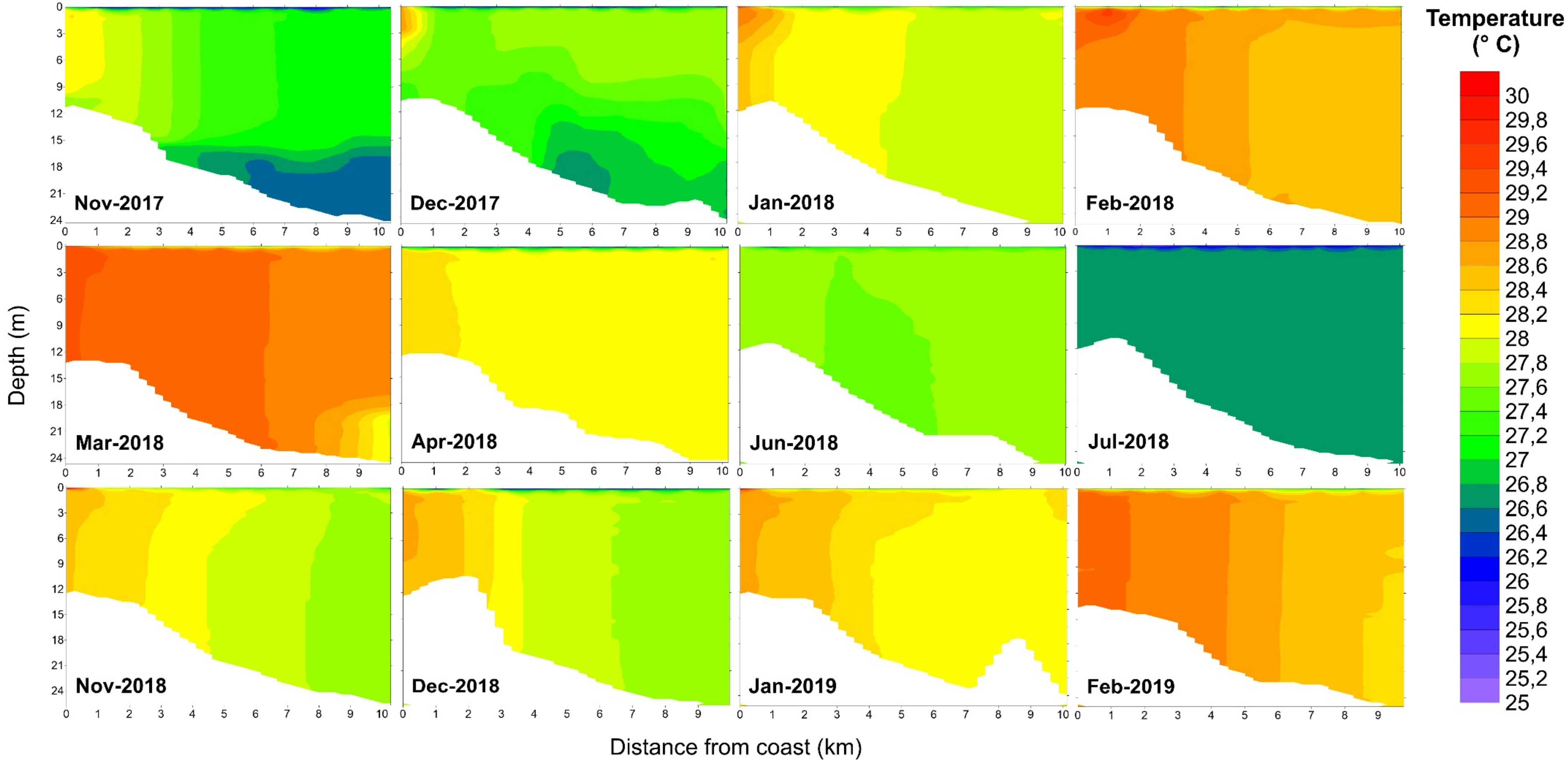


Fonte: O Autor (2020)

CTD profiles showed an unusual arrival of 1º-colder waters in November 2017 (still registered in December 2017) especially around the Taurus-Virgo shipwrecks area and depth (Figura 10) that was not registered in the following year. These waters contributed to an increase in oxygen saturation up to 98% in that month and year in the Taurus-Virgo area (Figura 11), and to a high homogenous turbidity from the coast to the shipwrecks (Figura 12).

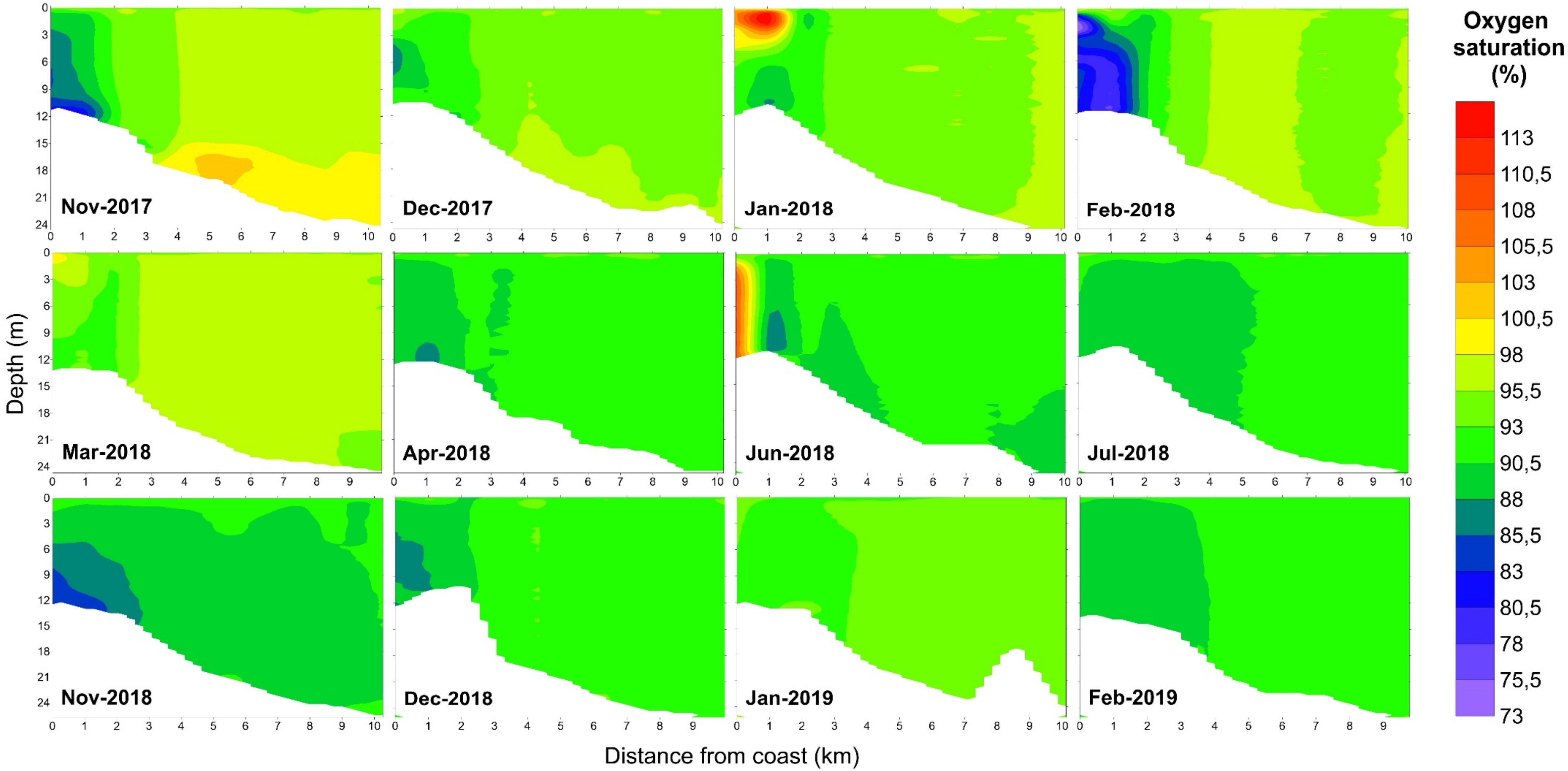
Salinity was always higher than 36.5 PSU around the shipwreck complex (Figura 13), and wider variations were only observed from the coast to the shipwrecks in April, 2018. The highest chlorophyll concentrations (Figura 14) were found in patches close to the surface (>10 µg/L). Concentration values ranging from 3 to 6 µg/L were found close to the bottom towards the Taurus-Virgo area mainly during the rainy season. Turbidity was also higher towards the shipwreck complex, near the bottom and during the rainy season.

