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PROSPECÇÃO PESQUEIRA DE TELEÓSTEOS DE PROFUNDIDADE NO TALUDE DE PERNAMBUCO, BRASIL

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UNIVERSIDADE FEDERAL RURAL DE PERNAMBUCO
PRÓ-REITORIA DE PESQUISA E PÓS-GRADUAÇÃO
PROGRAMA DE PÓS-GRADUAÇÃO EM RECURSOS PESQUEIROS E AQUICULTURA

PROSPECÇÃO PESQUEIRA DE TELEÓSTEOS DE PROFUNDIDADE NO TALUDE DE PERNAMBUCO, BRASIL

Alessandra Maria Advincula Pires

Tese apresentada ao Programa de Pós-Graduação em Recursos Pesqueiros e Aquicultura da Universidade Federal Rural de Pernambuco como exigência para obtenção do título de Doutora.

Prof. Dr. FABIO HISSA VIEIRA HAZIN
Orientador

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PRÓ-REITORIA DE PESQUISA E PÓS-GRADUAÇÃO PROGRAMA DE PÓS-GRADUAÇÃO EM RECURSOS PESQUEIROS E AQUICULTURA

DIVERSIDADE E ESTRATÉGIA DE VIDA DE TELEÓSTEOS DE PROFUNDIDADE DA COSTA DE PERNAMBUCO, BRASIL

Alessandra Maria Advincula Pires

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Resumo

Poucos estudos têm sido desenvolvidos até o momento sobre a fauna de profundidade na costa nordeste do Brasil, especialmente devido à ausência de pesca sobre esses recursos, além da carência de atividades científicas exploratórias em águas profundas. Buscando contribuir para o conhecimento sobre a fauna marinha no noroeste do Atlântico Sul, esse estudo registra a ocorrência de novas espécies de teleósteos no talude continental de Pernambuco, analisa a distribuição vertical e formação de assembleias, avalia a riqueza, diversidade e dominância em diferentes profundidades e reporta informações sobre a estrutura populacional e reprodução do teleósteo mais abundante (*Physiculus kaupi*). Entre outubro de 2014 a março de 2018 foram realizadas 24 coletas abrangendo 30 lances com espinhel e 38 lances com covos em profundidades de 200 a 600 m no talude de Pernambuco. Durante o estudo, onze espécies de teleósteos foram encontradas, oito representando os primeiros registros para a costa de Pernambuco (*Physiculus kaupi*, *Pontinus rathbuni*, *Antigonia capros*, *Conger esculentus*, *Dysommina rugosa*, *Gymnothorax maderensis*, *Gymnothorax conpersus* e *Gymnothorax polygonius*) e três já registrados no estado (*Lopholatilus villarii Epinephelus niveatus* e *Lutjanus vivanus*). Sobre os novos registros são indicadas as coordenadas e profundidades de coleta, características merísticas e morfométricas e comentários sobre a distribuição das espécies em todo o mundo. Análises de classificação e ordenação, utilizando a abundância relativa como captura por unidade de esforço (CPUE) em número de indivíduos, foram realizadas a partir de oito espécies capturadas em 18 lançamentos de covos de outubro de 2014 a fevereiro de 2018 (*P. kaupi*, *G. maderensis*, *G. polygonius*, *G. polygonius*, *G. conspersus*, *C. esculentus*, *P. rathbuni*, *A. capros* e *L. vivanus*). Os resultados indicam que os teleósteos encontrados são comuns em ambientes profundos, exceto *L. vivanus* que pode ser encontrado acima de 200 m, e moreias, que ocorrem apenas em regiões tropicais e subtropicais. Não foi detectada a formação clara de assembleias entre a composição taxonômica em termos de abundância relativa por profundidade, mas uma leve tendência indica a formação de uma zona de transição a uma profundidade de 300 m, a partir da qual a riqueza, a diversidade e a dominância começam a diminuir. As investigações sobre a estrutura populacional e reprodução do *P. kaupi* mostram uma maior proporção de fêmeas na população, particularmente em profundidades mais rasas, com possível migração ontogênica em função de alimentação e reprodução e características reprodutivas semelhantes ao que ocorre em outras espécies de Gadiformes e de profundidade, como uma desova contínua, desenvolvimento ovariano assincrônico e fecundidade baixa. O tamanho de primeira maturação para as fêmeas foi estimado em 17,9 cm de comprimento total. Os resultados apresentados fornecem uma linha de base que permitirá o monitoramento de futuras mudanças na estrutura e diversidade das populações de teleósteos de profundidade que ocorrem no talude de Pernambuco.

Palavras-chave: teleósteos de profundidade; novos registros; diversidade; assembleias; reprodução.

Abstract

Few studies have been carried out to date on the deep-sea fauna of the northeast coast of Brazil, especially due to the lack of commercial fishing on these resources, in addition to the lack of exploratory scientific activities on the sea floor. Seeking to contribute to the knowledge about marine fauna in the northwest of the South Atlantic, this study records the occurrence of new species of teleosts in the continental slope of Pernambuco, analyzes the vertical distribution and formation of assemblages, evaluates the richness, diversity and dominance at different depths and reports information on the population structure and reproduction of the most abundant teleost (*Physiculus kaupi*). Between October 2014 and March 2018, 24 fishing surveys were carried out covering 30 fishing sets with longline and 38 sets with bottom traps at depths of 200 to 600 m. During the study, eleven species of teleosts were found, eight representing the first records for the coast of Pernambuco (*Physiculus kaupi, Pontinus rathbuni, Antigonia capros, Conger esculentus, Dysommina rugosa, Gymnothorax maderensis, Gymnothorax conpersus and Gymnothorax polygonius*) and three already known (*Lopholatilus villarii Epinephelus niveatus* and *Lutjanus vivanus*). Data on the new species recorded include the coordinates and depths of collection, meristic and morphometric characteristics and comments on the distribution of species worldwide. Classification and ordering analysis, using abundance as capture per unit of effort (CPUE) in number of individuals of eight species, were carried out from eighteen traps fishing sets performed from October 2014 to February 2018 (*P. kaupi, G. maderensis, G. polygonius, G. polygonius, G. conspersus, C. esculentus, P. rathbuni, A. capros* and *L. vivanus).* The results indicate the teleosts found are common in deep water, except for *L. vivanus* and moray eels, which can be found, respectively, above 200 m and only in tropical and subtropical regions. There was no clear formation of assemblages among the species in terms of relative abundance by depth, but a slight trend that indicates the a transition zone at 300 m depth, from where richness, diversity and dominance begin to decrease. The data on the population structure and reproduction of *P. kaupi* showed a higher proportion of females, particularly at shallower depths, with possible ontogenic migration in function of feeding and reproduction. Reproductive characteristics similar to several Gadiformes species and deep-sea species, as a continuous spawning, asynchronous ovarian development and low average fertility was also observed in *P. kaupi*. The first maturation size for *P. kaupi* females was estimated at 17.9 cm total length. The results provide a baseline which allows the monitoring of future changes in the structure and diversity of the depth teleosts population that occurs in the continental slope off Pernambuco.

Key words: deep-sea teleosts; new records; diversity; assemblages; reproduction.

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Sumário

1. Introdução

Apesar dos diversos esforços empreendidos em todo o mundo em décadas recentes com o objetivo de expandir as informações disponíveis sobre a fauna demersal de águas profundas (FUJITA et al., 1995; KINGSTON e MANIKANDAVELU, 1998; PROKOFIEV, 2006; BAKER et al., 2012), o conhecimento acerca desse ambiente e dos animais que o habitam é ainda escasso e fragmentado, em razão, principalmente, das dificuldades logísticas envolvidas na sua exploração.

Naturalmente, a maioria desses esforços têm se desenvolvido em locais onde a pesca possui grande potencial econômico, como no Mar Mediterrâneo (MASSUTÍ et al., 1995; MORALES-NIN et al., 1996; CARRASÓN e MATALLANAS, 2002; FERNANDEZ-ARCAYA et al., 2016; ROMEU et al., 2016), no Atlântico Norte (MERRETT et al., 1991; KOSLOW, 1993; ALLAIN, 2001) e, no caso do Brasil, nas regiões sul e sudeste (HAIMOVICI et al., 1994; FIGUEIREDO et al., 2002; BERNARDES et al., 2005; COSTA et al., 2006).

No Atlântico Norte e Mar Mediterrâneo, pesquisas sobre a fauna de mares profundos têm sido realizadas ao longo de várias décadas, permitindo a geração de um volume significativo de informações acerca de sua composição, densidade, riqueza, estrutura das comunidades e biologia. Outros estudos têm buscado identificar tendências na distribuição batimétrica (MACPHERSON e DUARTE, 1991; MERRETT et al., 1991; D’ONGHIA et al., 2004, 2006), comparação entre a fauna de diferentes locais (CARTES et al., 2004; MASSUTÍ et al., 2004) e, mais recentemente, estudos de monitoramento e desenvolvimento de estratégias de conservação de ambientes profundos frente à mineração do assoalho marinho (TRANUM et al., 2019; DANOVARO et al., 2020).

No Brasil, pesquisas sobre espécies de águas profundas não são recentes, tendo se iniciado em 1873 com expedições de navios estrangeiros de pesquisa, cujos registros se estendem até meados de 1960, a exemplo do Challenger, Le Travailleur, Le Talisman e Albatross (GÜNTHER, 1880; VAILLANT, 1888; GARMAN, 1899; GOODE e BEAN, 1896). Contudo, durante esse período poucas amostras biológicas foram coletadas e conservadas. Em 1987 ocorreu a primeira expedição direcionada para o estudo da ictiofauna demersal profunda em águas brasileiras, por meio de redes e dragas, tendo sido coletadas amostras em até 5.155 m de profundidade na plataforma continental, talude e região abissal das montanhas submarinas da Cadeia Vitória-Trindade (SÉRET e ANDREATA, 1992).