Figura 10 – Distribution of seawater temperature along 12 transects carried out in the area between the port of Recife and the Virgo-Taurus shipwreck complex.



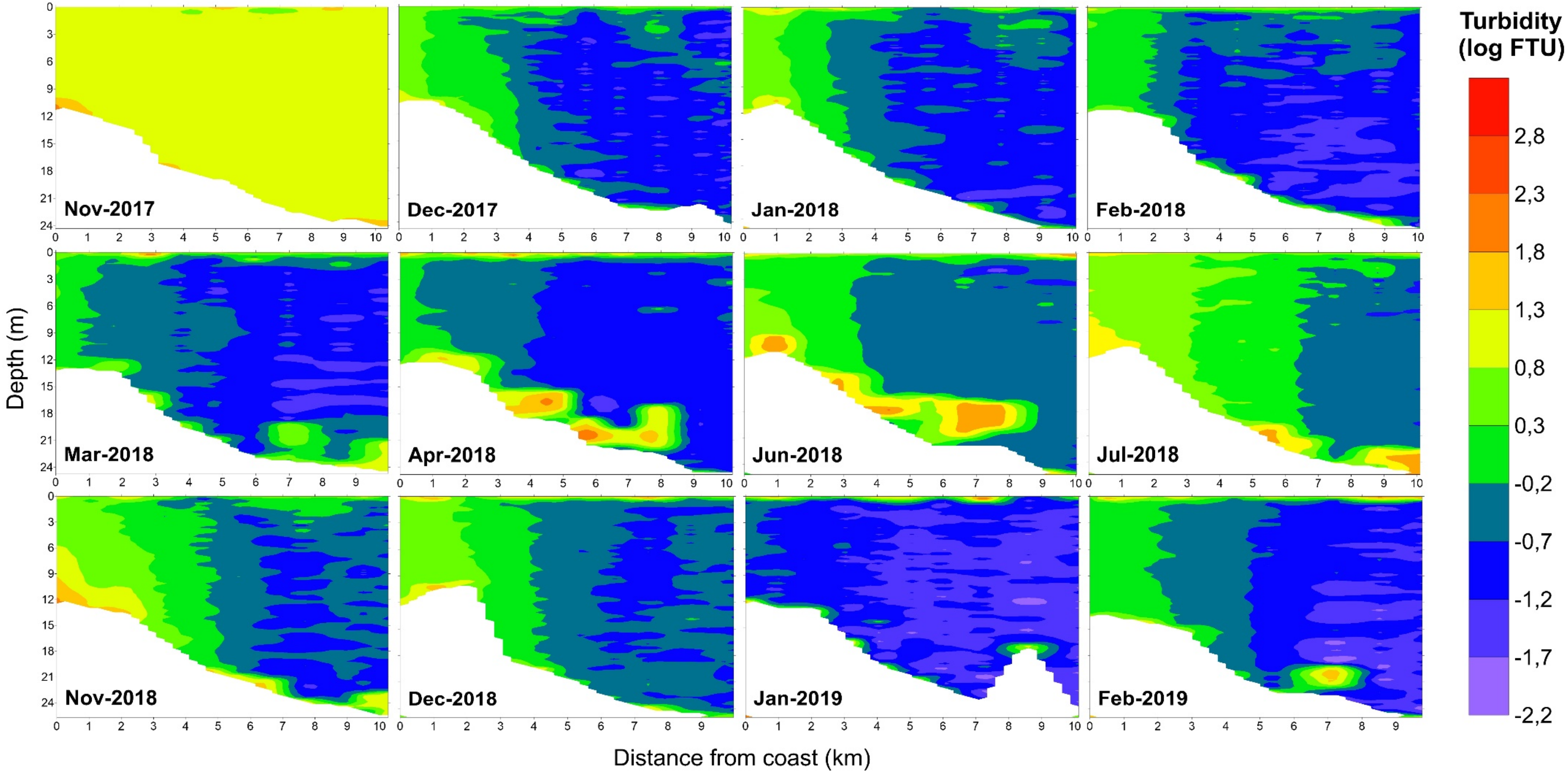
Fonte: O Autor (2020)

Figura 11 – Distribution of Oxygen saturation in seawater along 12 transects carried out in the area between the port of Recife and the Virgo-Taurus shipwreck complex.



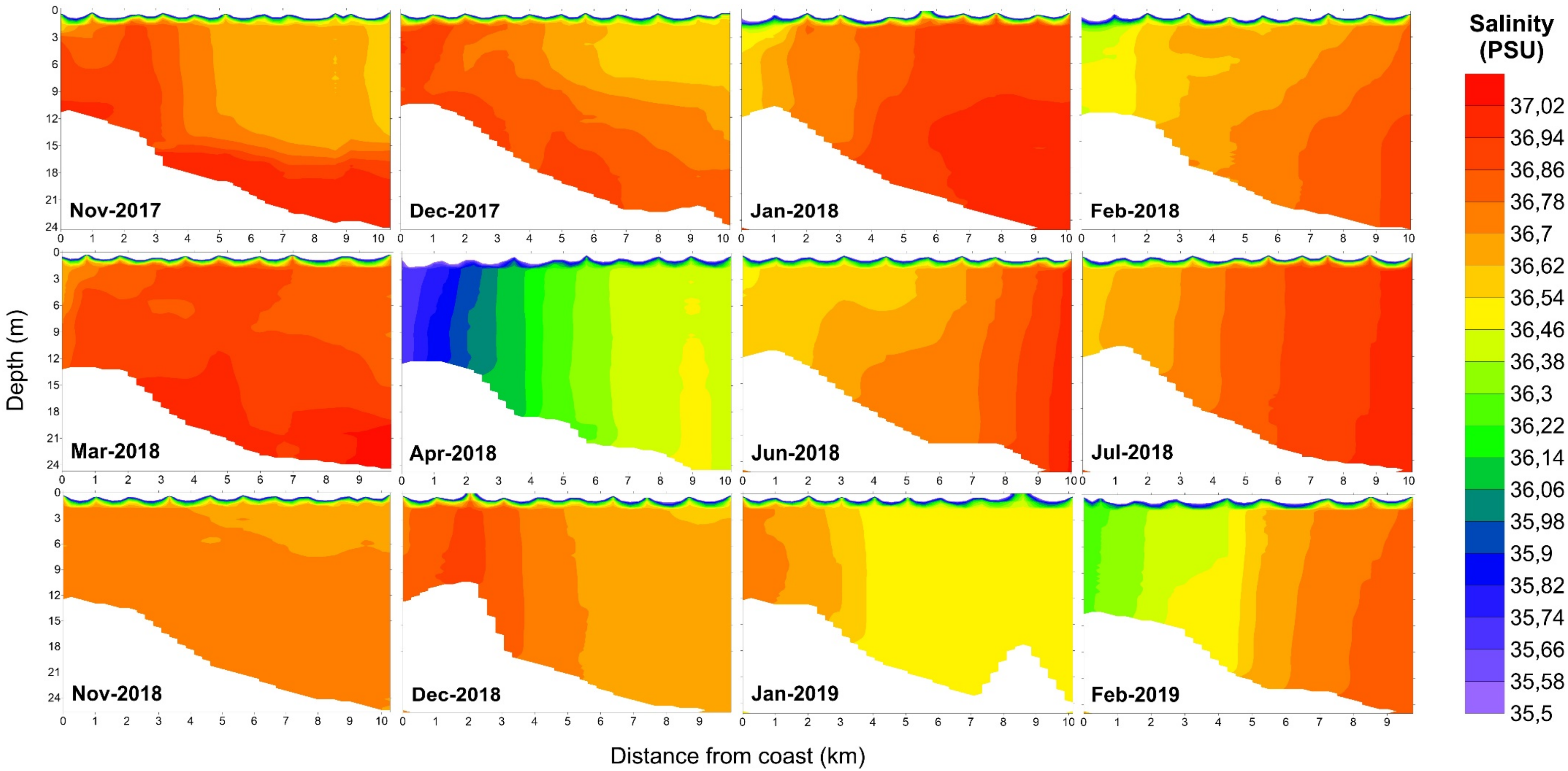
Fonte: O Autor (2020)

Figura 12 – Distribution of Log transformed Turbidity of seawater along 12 transects carried out in the area between the port of Recife and the Virgo-Taurus shipwreck complex.