A partir da década de 90, trabalhos realizados no âmbito do Programa REVIZEE (Programa de Avaliação do Potencial Sustentável dos Recursos Vivos na Zona Econômica Exclusiva) contribuíram de forma significativa para o conhecimento da fauna de profundidade e sua biologia em águas brasileiras (HAIMOVICI, 1998; FIGUEIREDO et al., 2002; MINCARONE et al., 2008; TAVARES e SEREJO, 2009; PAIVA et al., 2011). A maioria desses estudos, contudo, se concentraram mais uma vez nas regiões sul e sudeste, tendo focado principalmente no diagnóstico da biodiversidade, registro de novas espécies e distribuição batimétrica, com um esforço de pesquisa comparativamente muito mais reduzido na região nordeste e nas estratégias de vida das espécies.

Dessa forma, esse trabalho pretende não somente investigar a ocorrência de teleósteos de profundidade na costa de Pernambuco, mas também estudar a possível formação de assembleias e a estrutura populacional da fauna citada, aportando informações sobre a biologia da espécie mais abundante, a fim de melhor conhecer as suas estratégias de vida.

2. Objetivos

Realizar o levantamento e identificação dos teleósteos de profundidade na costa de Pernambuco, analisando a abundância relativa e distribuição batimétrica das espécies encontradas e gerar informações sobre a biologia e estrutura populacional da espécie mais abundante.

Objetivos específicos

a) Realizar o levantamento e identificação dos teleósteos de profundidade coletados na costa de Pernambuco;

b) Analisar a abundância relativa e a distribuição batimétrica das espécies de teleósteos capturados na costa de Pernambuco;

c) Realizar o estudo de estrutura populacional e reprodução do teleósteo mais abundante.

3. Artigo Científico I

Novas ocorrências de teleósteos de profundidade na costa de Pernambuco, nordeste do Brasil

Artigo científico a ser enviado para a revista “Brazilian Journal of Oceanography”

Novas ocorrências de teleósteos de profundidade na costa de Pernambuco, nordeste do Brasil

Resumo: Poucos estudos têm sido desenvolvidos até o momento sobre a fauna de profundidade na costa nordeste do Brasil, especialmente devido à ausência de pesca sobre esses recursos, além da carência de eatividades científicas exploratórias, seja na coluna d'água, seja no assoalho marinho. Buscando contribuir para o conhecimento sobre a fauna marinha de profundidade na costa de Pernambuco, entre outubro de 2014 e março de 2018, foram realizadas coletas com armadilhas de fundo e espinhel vertical, em profundidades entre 200 e 600 m. Das onze espécies obtidas, oito (*Physiculus kaupi*, *Pontinus rathbuni*, *Antigonia capros*, *Conger esculentus*, *Dysommina rugosa*, *Gymnothorax maderensis*, *Gymnothorax conpersus* e *Gymnothorax polygonius*) representam novos registros para a costa de Pernambuco. Nesse trabalho, além de registrarmos a ocorrência dessas espécies, detalhamos as suas características merísticas e morfológicas e comentamos sobre a sua distribuição no mundo e no Brasil.

Palavras-chave: armadilhas de fundo, espinhel, novos registros, nordeste, Brasil.

Introdução

Vários esforços têm sido empreendidos em todo o mundo com o objetivo de expandir o conhecimento acerca da fauna marinha demersal de águas profundas (Fujita et al., 1995; Kingston e Manikandavelu, 1998; Prokofiev, 2006). O mar profundo, constituído pelo ambiente abaixo de 200 m de profundidade, é o maior habitat do planeta, possuindo mais de um bilhão de quilômetros cúbicos de água e representando 75% da biosfera global (Angel, 1997; Robison, 2004). As características desse ambiente incluem ausência de luz solar, baixas temperaturas, elevada pressão e produção primária ausente, com exceção da atividade de algumas bactérias quimiotróficas. Essa combinação levou à formação de uma fauna especializada, tornando espécies incomuns em águas rasas, abundantes nos mares profundos (Drazzen e Suton, 2017).

Apesar do conhecimento acerca da história de vida da fauna de profundidade ter aumentado nos últimos anos, grandes lacunas ainda permanecem, principalmente devido à elevada complexidade e custos envolvidos na realização de coletas mais profundas que 200 m. Por essa razão, a maioria das publicações referem-se às populações do Atlântico Norte (Merrett et al., 1991; Koslow, 1993; Coggan et al., 1998; Allain, 2001) e do Mar Mediterrâneo (Massutí et al., 1995, 1996; Morales-Nin et al., 1996; Carrasón e

Matallanas, 1998, 2001, 2002), tendo sido oriundas de pesquisas realizadas por países desenvolvidos.

No Atlântico Sul, as regiões sul e sudeste da costa brasileira têm recebido maior atenção e produzido um razoável conjunto de informações sobre as populações de ambientes profundos, uma vez que nessas localidades a pesca possui maior potencial econômico (Haimovici et al., 1994; Figueiredo et al., 2002; Bernardes et al., 2005; Costa et al., 2006). A região noroeste do Atlântico Sul, onde está inserida a costa nordeste do Brasil, porém, embora seja reconhecida como uma região com elevada riqueza de espécies e baixas biomassas específicas (Nóbrega e Lessa, 2007), ainda conta com um número reduzido de estudos sobre os recursos vivos de águas profundas, com exceção dos resultados publicados pelo Programa REVIZEE (Programa de Avaliação do Potencial Sustentável dos Recursos Vivos na Zona Econômica Exclusiva). As publicações oriundas do Programa REVIZEE para a costa nordeste do Brasil, porém, com exceção de Oliveira et al. (2015), não indicam, muitas vezes, os pontos exatos de coleta nem a profundidade. Informações sobre as características merísticas e morfológicas das espécies coletadas, assim como o número de tombo, encontram-se, na maioria dos casos, igualmente ausentes.

Buscando contribuir para o conhecimento sobre a diversidade da fauna de profundidade da costa de Pernambuco, esse estudo registra a ocorrência de oito novas espécies de teleósteos de profundidade obtidos no talude continental do estado, detalhando os seus caracteres merísticos e morfológicos e a sua distribuição.

Materiais e Métodos

O material foi coletado a partir de prospecções de profundidade realizadas com armadilhas de fundo (covos) e espinhel, na costa de Pernambuco, nordeste do Brasil, entre as profundidades de 200 e 600 m, de outubro de 2014 a março de 2018. Os espécimes foram fotografados em sua coloração natural e depois fixados em formol e preservados em etanol a 70%. Após a realização de medições e contagens, os exemplares foram depositados no Museu de Ictiologia da Universidade Federal de Pernambuco. Caracteres morfométricos e merísticos foram registrados de acordo com Hubbs e Lagler (1958) e, no caso dos anguiliformes, conforme Kanazawa (1958) e Bohlke (1989). As abreviaturas D1, D2, A, P1 e P2 foram utilizadas para indicar o número de raios das nadadeiras primeira dorsal, segunda dorsal, anal, peitoral e pélvica.

Resultados

Ordem: Gadiformes
Família: Moridae
Physiculus kaupi Poey, 1865 (Figura 1A)

Material Examinado: MOCH1517, 4 espécimes, 225-270 mm; Brasil, Pernambuco, 08°11'13" S, 34°34'09" W, 300 m de profundidade, coletado em 30 de Outubro, 2014; 1 espécime, 235 mm, Brasil, Pernambuco, 7˚58' 49” S, 34˚30'08” W, 300 m de profundidade, coletado em 05 de Dezembro, 2014.

Descrição: D 10-12, 56-62; A 61-65; P1 28; escamas em série longitudinal 133-137; escamas acima da linha lateral 12-15; rastros branquiais pequenos e delgados 3 + 9-11 (incluindo rudimentares). Boca terminal, maxila superior alcança a margem posterior do olho; dentes maxilares e premaxilares viliformes, alguns curvados para trás e em várias fileiras irregulares; vômer e palato sem dentes. Corpo recoberto por pequenas escamasciclóides, incluindo a região gular e membranas inter-radiais das nadadeiras dorsal e anal. Linha lateral arqueada anteriormente e reta posteriormente, alcançando a nadadeira caudal.

Medidas em porcentagem do comprimento padrão: altura do corpo 21,3-23,7; comprimento da cabeça 26,4-27,2; diâmetro do olho 5,9-7,3; espaço interorbital 4,9-5,1; comprimento do focinho 7-7,6; comprimento da maxila superior 14,5-15,2; distância pré-dorsal 28,9-36,9.

Medidas em porcentagem da distância entre a linha interventral e origem da nadadeira anal: diâmetro do órgão luminoso 9,3-11,3; distância da linha interventral ao órgão luminoso 17,8-24,4; distância do órgão luminoso ao início da nadadeira anal 75,6-82,2.

Cor do espécime fresco: tom marrom escuro até a base das nadadeiras, regiões difusas em tom avermelhado ao longo da base das nadadeiras verticais; extremidades das nadadeiras dorsal, caudal e anal, marrom escuras; tom azul metalizado na porção ventral, desde a mandíbula até o final de 1/3 anterior da nadadeira anal e lateralmente estendendo-se até imediatamente acima da nadadeira peitoral.

Distribuição: reportado do Caribe ao sudeste da costa brasileira (Pires et al., 2019).

Ordem Scorpaeniformes
Família Scorpaenidae
Pontinus rathbuni Goode and Bean, 1986 (Figura 1B)

Material examinado: MOCH1525 1 espécime, 168 mm CP; Brasil, Pernambuco, 08°14'27" S, 34° 35'40" W, 301 m de profundidade, coletado em 15 de Julho, 2015; MOCH1526 1 espécime, 13,3 mm CP; Brasil; Pernambuco, 7°50’01” S, 34°27’18” W, 395 m de profundidade, coletado em 11 de Novembro, 2015

Descrição: D 12,10-11; A 3,5; P 17, P2 1,5. Focinho curto e próximo ao amanho do diâmetro da órbita; osso lacrimal com 2 espinhos apontando posteroventralmente e um espinho nasal pequeno; quatro espinhos sub-orbitais; cirros supra-oculares ausente. 45-47 escamas ctenóides em série horizontal.

Medidas em porcentagem do comprimento padrão: altura do corpo 29,8-31,6; distância pré-anal 55,7-64,3; distância pré-dorsal 36,3-35; comprimento da cabeça 44,6-45,9. Medidas em porcentagem do comprimento da cabeça: comprimento do focinho 28,7-31,3; diâmetro do olho 24-27,9; espaço interorbital 8,2-8,3.

Cor do espécime fresco: avermelhado com manchas vermelhas ou laranjas escuras nas nadadeiras dorsal, peitoral e caudal; o ventre possui uma coloração mais clara, tendendo para o branco.

Distribuição: Atlântico Ocidental, da Virgínia ao norte do Golfo do México, Caribe, Venezuela, Suriname e Guiana e Brasil (Eschemeyer, 1969; Robin e Rays, 1986; Uyeno et al., 1983; Acero e Navas, 1997; Menezes et al., 2003; Godefroid et al., 2003; Martins et al., 2005; Olavo et al., 2007; Oliveira et al., 2015; Pinheiro et al., 2015).

Ordem Perciformes
Família Caproidae
Antigonia capros Lowe, 1843 (Figura 1C)

Material examinado: MOCH1527 1 espécime, 47 mm CP; Brasil, Pernambuco, 08°11'15" S, 34°34'26" W, 238 m de profundidade, coletado em 30 de Outubro, 2014.

Descrição: D 8, 32; A 3, 31; P 13. Corpo muito alto, comprimido lateralmente e recoberto por escamas ctenóides; olhos grandes; boca pequena, oblíqua com dentes pequenos e cônicos; o espinho mais longo da nadadeira dorsal corresponde a cerca de 21% do comprimento padrão.

Medidas em porcentagem do comprimento padrão: altura do corpo 126; comprimento da maxila superior 3,8; diâmetro da órbita 16,1; comprimento da cabeça 42,9; comprimento da nadadeira peitoral 42,9; espinho mais longo da nadadeira pélvica 28,2; Medidas em porcentagem do comprimento da cabeça: comprimento do focinho 19,4; diâmetro do olho 37,5; comprimento da maxila superior 8,8.

Cor do espécime fresco: coloração prata no geral com tons avermelhados no dorso e porção posterior do corpo a partir do ânus; uma faixa vermelha estende-se da base dos raios duros da nadadeira dorsal até a nadadeira peitoral. Nadadeiras de coloração branca a translúcida.

Distribuição: Distribuído globalmente nos oceanos tropicais e subtropicais, exceto o Pacífico oriental. No Atlântico oriental, da França à Namíbia, incluindo os arquipélagos de Cabo Verde, Açores e Madeira (Vieira et al., 2016); no Atlântico ocidental, possui registros da Nova Inglaterra ao norte da Argentina (Figueiredo e Menezes, 1980; Cervigón, 1991; Cervigón *et al.*, 1992; Moore et al., 2003; Roa-Varón et al., 2003; Nión et al., 2016; Menezes et al., 2003; Figueiredo et al., 2002; Mincarone et al., 2004; Bernardes *et al.*, 2005; Lopes et al., 2011).

Ordem Anguiliformes
Família Congridae
Conger esculentus Poey, 1861 (Figure 1D)

Material examinado: MOCH1519, 2 espécimes, 853-949 mm; Brazil, Pernambuco, 08°11'19" S, 34°34'07" W, 312 m de profundidade, coletado em 22 de Março, 2015.

Descrição: P1 16–17. Poros: etimoidal 1; adnasal 1; preopercular mandibular 8; infraorbital 6; supraocular 1 + 2; supratemporal 1; nenhum poro pós-temporal; linha lateral com 36-37 poros pré-anais. Início da nadadeira dorsal após o término da nadadeira peitoral ou na altura do segundo poro da linha lateral. Boca terminal, com lábios grossos; maxila com uma fileira de dentes caninos e 4 fileiras de dentes caninos no pré-maxilar, não visíveis com a boca fechada, 4 fileiras de dentes caninos no vômer organizadas em formato triangular logo após os dentes da pré-maxila.

Medidas em porcentagem do comprimento total: altura do corpo 6,4; comprimento da cabeça 16,4-17,3; distância pré-dorsal 23,8; distância pré-anal 38-38,2; comprimento da nadadeira peitoral 5,8. Medidas em porcentagem do comprimento da cabeça: comprimento do focinho 25,2-28,4; diâmetro do olho 12,7-13,1; espaço interorbital 14,4-17,3; tamanho da abertura branquial 15,7-18,1; distância interbranquial 41,7-48,3; comprimento da nadadeira peitoral 33,9-35,0.

Cor do espécime fresco: marrom escuro no dorso em aproximadamente 1/4 da porção final do corpo e na porção superior do focinho; região ventral esbranquiçada; extremidades das nadadeiras dorsal e anal enegrecidas.

Distribuição: Atlântico Ocidental, da Flórida, Bermudas, Antilhas e Venezuela ao sul do Brasil (Kanazawa, 1958; Smith, 1989, 2003; Cervigón, 1991; Smith-Vaniz e Jelks, 2014; Faloh-Gandarrilla et al., 2016; Paiva et al., 2011; Bernardes et al., 2005; Mincarone e Smith, 2005).

Ordem Anguiliformes
Família Synaphobranchidae
Dysommina rugosa Ginsburg, 1951 (Figura 1E)

Material examinado: 1 espécime, 234 mm CT, Brasil, Pernambuco, 08°08'50" S, 34°33' 21" W, 300 m de profundidade, coletado em 27 de Abril, 2017.

Descrição: origem da nadadeira dorsal posicionada logo após o fim da nadadeira peitoral; nadadeiras peitorais pouco desenvolvidas e quase do mesmo tamanho que o espaço interbranquial; aberturas branquiais separadas; linha lateral visível até a extremidade posterior do corpo; narina anterior em formato tubular e posicionado próximo à extremidade do focinho; narina posterior em formato de poro posicionado em frente à extremidade inferior do olho. Ausência de dentes na intermaxila e presença de 4 dentes isolados, em série vertical, no vômer.

Medidas em porcentagem do comprimento total: altura do corpo (pela abertura branquial) 6,4; distância pré-dorsal 18,6; comprimento da cabeça 12,6. Medidas em porcentagem do comprimento da cabeça: comprimento do focinho 35,6; diâmetro do olho 10,2; espaço interorbital 19,7; comprimento da mandíbula 54,2; espaço interbranquial 24.

Distribuição: porção tropical dos oceanos Atlântico e oeste do oceano Pacífico (Ho et al., 2015).

Cor do espécime fresco: não foi possível realizar a descrição da coloração do indivíduo uma vez que ele foi encontrado no estômago de um *Gymnothorax conspersus*.

Ordem Anguiliformes

Família Muraenidae
Gymnothorax maderensis (Johnson, 1862) (Figure 1F)

Material examinado: MOCH1520, 1 espécime, 640 mm CP; Brasil, Pernambuco, 08°11'19" S, 34°34' 07" W, 300 m de profundidade, coletado em 22 de Março, 2015.

Descrição: origem da nadadeira dorsal após a abertura branquial; origem da nadadeira anal logo após o ânus; dentes caninos longos e organizados em única uma fileira; uma fileira com oito dentes caninos no vômer. Narina anterior tubular, próxima à ponta do focinho, narina posterior nivelada com a pele, posicionada anteriormente à metade superior do olho. Medidas em porcentagem do comprimento total: altura do corpo 24; altura até a abertura branquial 2,3; distância pré-anal 43; distância pré-dorsal 22; comprimento da cabeça 12,1. Medidas em porcentagem do comprimento da cabeça: comprimento do focinho 6,7; diâmetro do olho 12.9; espaço interorbital 11; comprimento da mandíbula 38,3.

Cor do espécime fresco: epiderme em tom marrom claro, com extremidades do focinho e cauda em tom marrom mais escuro; dorso recoberto por uma leve coloração amarelo-esverdeado, com várias pequenas manchas esbranquiçadas por todo o corpo, sendo mais visíveis na extremidade posterior, incluindo nadadeira dorsal.

Distribuição: Atlântico Oriental, no arquipélago de Madeira, Cabo Verde, ilhas Canárias e no Golfo da Guiné (Dooley et al. 1985; Böhlke et al. 1989). No Atlântico Ocidental das costas da Carolina do Norte e Flórida, no Arquipélago de Bermudas Ocidental e do Caribe até a Bahia e Ilha da Trindade no Brasil (Williams et al. 2010; SmithVaniz e Jelks 2014; Robertson e Van Tassel 2015; Martins et al., 2005; Olavo et al., 2007; Pinheiro et al, 2015; Carvalho-Filho e Paiva, 2017).