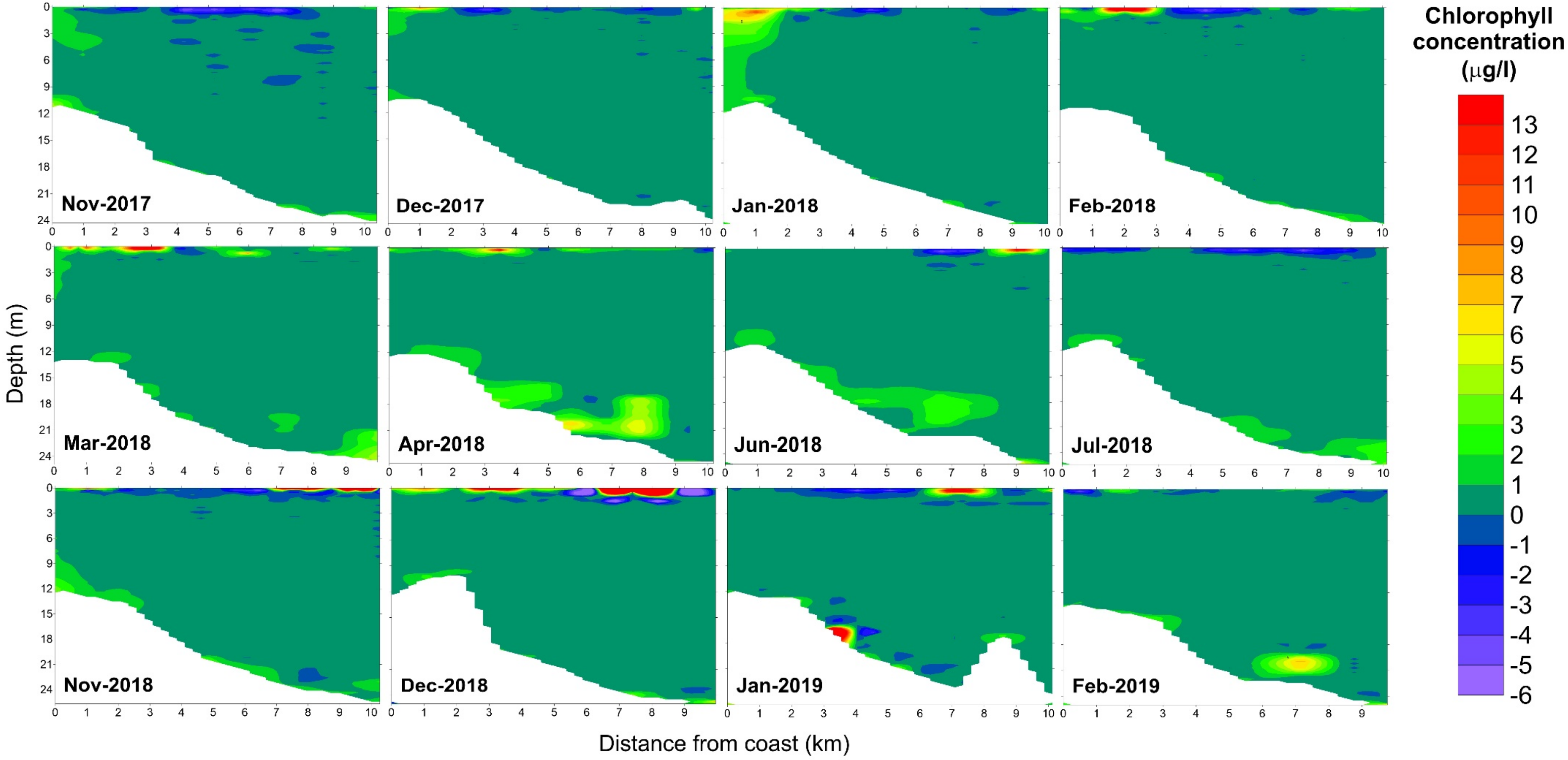
Fonte: O Autor (2020)

Figura 13 – Distribution of Salinity along 12 transects carried out in the area between the port of Recife and the Virgo-Taurus shipwreck complex.



Fonte: O Autor (2020)

Figura 14 – Distribution of Chlorophyll concentration in seawater along 12 transects carried out in the area between the port of Recife and the Virgo-Taurus shipwreck complex.



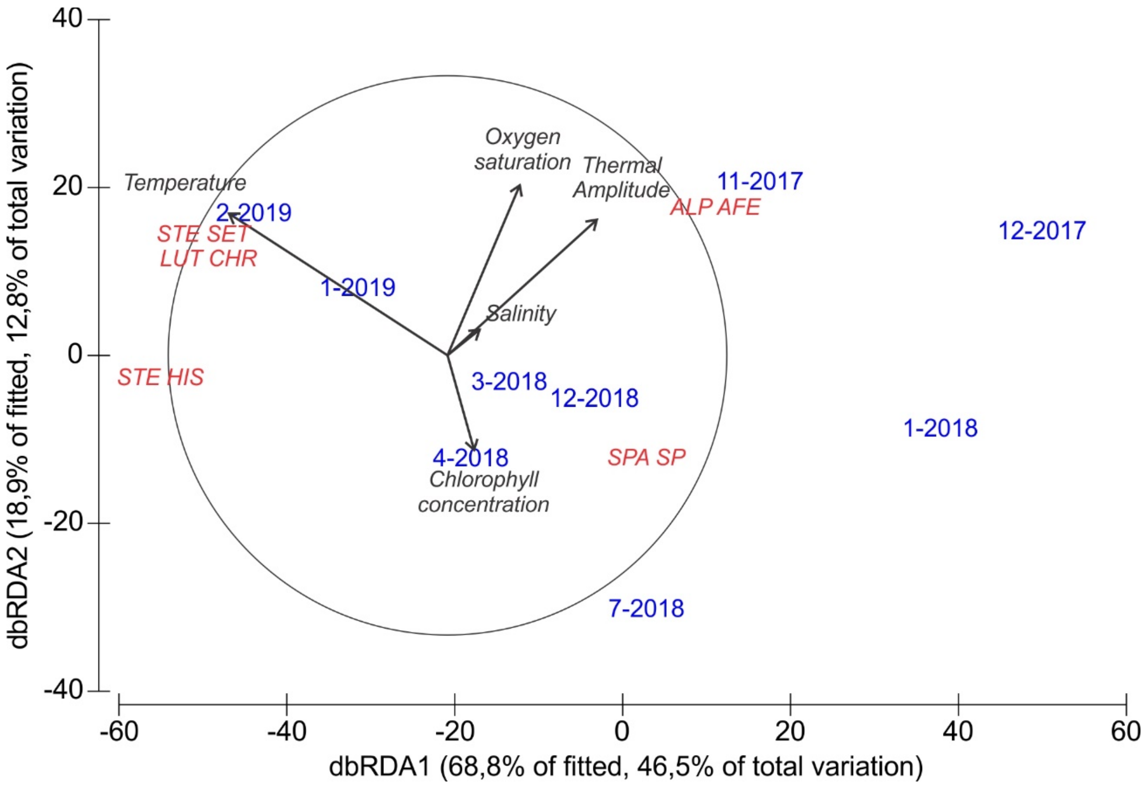
Fonte: O Autor (2020)

Relationships between biological data and oceanographic parameters

DistLM analysis showed that all five environmental variables contributed to a correlation of 0.67, although Temperature (HOBO) and Thermal amplitude (HOBO) alone were responsible for most of this correlation: 36% and 25%, respectively. Only Temperature (HOBO) was significantly correlated with biological data ($p = 0.009$).