Ordem Anguiliformes
Família Muraenidae
Gymnothorax conspersus Poey, 1867 (Figura 1G)

Material examinado: MOCH1522, 1 espécime, 101,1 mm CP; Brasil, Pernambuco, 08°30'75" S, 34°41'28" W, 291 m de profundidade, coletado em 11 de Junho, 2015.

Descrição: origem da nadadeira dorsal entre a porção posterior do olho e o fim da mandíbula; origem da nadadeira anal após o ânus; na maxila dentes caninos organizados em uma fileira com dois pares de caninos mais longos e voltados para o interior da boca; narina anterior tubular próxima à ponta do focinho; narina posterior nivelada com a epiderme; cinco poros ao longo da parte inferior da maxila.

Medidas em porcentagem do comprimento total: altura do corpo 7; distância pré-anal 49,2; distância pré-dorsal 11,5; comprimento da cabeça 14,2. Medidas em porcentagem do comprimento da cabeça: comprimento do focinho 16,9; diâmetro do olho 7,6; espaço interorbital 10,2; comprimento da mandíbula 39,8.

Cor do espécime fresco: epiderme marrom escura, com tom mais claro no focinho e nadadeiras em tom mais escuro que o corpo; manchas circulares brancas em todo o corpo, maiores e mais evidentes na metade posterior e com formato alongado na nadadeira dorsal.

Distribuição: Atlântico Ocidental, da Carolina do Norte, Flórida, Caribe, Venezuela, Suriname, e Guiana Francesa ao Sul do Brasil (Bohlke e Smith, 2003; Faloh-Gandarilla et al., 2016; Cervigón, 1991; Uyeno et al., 1983; Menezes et al., 2003; Bernardes et al., 2005; Olavo et al., 2007; Oliveira et al., 2015).

Ordem Anguiliformes
Família Muraenidae
Gymnothorax polygonius Poey, 1875 (Figura 1H)

Material examinado: MOCH1524, 1 espécime, 612 mm CP; Brasil, Pernambuco, 8°11'14" S, 34°34'27" W, 300 m de profundidade, coletado em 26 de Setembro, 2017.

Descrição: origem da nadadeira dorsal após fim da mandíbula; origem da nadadeira anal logo após o ânus; dentes caninos longos e organizados em três fileiras de dentes intermaxilares e uma fileira no maxilar; dentes no vômer em uma série; dentes não expostos quando a boca está fechada; mandíbula não arqueada; narina posterior nivelada com a epiderme.

Medidas em porcentagem do comprimento total: altura do corpo 7; distância pré-anal 43,3; distância pré-dorsal 10,6; comprimento da cabeça 12,9. Medidas em porcentagem do comprimento da cabeça: comprimento do focinho 21,5; diâmetro do olho 11,4; espaço interorbital 13,9; comprimento da mandíbula 45,6.

Cor do espécime fresco: tonalidade marrom escuro com pequenas manchas brancas irregulares recobrindo toda a superfície do corpo, sobre o qual é possível distinguir um padrão de cor mais escuro formando grandes polígonos sobre todo o corpo. As extremidades das nadadeiras dorsal e anal são brancas.

Distribuição: Atlântico Oriental, no arquipélago de Madeira, Cabo Verde, Ilhas Canárias (Richardson e Brito, 2015; Wirtz et al., 2013) e Atlântico Ocidental, do Caribe e Venezuela ao Sudeste do Brasil (Faloh-Gandarilla et al., 2016; Cervigón, 1991**;** Gasparini e Floeter, 2001; Menezes et al., 2003; Martins et al., 2005; Olavo et al., 2007; Pinheiro et al., 2015, Oliveira et al., 2015).

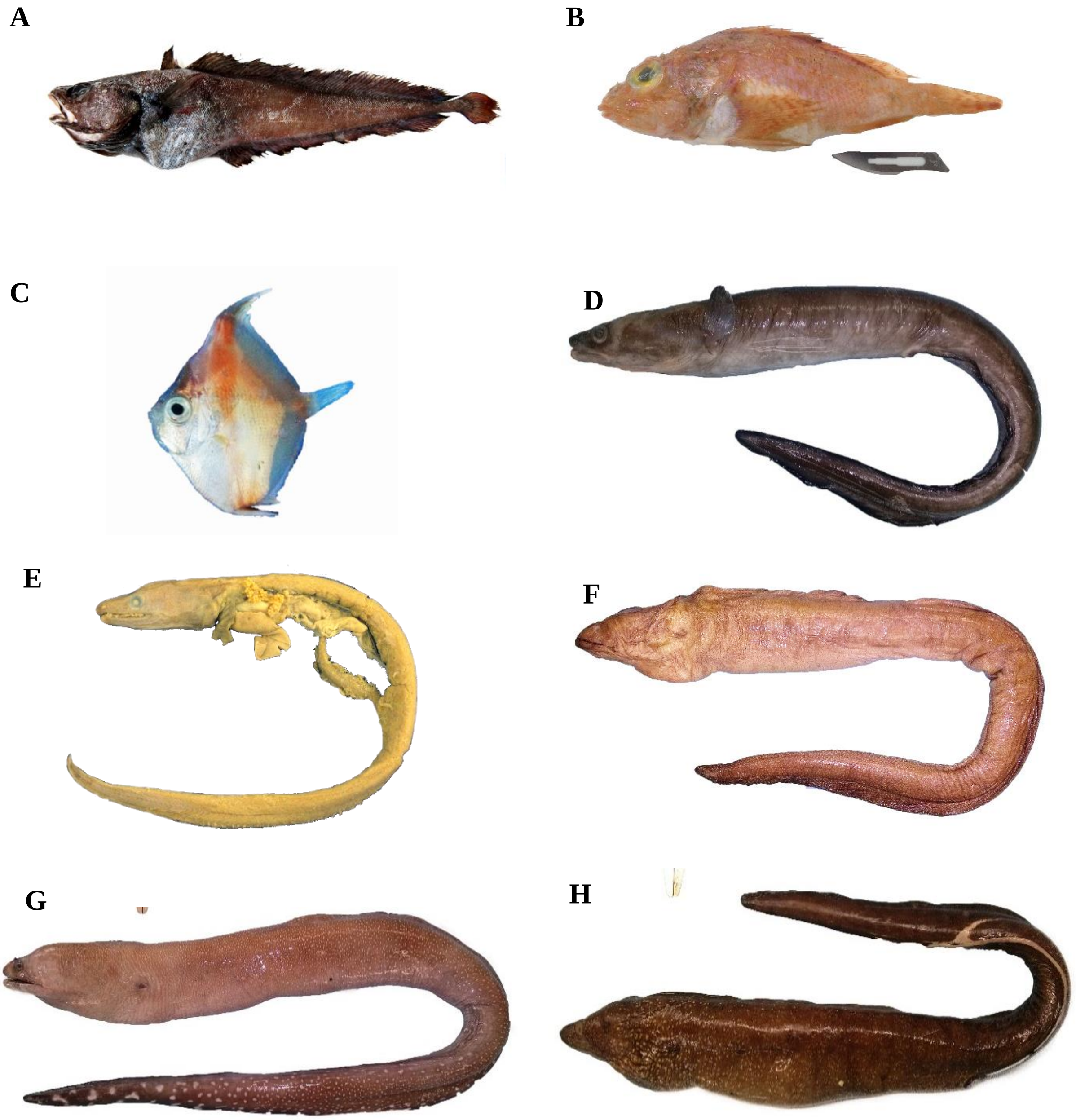

Figura 1 - A) *Physiculus kaupi* MOCH1518, 235 mm de comprimento total; (B) *Pontinus rathbuni* MOCH1525, 168 mm de comprimento total; (C) *Antigonia capros* MOCH1527, 47 mm de comprimento total; (D) *Conger esculentus* MOCH1519, 853 mm de comprimento total; (E) *Dysommina rugosa*, 234 mm de comprimento total; (F) *Gymnothorax maderensis* MOCH1520, 640 mm de comprimento total; (G) *Gymnothorax conspersus* MOCH1522, 1011 mm de comprimento total; (H) *Gymnothorax polygonius* MOCH1524, 612 mm de comprimento total.

Discussão

As espécies retratadas nesse trabalho representam novos registros para o talude de Pernambuco, nordeste brasileiro, mas não ampliam a distribuição geográfica de nenhuma das espécies. Os novos registros expõem a superficialidade do conhecimento acerca da fauna de profundidade, mesmo considerando a similaridade de prospecções de profundidade realizadas nos anos de 1997 e 2000 no talude de Pernambuco.

Os principais resultados dessa amostragem estão descritos na tese "Distribuição e Abundância Relativa de Peixes e Crustáceos capturados no Programa REVIZEE/Score-NE na Plataforma externa e Talude da costa do Nordeste do Brasil" (Oliveira, 2005), e mesmo tendo efetuado amostragem num intervalo batimétrico mais amplo e ambas as pesquisas utilizarem artes de pesca muito similares (armadilhas e espinhel), as novas ocorrências são atribuídas ao enfoque no levantamento da diversidade, enquanto as prospecções anteriores integravam o projeto REVIZEE, que pretendeu mensurar o potencial pesqueiro na zona econômica exclusiva brasileira e foi desenvolvido em toda a costa brasileira.