In the dbRDA plot (Figura 15) *Alphestes afer* shows a strong correlation with the Thermal amplitude (HOBO) vector and with Nov-2017, Dec-2017 and Jan-2018 data sets. Diversely, *Lutjanus chrysurus*, *Stephanolepis hispidus* and *S. setifer* were more correlated with Temperature (HOBO) and Jan-2019 and Feb-2019 data sets.

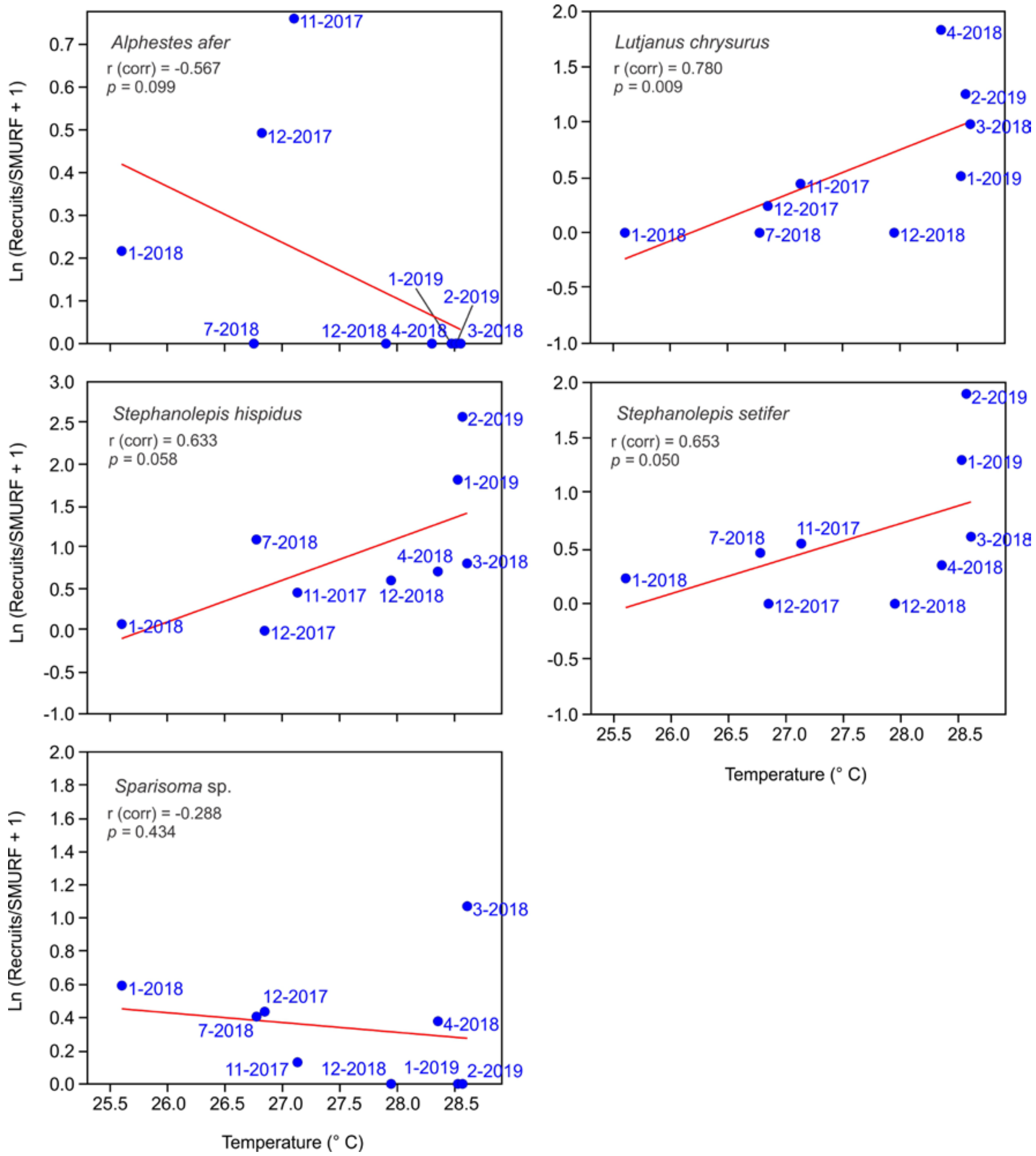
Figura 15 – Redundancy analysis based on the linear model (dbRDA) showing the most important predictor variables in the model. Date: Month-Year. *Stephanolepis hispidus* (STE HIS), *Stephanolepis setifer* (STE SET), *Lutjanus chrysurus* (LUT CHR), *Alphestes afer* (ALP AFE) and *Sparisoma* sp. (SPA SP).



Fonte: O Autor (2020)

Permutational regressions of ln (x+1)-transformed abundance data for the five most abundant species against Temperature (HOBO) and Thermal amplitude (HOBO) revealed a high positive correlation of Temperature (HOBO) and biological data for *L. chrysurus*, *S. hispidus* and *S. setifer*, and a negative correlation with *A. afer*. *Sparisoma* sp. species had no strong correlation with Thermal amplitude (Figura 16).

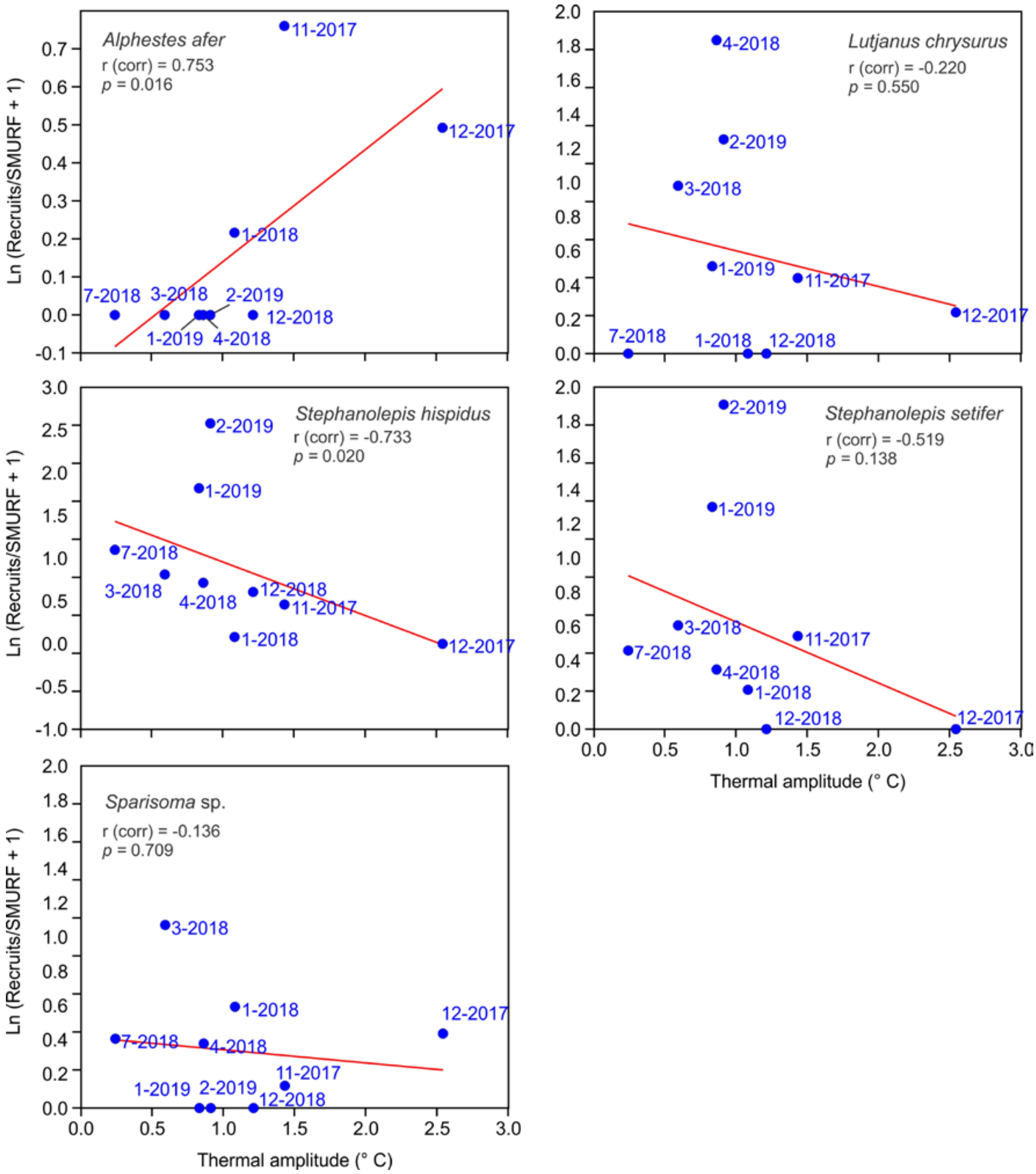
Figura 16 – Linear regression plots of Temperature (mean) with ln (x+1) transformed abundances of five species recruits sampled by SMURFs on the studied shipwrecks. r(corr) and p results from the Permutational linear model. Date: month-year.