Em geral, as espécies encontradas fazem parte de famílias que ocorrem com frequência em populações de mar profundo em todo o mundo. O *Physiculus kaupi*, por exemplo, integra a família Moridae, que é apontada por Clark et al, (2010) como uma das três famílias mais abundantes entre as assembleias de peixes de profundidade no Atlântico Norte, e também destaca-se como uma das famílias com maior biomassa no Mediterrâneo (Massutí et al., 2004; D'Onghia et al., 2004).

Escorpenídeos e congrídeos, dos quais fazem parte o *Pontinus rathbuni* e *Conger esculentus*, são famílias comumente encontradas nas listas de assembleias de peixes de profundidade (Massutí et al., 2004; Paramo et al., 2012; Nunes et al., 2016) e recursos pesqueiros de importância comercial (Jarrin et al., 2018; O'Sullivan et al., 2003). Estudos de idade e crescimento de escorpenídeos, inclusive, contribuem fortemente para a hipótese que peixes de profundidade são mais vulneráveis aos impactos antrópicos devido às baixas taxas de crescimento e maturação tardia, como ocorre com o *Pontinus clemensi* e *Scorpaena notata* (Jarrin et al., 2018; Scarcella et al., 2011).

Não tão comuns em estudos de mar profundo, as moréias são espécies comuns em ambientes recifais rasos de regiões tropicais e temperadas em todos os oceanos (Reece et al., 2010). Contudo, algumas espécies possuem distribuição batimétrica mais ampla, como a *Muraena helena* encontrada em até 800 m no Mar adriático, *Gymnothorax conspersus* até 286 m no Caribe e *Gymnothorax maderensis* em 200 m na costa brasileira (Jiménez et al., 2007; Paramo et al., 2012; Carvalho e Paiva, 2017). Além das duas espécies de Gymnothorax citadas acima, outra moréia registrada pela primeira vez no talude de Pernambuco e indicada no atual estudo é a G*ymnothorax polygonius*.

Apesar dos novos registros para o talude de Pernambuco realizados aqui, devido ao estado inicial de conhecimento da fauna marinha profunda, era esperado que um número maior de teleósteos fosse encontrado. Nesse ponto, acreditamos que as artes de pesca utilizadas desempenharam uma forte seleção, coletando espécies carnívoros de maior tamanho corpóreo, de forma que indivíduos de pequeno porte permanecem desconhecidos para a região. Basta citar que os menores teleósteos capturados, o *Antigonia capros* e o *Dyssomina rugosa*, foram encontrados como conteúdo estomacal.

Em relação à distribuição geográfica no nordeste brasileiro, todas as espécies que registramos para o talude de Pernambuco, exceto pelo *G. maderensis*, possuem ocorrência confirmada no Rio Grande do Norte, cerca de 140 km ao norte da costa de Pernambuco (Oliveira et al., 2015). *P. kaup*i e *C. esculentus* já tinham sido registrados na costa do Ceará (456 km ao norte de Pernambuco) como resultado do Programa REVIZEE, *A. capros* e *G. maderensis* na costa da Bahia (392 km ao sul de Pernambuco), o primeiro capturado acidentalmente por pescadores e o último em um projeto do TAMAR que avaliaram a capturabilidade de anzóis circulares sobre tartarugas marinhas (Paiva et al., 2011; Carvalho e Paiva, 2017).

Na costa do Rio Grande do Norte, arrastos financiados por empresa de extração de petróleo do assoalho marinho revelaram uma grande diversidade de peixes de profundidade (Oliveira et al., 2015). E mais recentemente, arrastos realizados por um projeto compartilhado entre França e Brasil na costa e ilhas oceânicas no nordeste do Brasil, resultaram em novos registros para águas brasileiras e Atlântico Sul (Eduardo et al., 2018; Mincarone et al., 2019). Tais resultados evidenciam o quanto a compreensão sobre a fauna marinha de profundidade é sincipiente, especialmente para regiões com investigação reduzida, como no talude de Pernambuco.

Martin et al. (2020) afirmam que a zona marinha entre 200 e 1000 m de profundidade concentra o maior e menos explorado estoque de peixes dos oceanos, mas devido às dificuldades em realizar amostragem, esse vasto domínio do oceano encontra-se em risco mesmo antes que os efeitos das mudanças climáticas e mineração do assoalho marinho possam ser compreendidos. Diante de tal cenário, desvendar a diversidade e quantidade dos organismos que habitam essa zona crepuscular é uma das questões prioritárias para compreender as consequências potenciais das atividades humanas sobre o mar profundo.

Dessa forma, esse trabalho contribui para o conhecimento da fauna marinha de profundidade do talude de Pernambuco e do nordeste brasileiro, fornece dados merísticos e morfométricos que podem contribuir com outras identificações bem como tombamento de exemplares dos novos registros em coleção oficial para possíveis comparações.

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4. Artigo Científico II

Artigo científico submetido à Revista *Marine Biology*.

Diversity and Distribution of deep-sea fish on the continental slope off Pernambuco, Equatorial Atlantic

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Abstract:

Studies outlining the ecology and zonation of deep-sea ichthyofauna from different parts of the world have provided many insights into the life adaptations and strategies, diversity and vertical distribution of deep-water fish assemblages. However, as a result of potential local fishing, most of the knowledge has come from the North Atlantic and the Mediterranean Sea. Likewise, in the case of Brazil, the vast majority of the information available is from the south and southern coasts. In this study, the diversity and bathymetric distribution of deep-sea teleost from the continental slope off Pernambuco, Brazil, equatorial Atlantic, was investigated. From October 2014 to March 2018, 39 fishing sets were carried out between 200 and 600 m, using bottom traps, although only 18 of them resulted in catches. Eight demersal species were caught: *Physiculus kaupi*, *Gymnothorax maderensis*, *Gymnothorax polygonius*, *Gymnothorax conspersus*, *Conger esculentus*, *Pontinus rathbuni*. *Antigonia capros* and *Lutjanus vivanus*. The fauna recorded in this survey is common to those reported in other deep-sea studies, except for the Muraenidae family specimens and the *Lutjanus vivanus*. Classification and ordination analyses did not indicate a clear formation of assemblages among the different species, in terms of relative abundance by depth, but there was a slight trend indicating a formation of a transition zone at 300 m depth, from where richness, diversity and evenness begin to decline.

Key words: assemblages; bottom traps; diversity; deep-sea fauna; Equatorial Atlantic.

Introduction

The deep-sea, recognized as the environment below 200 m depth, is the largest habitat on the planet, including more than one billion cubic kilometers of water and representing 75% of the global biosphere (Angel, 1997). The characteristics of this environment include absence of sunlight, low temperatures, high pressure and absence of primary production, except by the chemotrophic bacteria activity. This combination of features led to a specialized fauna, with species that are unusual or absent in shallower waters (Drazen and Suton, 2016).

Although the knowledge about the life history of deep-water fauna has increased in recent years, large gaps still remain, essentially due to logistical difficulties and the high costs involved in collecting samples in that environment. Consequently, most publications were made on samples obtained from the North Atlantic (Merrett et al., 1991; Koslow, 1993; Coggan et al., 1998; Allain, 2001) and the Mediterranean Sea (Massutí et al., 1995; Morales-Nin et al., 1996; Carrasón and Matallanas, 2002; Alonso-Fernandez et al., 2013; Fernandez-Arcaya et al., 2016), by developed countries.

In Brazil, the south and southeast regions have received much more attention than the northeast region, resulting in a much larger set of information about the deep-sea populations, mainly because of the greater economic potential of fishing activities in these localities (Haimovici et al., 1994; Figueiredo et al.; 2002; Bernardes et al.; 2005; Haimivici e al., 2006; Costa et al., 2007; Franco et al, 2007, 2009; Braga et al., 2008; Dallagnolo et al., 2009; Melo et al., 2010; Costa et al., 2011). In the northeast Brazilian coast, with an overall low fish biomass and consequently a much lower potential for commercial fishing (Nobrega and Lessa 2007), little so far has been done to study and understand the life strategies of deep-sea species.

In order to contribute to the knowledge about the diversity and distribution of deep-sea fauna of Pernambuco coast, equatorial Atlantic, the bathymetric distribution of the species sampled, the assemblages formation and species richness, diversity and dominance indices for different depth intervals were assessed.

Material and Methods

Study area

The Pernambuco coast, located in the equatorial region of the southwestern Atlantic Ocean, is 187 km long (Pereira et al., 2007), with a shelf break around 55 to 65 m depth and an average width of 33.3 km (Araújo et al. 2004). The suspended material concentration in platform waters is generally low (less than 0.5 mg/l), with the exception of areas in front of large rivers (Manso et al., 2006). It has two well defined seasons throughout the year: the rainy season, with the highest rainfall from April to July, and the dry season. The average air temperature ranges from 21 to 30°C, with a sea surface temperature from 26 to 29°C (Manso et al., 2006).

Sampling and sample processing

From October 2014 to March 2018, 39 bottom-trap fishing sets were carried out along Pernambuco coast, Brazilian northeast, but teleost specimens were caught in only 18 of them. The depth of catch and the geographic coordinates of the fishing sets were recorded by the vessel's echo sounder. Bottom traps of four different shapes and sizes were used: rectangular (2.0 x 0.9 x 0.9 m, with 0.3 m opening); rectangular (2.0 x 0.6 x 0.6 m, and 0.2 m opening); conical (0.6 m high, 1 m base diameter, 0.6 m top diameter, and 0.3 m opening); and cylindrical (1 m high x 0.5 m base diameter, and 0.2 m opening). All were made with steel and wrapped with a polyamide mesh of 10 mm. In each cruise, the fishing gear remained submerged for an average period of 14 hours, with some variation due to the prevailing environmental conditions.