Fonte: O Autor (2020)

On the other side, *A. afer* had the highest positive correlation with Thermal amplitude (HOBO) while *S. hispidus* and *S. setifer* had highly negative correlations. *L. chrysurus* had a low negative correlation with mean temperature recorded by HOBO sensor (Figura 17).

Figura 17 – Linear regression plots of the Thermal amplitude (mean) with ln (x+1) transformed abundances of five recruit's species sampled by SMURFs on the studied shipwrecks. r(corr) and p results from the Permutational linear model. Date: month-year.



Fonte: O Autor (2020)

DISCUSSION

The current research has generated important results on the diversity of fish that recruit near shipwrecks using FADs. 25 species of reef fish recruits were identified on the studied shipwrecks, which belong to 21 genera and 13 different families. Other studies carried out in the area registered a total of 95 fish species (COXEY 2008; MARANHÃO 2011), 15 of which were also identified in the present study.

Out of the 25 species identified in this research, seven were registered for the first time on shipwrecks in Pernambuco: *Decapterus tabl*, *Apogon robbyi*, *Astrapogon* sp., *Lutjanus buccanella*, *Doratonotus megalepis*, *Stephanolepis hispidus* e *Stephanolepis setifer*. This result shows that even though FAD technique only registered 25% of all species identified by visual census, it was able to increase ichthyofauna diversity records by 30%. These recruit species of the *Stephanolepis* genus (Monacanthidae) are different from the two others of the same family (*Aluterus scriptus* and *Cantherhines pullus*), which were registered on the studied shipwrecks in juvenile and adult phases by COXEY (2008) and MARANHÃO (2011). Thus, these results may imply that shipwrecks provide different environments for different life stages of some species even if they are phylogenetically close (e.g. family), as observed in these monacanthids.

There were three new records of reef fish associated with the shipwreck complex Taurus-Virgo; *Antennarius multiocellatus*, *Serranus baldwini* and *Mycteroperca interstitialis*. Additionally, the geographic distribution of *Apogon robbyi* was expanded to include Pernambuco State and to shallower depths. According to the previous record, this species was only registered in Paraíba State, at a 53-54 m depth (FLOETER *et al*. 2003, FEITOZA; ROSA; ROCHA, 2005). The record of new species associated with shipwrecks and the *A. robbyi* observation in Pernambuco may be an indication of the level of difficulty associated with registering fish recruits and/or smaller cryptic species (like apogonids) using visual census.

These records also suggest that FADs are important tools that contribute to the general knowledge of fish assemblages. At least for the five most abundant taxons identified on Taurus-Virgo shipwrecks (i.e. *Alphestes afer*, *Lutjanus chrysurus*, *Sparisoma* sp., *Stephanolepis hispidus* and *S. setifer*), the number of these species recruits was higher than the number of adults or juveniles ever registered in the same area (in BARROS, 2017; CORREIA, *et al*., in prep.).

It is interesting to notice that there is usually a high occurrence of carangids in FADs' studies around the world (STEPHAN; LINDQUIST, 1989; ROUNTREE, 1990; PAIVA *et al*., 2016; KLEIN *et al*., 2018, OLIVEIRA *et al*. in prep.). In these studies, fishes of the Carangidae family were observed in FADs placed in depths ranging from 1 to 7 meters. However, only 23 individuals of species *Decapterus macarellus* (22 individuals) and *Decapterus tabl* (1 individual) were observed in this research, and only in the pilot experiment in 2016. This low representativeness may be due to the general behavior of juvenile individuals of *Decapterus* genus, known to inhabit regions close to the surface (RICHARDS, 2005), and the FADs used in the present study were at minimum depths of 18 meters. Besides, carangids individuals are also associated with *Sargassum*, and are sampled by FADs in higher numbers during bloom seasons of this macroalgae genus (ROUNTREE, 1990).

Species of the *Stephanolepis* genus were also among the most abundant in other studies using FADs, especially *S. hispidus* (the most abundant species on the Taurus-Virgo complex), despite geographical and temporal differences (STEPHAN; LINDQUIST, 1989, ROUNTREE, 1990; PAIVA *et al*., 2016; OLIVEIRA *et al*., in prep). The great number of monacantids occurrences in FADs can also be related to the similarity of natural microhabitats formed by sargassum and floating, drifting materials, where monacantids usually recruit (RICHARDS, 2005).

The size of individuals sampled on the shipwrecks ranged from 0,9 to 6,1 cm and it is in conformity with other researches that applied FADs to study fish recruitment. The size of post-settlement fish in tropical reefs ranges from 0,8 to 3,5 cm (LEIS; CARSON-EWART; WEBLEY, 2002) and from 0,6 e 6,7 cm in rocky shores in temperate zones (KLEIN, 2016). This indicates that the fish captured in this study are mostly in between pre- and post-settlement phases, since their average size was 2,3. In natural reefs of Pernambuco the average size of pre settlement fish was 3,8 cm (GRANDE *et al*., 2019), which corroborates with the results of the present study.

Long term experiments were successful in indicating shifts in the structural patterns of recruits' assemblages. Seasonal differences were observed, in which fewer recruits were registered during the dry season when compared to the rainy season. To date, there were no scientific publications approaching seasonal variations of the region's shipwrecks' ichthyofauna. Nonetheless, other studies carried out in coastal ecosystems of Pernambuco indicate that during the dry season there is usually an increase in estuarine fish diversity (PAIVA *et al*., 2009) and in larval density, including in reef environments (SILVA-FALCÃO, 2012; SILVA-FALCÃO; SEVERI; DE ARAÚJO, 2013). According to the only seasonal variation assessment of adult fish, carried out using visual census on the four shipwrecks sunk in 2017 in Pernambuco (i.e. Virgo, Phoenix, Bellatrix and São José), fish diversity was lower during the dry season; on the other hand, density was higher (BARROS, 2017).

Due to its narrow width, Pernambuco's continental platform is also affected by oceanographic processes of larger scale, such as oceanic currents and climate. According to Schettini *et al*. (2017), considering the hydrography, continental influence is little, being noticeable only close to the coast. This means that even during the rainy season (May/August) there is no decrease in salinity due to increasing fluvial discharge, as the rivers in the region are considered very small. The main variation is related to wind action which is weakest in January and practically perpendicular to the coast. Wind direction varies and rotates through the year, reaching its wider angle in September and October, forcing the currents to the North (SCHETTINI *et al*., 2017). The lowest water transparency is usually registered during the rainy season on the shipwrecks of Pernambuco (SANTOS *et al*., 2010). In Puerto Rican coral reefs, lower transparency waters have been related with fish assemblages with lower species richness and diversity, in addition to low fish density (BEJARANO; APPELDOORN, 2013). Even though these authors have not estimated fish size, it is known that there is a tendency of higher concentration of juveniles, possibly linked to reduced predation pressure (BLABER; BLABER, 1980).