Data analysis

The vertical distribution of the specimens was analyzed according to the relative abundance, calculated as the catch per unit effort (CPUE) in number of specimens caught per soaking time and number of traps used.

Classification and ordination analyses were performed in order to identify demersal faunal assemblages among fish species on the continental slope off Pernambuco. The former was accomplished by means of a cluster analysis using the Euclidean distance coefficient and the complete linkage and UPGMA methods (Ludwig and Reynolds 1988). The latter was done by a non-parametric multi-dimensional scaling (MDS) (Kruskall, 1964).

Since no clear assemblage was detected by depth strata, the data were pooled into two depth intervals: 200 to 350 m and 350 to 500 m, to allow a comparison of richness, diversity and dominance by depth. The interval between 500 to 600 m was not considered in the analysis due to the lack of catch in this range.

The dissimilarity by CPUE of species among the depth was estimated by Euclidean distance analysis, expressed by the function $D(x,y)= \surd \Sigma^{n}{}_{k=1}(X_k-Y_k)^2$, where X= the axis X object and Y= the axis Y object. CPUE logarithmization was performed from the log (x + 1) formula, where x = CPUE, to avoid the effect of dominant species on the grouping of samples. Euclidean distance analysis was also used among abundance clusters. To determine the statistical accuracy between the clusters formed by the Euclidean distance, a permutation test of a distance matrix with data ranking - ANOSIM (Clark, 1988, 1993) was performed, with the function R = (rb - rw) / (n (n-1) / 4), in which rb and rw are the means of dissimilarity between groups and within groups respectively. The multivariate analysis of similarity percentages (SIMPER) was used to determine which of the variables most influenced the group formations.

Richness, diversity and dominance per each stratum were obtained by the number of species per stratum, the Shannon diversity index (H') and the Simpson dominance index (D). The Shannon index was calculated by the formula: $H' = \sum_{i=1}^{S} Pi - lnPi$, where Pi is the relative abundance of species i, estimated through Pi = ni / N, ni = number of individuals of species i, and N= total number of individuals sampled. The Simpson index was expressed by $\sum_{i=1}^{S} Pi^2$ (Melo, 2008). All the statistical analyses and diversity indices assessments were performed using the software R version 3.5.3, with the following packages: ggplot2 (Wickham, 2016), vegan (Oksanen et al. 2019) and iNext (Hsieh and Chao, 2014).

Results

Eighty-one specimens of 8 teleost species were caught in 18 of the 39 fishing sets carried out with bottom traps on Pernambuco slope: *Physiculus kaupi*, *Gymnothorax maderensis, Gymnothorax polygonius, Gymnothorax conspersus, Conger esculentus, Pontinus rathbuni*, *Antigonia capros* and *Lutjanus vivanus.* The Moridae family was the most abundant with 56 specimens of *P. kaupi*, while the Muraenidae was the most representative family in number of species, with 3 different eel species, all belonging to the *Gymnothorax* gender (Table 1).

Table 2 - Family and absolute and relative frequency of deep-sea species caught in Pernambuco slope, equatorial Atlantic.

Family	**Species**	**Frequency (n)**	**Frequency (%)**
Moridae	*Physiculus kaupi*	56	69.1%
Muraenidae	*Gymnothorax polygonius*	6	7.4%
	Gymnothorax conspersus	6	7.4%
	Gymnothorax maderensis	2	2.4%
Scorpaenidae	*Pontinus rathbuni*	5	6.2%
Congridae	*Conger esculentus*	4	4.9%
Caproidae	*Antigonia capros*	1	1.2%
Lutjanidae	*Lutjanus vivanus*	1	1.2%

The same number of fishing sets (14) was performed in the 200 to 299 m and 300 and 399 m depth strata. From 400 m on, however, due to logistical and operational difficulties, including the loss of fishing gear due to the greater depths and winch limitations, there was a reduction in the number of sets, with 10 sets done between 400 and 499 m and only 3 from 500 to 600 m. The 300-400 m depth stratum accounted for the largest number of specimens caught (36) (Fig. 1).

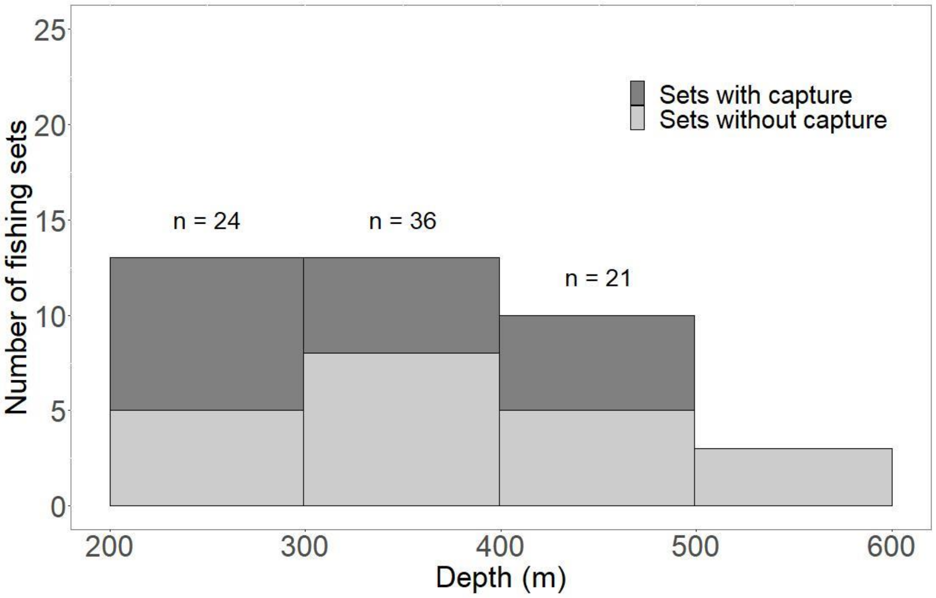

Figure 1- Number of fishing sets with and without catch per strata, with the number of specimens caught, on the continental slope of Pernambuco state, northeast Brazil, from October 2014 to March 2018.

Most specimens were caught from 200 m to 400 m deep, with only *P. rathbuni* and *P. kaupi* being caught after that depth. *L. vivanus* and *A. capros*, which had only one individual caught, were found at 238 m, while all the moray eels were caught between 260 and 300 m. The species with the greatest range of distribution was *P. kaupi* (296 to 424 m), which was also the one caught at the greatest depth, followed by the scorpaenidae *P. rathbuni*, found between 301 and 400 m, with a median at 396 m (Fig. 2).

The dendrogram of fishing sets related to the CPUE of the total catch grouped them in order of abundance of the dominant species (Fig. 3). The first cluster consisted of the three sets with the greatest values of *P. kaupi* CPUE. The last group was formed by sets where there was no evident dominance of a single species. The middle clusters were formed by the occurrence of just one species in each group, *P. rathbuni*, in 396 m, and *G. polygonius*, in 260 m.

The nMDS results (stress level= 0.04) showed a two-dimensional representation, in agreement with the clustering, indicating four groups formed by more similar points, four dissimilarity groups among themselves and, at the same time, the similarity within each group (Fig 4). The global R of NMDS was 0.996 indicating a strong correlation between groups, while, according to ANOSIM, all R values were 0.6 (p= 0.11), indicating that there was no significant difference between groups.

The SIMPER analysis confirmed the high influence of *P. kaupi* abundance (average= 0.37; sd= 0.28; ratio= 1.33) in the formation of the groups, followed by *L. vivanus* (average= 0.20; sd= 0.08; ratio= 2.29) and *A. capros* (average= 0.20; sd= 0.88; ratio= 2.29), but different from the former, the last two species influenced the analysis, by their rarity on sampling.

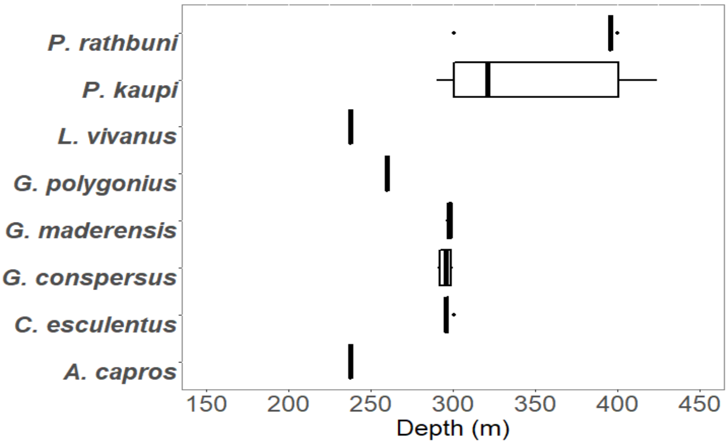

Figure 2- Bathymetric distribution of teleost species caught on the continental slope of Pernambuco state, northeast Brazil.