In the pelagic environment, prey availability also contributes to the increase of fish larvae abundance (BURROW; HORWOOD; PITCHFORD, 2011), since high biomasses of fish larvae can be supported by high growth rates of zooplankton and phytoplankton (PUSPASARI *et al*., 2018). As observed in a previous study on phytoplankton carried out on two other shipwrecks in Pernambuco (in average depths of 30 meters), these organisms' abundance was higher in the vessels' surrounding areas when compared middle and upper layers of the water column (SANTOS, 2012). In the region of Servemar X shipwreck, approximately 6 km away from the Taurus-Virgo complex, a seasonal pattern of increased phytoplankton abundance and diversity during the dry season was also described (SANTOS, 2012).

In a region of Gulf of Mexico where there is mixing of seawater and the Mississippi river plume, high biomasses of zooplankton were registered and related to an increase of biomasses of fish larvae, and, consequently, to higher survival rates from this stage to recruitment (GRIMES; FINUCANE, 1991). Considering that the fluvial influence on phytoplanktonic growth extends to more than 4 miles from the coast of Recife (ESKINAZI-LEÇA, 1997), the fish recruitment peak during the rainy season observed in this study may be related to higher larvae supply in the dry season, since this is the most productive season in the region.

The results for Taurus-Virgo complex showed that even though most of the recruitment occurs in the first months of the rainy season, the data has indicated a specific variation of seasonality in recruitment. Oppositely, *Alphestes afer*'s recruitment peak was registered during the dry season, in consonance with this species' spawning period (i.e. between August and October-December), as observed by Marques and Padovani (2011). However, *Alphestes afer*'s pelagic larvae duration (PLD) has not been recorded so far. Nonetheless, if this species' PLD is similar to the ones of other species from the same family, i.e. longer than 25 days (THRESHER 1984; BRULE *et al*. 2004), recruitment period will match with the spawning season.

The higher incidence of *Lutjanus chrysurus* recruits found from March to May in 2017 and 2018 on the shipwrecks studied in this research occurred after the spawning period described for this species (January to February) (CALADO-NETO; SILVA; MATTOS, 1997). This result is also corroborated by the greater number of pre-settlement fish captured between December and May by Grande *et al*. (2019). In other words, for the littoral zone of Pernambuco, *L. chrysurus*' spawning season possibly occurs around January and February; recruitment period from March to May and pre-settlement from May on, completing the cycle. This species' PLD is longer than 30 days (RILEY; HOLT; ARNOLD, 1995) and is related to the spawning season in the area and recruitment data presented here.

The recruitment period of a species of the genus *Sparisoma* (still unidentified) was registered in the Taurus-Virgo complex, occurring in all months, except from January to March 2019, accordingly with the available literature. Two species of *Sparisoma* have already been identified on the same shipwrecks: *S. axillare* and *S. frondosum* (MARANHÃO, 2011). These species spawn throughout the year (VÉRAS, 2008; VÉRAS *et al*., 2009) and the recruitment, at least for *S. axillare*, is also annually continuous (GASPAR, 2006). Nevertheless, most pre-settlement fish of this species were sampled in February in natural reefs of Pernambuco's coast (GRANDE *et al*., 2019), in accordance with the results, which showed that the higher peaks were found between January and March, suggesting a regional pattern. Both *Stephanolepis* species (*S. hispidus* and *S. setifer*) have this annual recruitment pattern, observed not only in Pernambuco but also in the Gulf of Mexico (RICHARDS, 2005). However, *S. hispidus* recruitment registered in Florida (USA) is considered seasonal, with low catches between December and April and high catches between May and November (CLEMENTS; LIVINGSTON, 1983), which probably correlates recruitment patterns with the climate.

Studies comparing recruit abundances sampled by different FADs models and at different depths are scarce. During the development of SMURFs models, Ammann (2004) showed that there were no differences in sampling recruitment abundance related to the SMURFs' depth position. A recent study (KLEIN, 2016) compared SMURFs placed on the bottom, in which one was suspended by a rope a few centimeters from the seafloor and the other was fixed on the bottom. The results of the aforementioned study showed that fixed models were more effective in sampling juvenile individuals, but the model suspended by a rope (similar to the ones used in the present study) was more effective in sampling recruits. The general results of the current study showed that there is a difference between the recruits' assemblages sampled by mid-water and bottom SMURFs, in which the bottom SMURFs registered higher species richness when compared with mid-water SMURFs. However, average total abundance of the sampled recruits showed no difference between depths. In a previous study, Leis, Carson-Ewart and Webley (2002) observed that more species were found in FADs near the bottom and registered higher abundance of the Apogonidae family. These findings corroborate with Klein (2016), who has also registered higher species richness in SMURFs placed on the bottom. Additionally, Klein (2016) also observed that most of the individuals sampled by SMURFS placed near the water surface were the carangid *Trachurus trachurus* (Linnaeus, 1758).

The present study has identified recruitment patterns not only related to seasonality, but also in relation to the proximity of the SMURF to the bottom, and conditioned to ecological characteristics of the sampled fish. Specimens of the families Apogonidae, Epinephelidae, Scaridae and Serranidae were mostly present in the bottom FADs, as they have close association with the substrate. Apogonids have a commensal relationship with mollusks and sponges, and their diet is based on small invertebrates (CARPENTER, 2002). Epinephelids and serranids inhabit coral reefs and muddy bottoms or seagrasses substrates and also feed on invertebrates, mollusks and fish (FERREIRA; GONÇALVES; COUTINHO, 2001; CARPENTER, 2002). According to Carpenter (2002), scarids are considered grazers of biofilm or small invertebrates that live on algae, corals or rocks, but the species that were found in the shipwrecks' area are considered herbivores (FERREIRA; GONÇALVES; COUTINHO, 2001).

The structure of recruit's assemblages also showed differences related to depth, reinforcing the distinct zonation found between depth strata, sea bottom and hull, also registered for adult fish assemblages in other studies on the same shipwrecks (COXEY, 2008; MARANHÃO, 2011; BARROS, 2017; CORREIA *et al*., in prep.). *Lutjanus chrysurus*' recruits feed on zooplankton (i.e. small crustaceans, fish and mollusks larvae) near the substrate

(BORTONE; WILLIAMS 1986, WATSON; MUNRO; GELL, 2002). It is possible that this generalist carnivore feeding behavior (FERREIRA *et al*., 2004) is the reason this species was found in both depths investigated in this study. Ontogenetic variations registered in feeding habits may explain the higher abundance of monacanthids in mid-water SMURFs. Recruits of the species *Stephanolepis hispidus* feed on zooplankton while the adults are substrate grazers (CLEMENTS; LIVINGSTON, 1983). The predilection towards mid-water and sub-superficial attractors shown by pre-settlement and recruits of the Monacanthidae family was also registered in many other studies (LEIS; CARSON-EWART; WEBLEY, 2002, BEN-DAVID; KRITZER, 2005; PAIVA *et al*., 2015).

On shipwrecks, every part of the vessels' structure may function as a distinct microhabitat for some species, as observed in other artificial constructions (OGDEN; EBERSOLE, 1981). This is evidenced by other studies which have shown distinct ichthyofauna in different locations of the vessel such as the deck, hull, cabin and interior spaces like the engine room (COXEY, 2008; LIPPI, 2011; BARROS, 2017). Apart from the vessels' physical structure, the development of microhabitats in shipwrecks may be due to oceanographic factors such as oceanic currents, generating Horseshoe and Lee wake vortices that remove or deposit sediment, creating deeper and shallower regions around the shipwrecks (QUINN, 2006). In the present study, the local current flow, which is predominantly North-Northeast (SCHETTINI *et al*., 2017), is attenuated by the shipwrecks structure, creating distinct features related to the current's velocity and flow pattern around the vessels. On the starboard region, stronger currents created excavated sites, while on the port side, local vortices produced sediment deposition zones.

This hydrodynamic regime registered around the shipwrecks facilitates the occurrence of some species. According to Lindquist and Pietrafesa (1989), only fish of the species *Decapterus punctatus* (Cuvier, 1829) reacted to the current action on a tugboat wreck and were more abundant upstream. Oppositely, Gobiidae recruits, which are demersal cryptic fishes typical of estuarine environments, prefer sheltered regions, protected from the currents (BREITBURG; PALMER; LOHER, 1995). However, the similarities between fish assemblages on each side of the Taurus-Virgo complex did not reflect the hydrodynamics differences registered between the vessels' port side and starboard. In general, the recruits' morphological traits are sufficient to allow them to withstand the varying velocities registered on each side of the shipwrecks studied here.

Pre-settlement larvae of reef fish are considered efficient swimmers (LEIS; MCCORMICK 2002). The aforementioned authors have demonstrated that these larvae swim approximately 6 times faster than larvae in previous developmental stages, and have concluded that swimming speeds are more related to the life stage than to the individuals' size. This conclusion seems to have been verified in the present study: even though the flow speed on starboard side was averagely two times faster than on port side, as the individuals were at the same developmental stage, it was possible to infer that the hydrodynamic patterns on both sides of the shipwrecks complex did not influence the fish assemblages' composition. In other words, the recruits' swimming speed must be enough for them to compensate for the differences in flow velocity that were found around the shipwrecks. These characteristics also contribute to the balance between dispersal and retention of post settlement fish in reef environments (FISHER, 2005).

Out of all oceanographic parameters studied here, only those related to sea water temperature have influenced the structure of recruit's assemblages. The mean lower temperatures were concurrent with the widest temperature range from November, 2017 to January, 2018. Apparently, the event which caused this thermal fluctuation was the arrival of deep cold waters in November and December of 2017, evidenced in the CTD profiles. This temperature is unusual in the region and time of the year, being usually at least 1°C hotter, ranging between 27.5º and 28º (SCHETTINI *et al.*, 2017).

Tropical fish recruits are known for having their pelagic larval stage shortened due to the increase of sea water temperature, which can also cause an increase in the abundance of certain species (MCCORMICK; MOLONY, 1995; SPONAUGLE; GRORUD-COLVERT; PINKARD, 2006). Fishes of species *Lutjanus chrysurus*, *Stephanolepis hispidus* e *S. setifer* responded similarly to the findings of these previous. On the other hand, *Alphestes afer* had its increased recruitment numbers related to lower temperatures and wider temperature range.

In small reefs, space limitation may hinder the settlement of a large number of larvae. For this reason, regions around the reefs may act as nursery habitats, dampening the larvae supply and providing the reefs with adult and juvenile populations, and even maintaining recruitment during less abundant times (PARRISH, 1989). Nursery habitats are defined as regions where the contribution for the production of new individuals of a certain species is greater than the production where the adult individuals occur (BECK *et al.*, 2001). Many species of adult fish and even large schools were observed only a few months after the sinking of Virgo (BARROS,

2017) and three other tugboats (Phoenix, Bellatrix and São José) in Pernambuco (CORREIA *et al*., 2018).

It is not clear where these fish came from, whether from unmapped natural reefs close by or other shipwrecks in the region. Information generated in this research may shed some light on the questions related to the role of shipwrecks, though this study does not affirm that the shipwrecks act as nursery habitats. It was possible to show that, at least in the surrounding of the wrecks, these environments are supplied with a significant number of recruits of species which the adults are not commonly observed in the area. The shipwrecks may act as both attractors and producers of ichthyofauna, depending on the life stage in which the fish reaches the structure.

The question on the role of shipwrecks on fish stocks still remains, and it is important to use more techniques and researches to try and understand marine connectivity. Thus, it is evident that actions that encourage the sinking of structures in the ocean under ecological pretexts must be cautious and seek to solve these basic questions first. Additionally, claims on the ecological advantages to justify the intentional sinking of vessels as a mitigating measure may not be useful if it is followed by ecosystemic impact, such as the overexploitation of fish on shipwrecks (CASTANHARI; TOMÁS; ELLIFF, 2012) and bioinvasion (CREED *et al*., 2016). Specifically concerning bioinvasion, once the artificial reefs are affected by it, they may act as "bridges" promoting the displacement of the invasive species to natural reefs (CASTANHARI; TOMÁS; ELLIFF, 2012). For example, it was recently observed (2019 - 2020) in Pernambuco state that the 5 most recent shipwrecks (among which, the Virgo vessel) were colonized by the sun coral of the genus *Tubastraea* (MIRANDA *et al*, 2020).

The present study, apart from being pioneer for the Northeast region of Brazil, has demonstrated that the biological traits of each species, the water column depth and other oceanographic parameters (especially mean temperature) influence fish recruitment in artificial reefs. However, further studies are necessary, aiming to specify larvae's region of origin and the destination of the recruits that reach maturity and thus, explicitly demonstrating the role of artificial environments.

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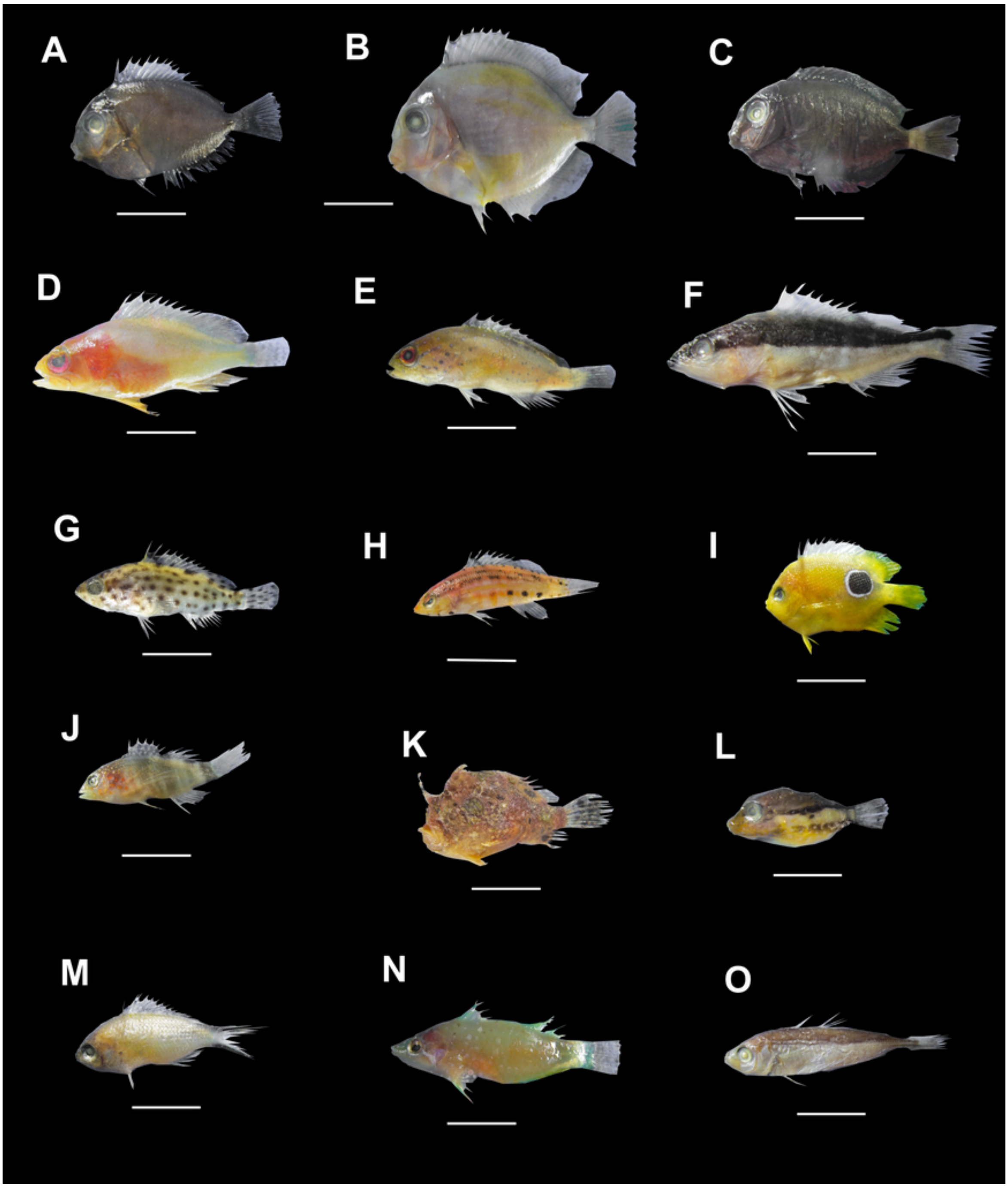
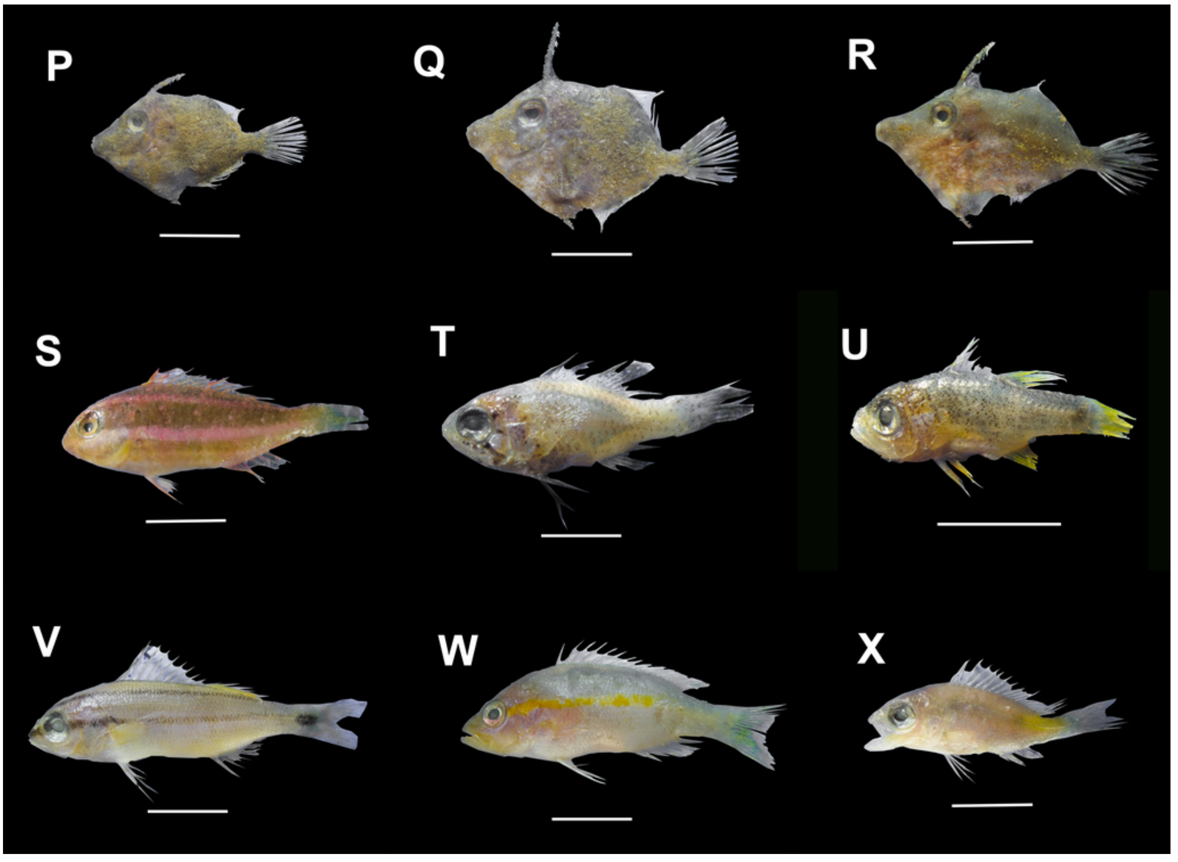
SUPPLEMENTARY MATERIAL