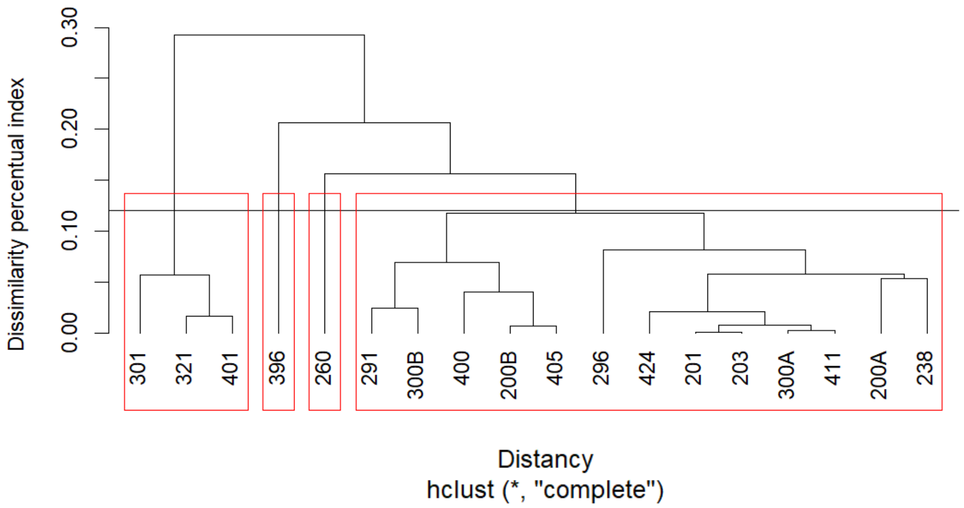

Figure 3 - Dendrogram of fishing sets on Pernambuco continental slope, northeast Brazil, using group-average clustering by Euclidian distance by depth strata in terms of CPUE of total catches.

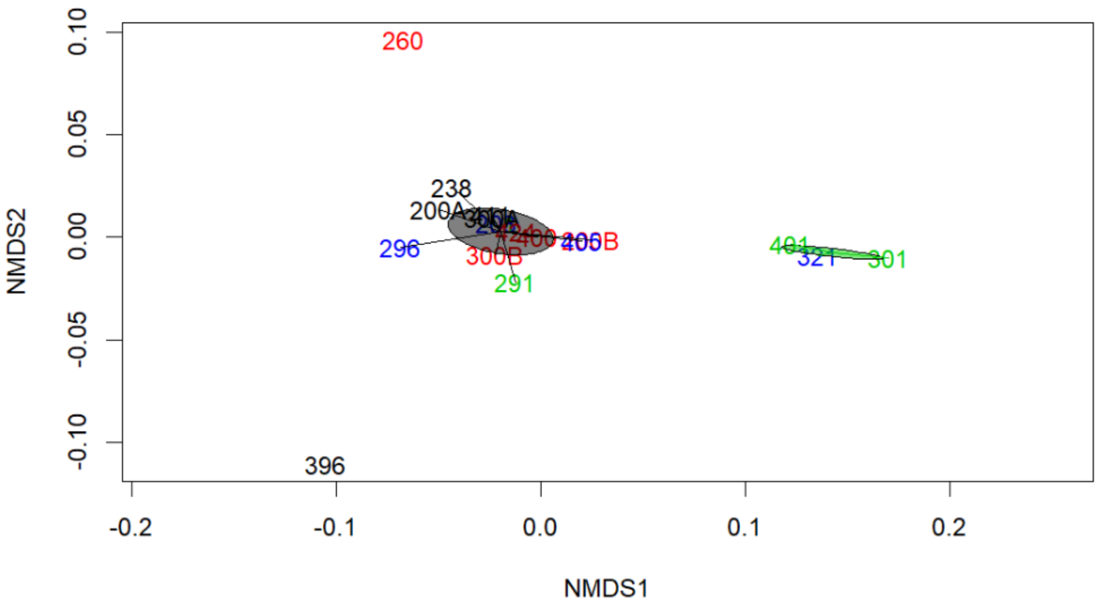

Figure 4- Non-parametric multi-dimensional scaling (nMDS) plot for the deep-sea species.

The dendrogram for CPUE of the different species formed three groups from the similarity of susceptibility of capture by depth. The first group formed only by *P. kaupi* occurred due to the high abundance of this species in all the sampled depths, indicating the greatest susceptibility to the effort undertaken. *P. rathbuni* was isolated in one group for having a CPUE similar to the CPUE of the species of the third group, but in different depths. The third cluster aggregated species that occurred at shallower depths and had similar CPUE (Fig. 5).

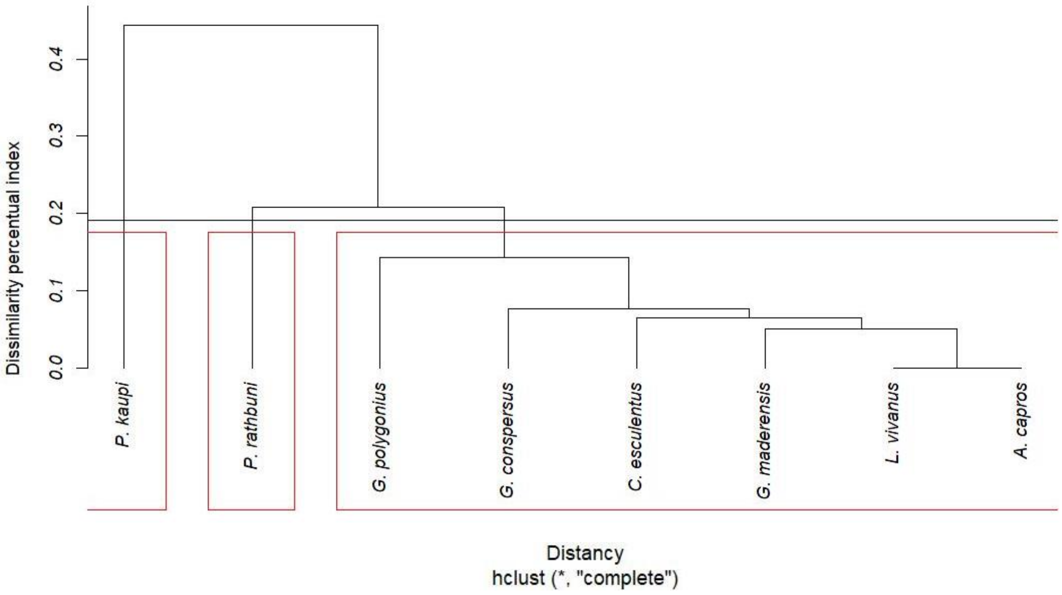

Figure 5- Dendrogram of dissimilarity analysis of hauls related to the species abundance and depth stations.

In the absence of assemblage formation, two groups of species collected at depths of 200 to 350 m (shallow) and 350 to 500 m (deeper) were assumed (Fig 6) to allow the verification of differences in richness, Shannon's diversity and Simpson's dominate index between different depth intervals.

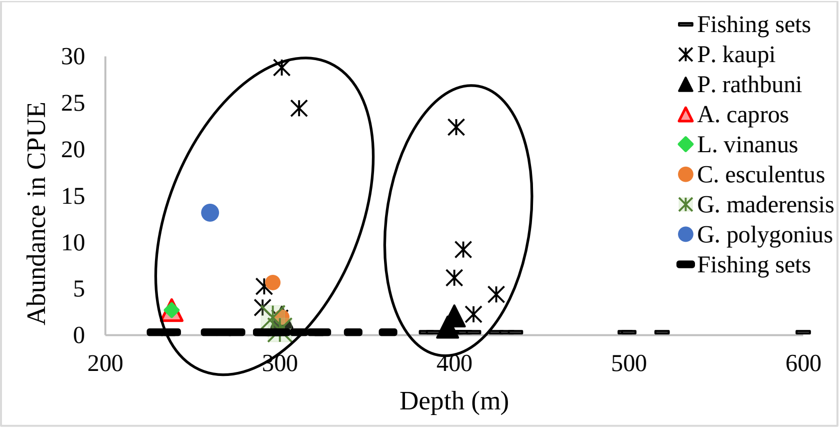

Figure 6- CPUE per depth, of fish caught by bottom traps in the continetal slope of Pernambuco state, northeast Brazil, highlighting the depths where there were sampling (black lines) and the two groups assumed for division between depth classes (shallower and deeper).

Shannon's diversity index corroborated the species richness data for both depth intervals, decreasing towards the deeper strata. Since the Shannon's diversity is a concept that takes into account the richness and equitability, this index is influenced when there are few highly dominant species among a large number of rare species. This observation is explained by the higher Simpson index in the shallow depth interval. Although *P. kaupi* is clearly the dominant species for the entire sample, there is a greater number of species with less occurrence in the shallower depths (Fig. 7).

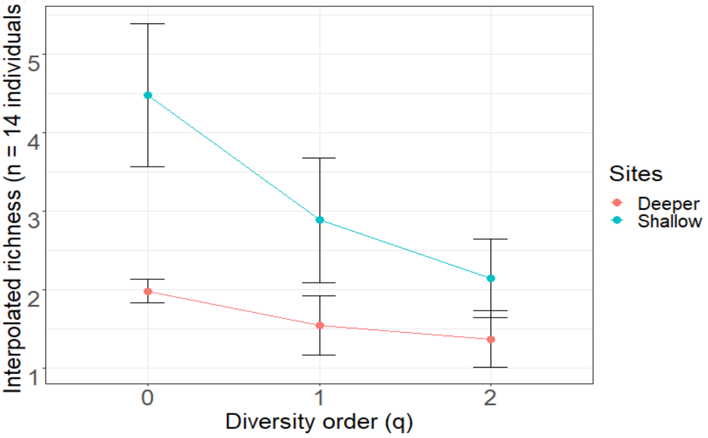

Figure 7- Species richness values (0), Shannon diversity (1) and Simpson dominance (2) for the shallower (200 to 350 m) and deeper (350 to 500 m) depth intervals.