Figura 18 – Taxons of fish recruits sampled with SMURFs Family Acanthuridae: *Acanthurus bahianus* (A), *Acanthurus coeruleus* (B), *Acanthurus chirurgus* (C), Family Epinephelidae: *Alphestes afer* (D), *Cephalopholis fulva* (E), *Mycteroperca interstitialis* (F), *Epinephelus adscensionis* (G), Family Serranidae: *Serranus baldwini* (H), Family Pomacanthidae: *Holacanthus tricolor* (I), Family Cirrhitidae: *Amblycirrhitus pinos* (J), Family Antennariidae: *Antennarius multiocellatus* (K), Family Tetraodontidae: *Canthigaster figueiredoi* (L), Family Pomacentridae: *Chromis multilineata* (M), Family Labridae: *Doratonotus megalepis* (N), Family Carangidae: *Decapterus macarellus* (O). For more information about the above species see Tabela 3. Lack of *Decapterus tabl* is due to specimen destruction during identification. Scale bar: 1 cm.



Fonte: O Autor (2020)

Figura 18 – continuation. Monacanthidae: *Stephanolepis hispidus* (P), *Stephanolepis setifer* (Q), *Monacanthus ciliatus* (R), Family Scaridae: *Sparisoma* sp. (S), Family Apogonidae: *Astrapogon* sp. (T), *Apogon robbyi* (U), Family Haemulidae: *Haemulon aurolieatum* (V), Family Lutjanidae: *Lutjanus chrysurus* (W), *Lutjanus buccanela* (X). For more information about the above species see Tabela 3. Scale bar: 1 cm



Fonte: O Autor (2020)

4 CONSIDERAÇÕES FINAIS

A presente tese demonstra que as estruturas de agregação podem ser técnicas bastante confiáveis para o estudo de monitoramento nos estágios iniciais da vida de peixes em regiões tropicais e próximas a ambientes consolidados. As estruturas do modelo SMURF amostraram a maior abundância de recrutas em relação ao modelo ARM. Ambas estruturas apresentam várias vantagens operacionais: são fáceis de serem construídas, podem ser instaladas de maneira padronizada, obedecendo o desenho do experimento, no fundo marinho ou na coluna d’água e recolhidas de forma simples sem necessidade de utilização de maquinário. A facilidade de instalação também permite amostrar significantes quantidades de organismos em diferentes estratos, considerando-se o modelo da estrutura de agregação empregado e a dinâmica de massas da região pesquisada para garantir que a estrutura de sustentação se mantenha na profundidade planejada.

As estruturas do tipo SMURF também amostraram uma riqueza de espécies de recrutas bastante representativa. Nos experimentos desenvolvidos nos naufrágios Taurus-Virgo, pode-se registrar sete novas ocorrências para esses tipos de ambientes artificiais e uma nova ocorrência de espécie (*Alfestes afer*) para Pernambuco. Os registros de recrutas podem indicar seu comportamento ecológico sazonal. No presente caso, durante a estação chuvosa ocorreu a maior abundância de recrutas de um modo geral, entretanto, essa relação sazonal variou entre as cinco espécies mais abundantes no estudo.

Pela primeira vez, um modelo digital batimétrico foi produzido para a região dos naufrágios aqui estudados, revelando as informações oceanográficas sobre a movimentação do substrato ao redor desses recifes artificiais. Também - pela primeira vez - foi registrada diferença no hidrodinamismo ao redor desse complexo durante a estação chuvosa.

A análise dos dados de hidrodinamismo, entretanto, não indicou haver diferenças na ictiofauna de recrutas que vive nas áreas mais e menos abrigada do complexo formado pelos naufrágios. Houve diferença quanto aos posicionamentos dos SMURFs em relação à profundidade (coluna d’água e fundo). Esses resultados foram associados provavelmente a características ontogenéticas das espécies estudadas que definem os hábitats mais prováveis para ocorrência de cada uma delas na fase de recrutamento. O estudo mostrou também que há influência da temperatura da água sobre a comunidade de recrutas pesquisada. A relação entre as espécies mais abundantes e este fator oceanográfico pode ser direta ou indireta.

Os ambientes artificiais dos naufrágios parecem ser abastecidos com aportes larvais em quantidades suficientes para formar populações de recrutas de peixes para determinadas espécies. Os resultados da presente pesquisa sugerem que esses ambientes podem ser considerados berçários de vida marinha, mas para afirmar esta constatação seria necessário avaliar a migração entre indivíduos, em diferentes fases de vida, para recifes naturais. A escassez de informação sobre a existência de recifes naturais submersos próximos aos naufrágios torna bastante difícil a realização de investigações que sustentem hipóteses como essa. Por fim, mostrou-se que existe recrutamento de peixes em ambientes artificiais formados por naufrágios, mas há necessidade de mais evidências para se compreender como funcionaria esse berçário.

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