Discussion

Frequent in deep-sea surveys, the families of fish recorded in this study are commonly found below 200 m depth. Nunes et al. (2015) indicated *Physiculus* sp. as the most abundant species among the deep-sea fish around São Pedro and São Paulo Archipelago, a small set of islands located in the equatorial Atlantic, about 1,000 km off the Brazilian coast. In the Mediterranean Sea, also an oligotrophic environment, D'Onghia et al. (2004) described the occurrence of Moridae species throughout the entire basin, with this family showing the third largest abundance among deep sea fish. According to Fernandez-Arcaya et al. (2016), the Gadiformes, order that includes the genus *Physiculus*, has the widest depth range distribution in the Mediterranean Sea, similarly to the high abundance and wide distribution of *P. Kaupi* recorded in this study. Scorpaenidae and Congridae species have also been often recorded in deep fauna studies worldwide (Scorpaenidae: Fujita et al., 1995; Moranta et al., 1998; Massutí et al., 2004; D’Onghia., et al, 2004; Sousa et al., 2006; Tolimieri, 2007; Paramo et al., 2012; Barker et al., 2012; Fernadez-Arcaya et al., 2016; Nunes et al., 2016; Congridae: Fujita et al., 1995; Moranta et al., 1998; Massutí et al., 2004; Sousa et al., 2006; Paramo et al., 2012; Nunes et al., 2016).

Specimens of the Muraenidae family usually occur at depths up to 500 m, but just in tropical and subtropical waters (Böhlke et al., 1989). This is likely the reason why moray eels are seldomly reported in deep-sea fauna studies but are indicated to deep-sea fauna in the equatorial region, such as in the Caribbean Sea (Paramo et al., 2012) and in São Pedro and São Paulo Archipelago (Nunes et al., 2016). *Antigonia capros* and *Lutjanus vivanus* were caught just one time and at the same set and, therefore, depth. Both species are recognized to have a tropical distribution, although *A. capros* is reported to have a much wider vertical distribution, inhabiting mainly at depths from 100 to 385 m (Fock et al., 2002; Powel et al., 2003; Paramo et al., 2012), while *L. vivanus* inhabits mostly in depths from 90 to 240 m (Allen, 1985).

Understanding the assemblage structure and patterns in diversity distribution helps to elucidate large-scale ecological trends of deep-water fish, being thus one of the very first steps towards developing a more complete picture of the ichthyological community on the continental slope (Tolimieri, 2007). Assemblages consist of loosely co-occurring groups of species in a given location (Haedrich and Merrett, 1990), eventually interrupted by a transitional zone, where some dominant species are substituted for subdominant species (Stefanescu et al., 1993).

The classification and ordination analyses derived from the relative abundance (CPUE) for the species caught on Pernambuco slope did not group the depths in any coherent pattern to allow the characterization of different assemblages by different depth ranges. Haedrich and Merrett (1990) argued that there was an overall lack of zoning and/ or distinct communities at the bottom of the sea, with distinct assemblages instead occurring at random. Other studies around the world, however, indicate the existence of deep-sea assemblages, with several overlapping patterns. Although there is a wide variation in the number of assemblages in then deep-sea (generally from 2 to 4) and in their depth range, transition zones are common at depths of 300- 400, 600-800 m and 1300 m, as indicated by Powel et al. (2003), to the Gulf of Mexico; Moranta et al. (1998) and D'Onghia et al. (2004), to the Mediterranean Sea; Nunes et al. (2016), to São Pedro and São Paulo Archipelago; and Baker et al. (2012), to the Northwest Atlantic.

Although evidence of different assemblages of deep-sea fish by depth on the continental slope off Pernambuco state could not be found in this study, probably due to the small number of specimens caught, the results do indicate a trend towards some degree of structuring, with 5 species occurring up to 300 m deep, one species exercising strong dominance over most of the sampled depths, and one species occurring only after 300 m. The 300 m depth, therefore, probably marks the first transition zone for deep water assemblages on the continental slope off Pernambuco, Brazil.

The causes of depth zonation in the distribution of deep-water fish species have been attributed to sunlight (or absence of), temperature, pressure, changes in topography with depth, water masses, and, most importantly, availability of food (Carney et al. 1983; Koslow etal.,1994; Carney 2005).

The strong stratification in the water column generated by the thermocline acts as a physical barrier preventing the transfer of nutrients to the surface waters (Macêdo et al. 2009; Travassos et al. 1999), limiting primary production and contributing to the scarcity of food in equatorial regions. Upwelling events, however, are capable of breaking or lifting the thermocline (Navrotsky et al., 2004), making it possible to increase primary production. Food input to the deep sea can also occur by phytodetrital material arriving on the bottom from the surface water layers (Riaux-Gobin et al., 2004) or from terrestrial sources via submarine canyons (Rumolo et al., 2015), supporting the increase of benthic and benthopelagic organisms (Cartes et al, 1993). The amount of food reaching bathyal depths may also vary seasonally, depending on variations in primary production in the euphotic zone and on changes in advective fluxes (Papiol et al., 2013; Romeu et al., 2016).

Since surface productivity, through the food web, eventually becomes available to upper-slope assemblages (Tolimieri, 2007), a significant decrease in species richness and diversity across the whole depth range have been found in several studies (Powel et al., 2003; D’Onghia et al., 2004; Tolimieri, 2007; Nunes et al., 2016). Despite the low sampling in this study, the results corroborate with this pattern, with richness and diversity decreasing towards deeper areas.

D’Onghia et al. (2004) reported that the significant decrease in species richness and diversity across the whole depth range indicate the existence of a deep-sea ichthyofauna dominated by small species living in a food-scarce environment and larger predators, which are capable to roam a wide area to prey on some randomly scattered food items. The wide distribution and abundance of *P. kaupi* is certainly attributable to its wide trophic strategy, common in Macrouridae and Moridae family, which feed on food occurring within the benthic boundary and the bottom interface, together with an opportunistic and euryphagic feeding strategy (Carráson and Matallanas, 2002).

Despite various studies have investigated the factors that influence the distribution of deep-sea fauna, sampling limitations and gear selectivity have a high influence on the specific composition of catches (D’Onghia et al., 2004; Pajuelo et al., 2016). So, despite the present results corroborate previous results on the composition and distribution of deep-sea species worldwide, the use of traps to carry out the sampling and the rather narrow depth range of the sampling done may have limited the scope of the achieved results.

Documenting patterns of biodiversity distribution is important for a large-scale understanding of the ecosystem function, crucial for a proper management of natural resources (Hooper et al. 2005). It is essential, therefore, to expand the quality and quantity of basic information on the deep-sea fauna to develop a more complete picture of the deep-sea assemblages on the continental slope of the western equatorial Atlantic. The information hereby presented provides a baseline that will allow the monitoring of any future changes in the structure and diversity of the assemblages, an important issue in ecosystem approaches to fisheries (Garcia and Cochrane 2005), in particular under a scenario of climate change.

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5. Artigo Científico III

Artigo científico a ser enviado para a revista especializada.

Population structure and reproduction of *Physiculus kaupi*, a deep-sea fish from Pernambuco coast, western equatorial Atlantic

Abstract: *Physiculus kaupi* is a deep-sea fish distributed in the western equatorial Atlantic, from the Caribbean Sea to Southern Brazil. Besides its taxonomic description, however, no information is yet available on its biology. This study presents the first data on *P. kaupi* population structure and reproductive characteristics from 55 specimens, caught by bottom baited trap, on the continental slope off Pernambuco, Brazil, from 290 m to 430 m depth, between October 2014 and September 2017. The results show a higher proportion of females in the population, particularly in shallower depths. The reproductive characteristics resemble those of several Gadiformes species. Microscopic analyzes of the gonads showed a probably continuous reproduction, with females in spawning capable phase present in almost all sampled months. The distribution of oocyte diameter indicates an asynchronous ovarian development, with a rather low average fecundity (11,517 oocytes). Female size at first maturity was estimated at 17.9 cm of total length.

Keywords: bottom trap, depth distribution, ontogenic migration, reproductive cycle, length at maturity, continuous reproduction, asynchronous ovarian development, fecundity.

Introduction

The knowledge about deep-sea species has increased exponentially around the world in the last decades. The peculiar characteristics of this kind of environment, such as the absence of sunlight, lack of primary production and physico-chemical stability (Rotllant et al., 2002; Drazzen e Suton, 2017), have attracted the attention of various researchers who have studied different aspects of the biology of deep-water organisms, including population structure and connectivity (Aboim et al., 2005; Knutsen et al., 2007; Longmore et al., 2014), bathymetric distribution (Olavo et al., 2007; Massutí et al., 1996, D'Onghia et al., 2004), growth (Morales-Nin et al., 1996; Kaariainen and Bett, 2006) and reproduction (D'Onghia, 1999; Allain, et al., 2006; Fernandez-Arcaya et al., 2013; Fernandez-Arcaya et al., 2016).

Due to the logistical difficulties and high costs involved in sampling, studies on deep-water organisms, however, have been mostly carried out in regions with high economic fishery potential. This association is positive, on one hand, to provide stock assessment and allow the adoption of management measures early in the development of a fishery, but, on the other hand, it hinders the development of researches focusing on the conservation of biodiversity. Both aspects are, however, important, since deep-water species, in general, tend to exhibit ‘‘K-selected’’ life history characteristics, such as low fecundity, late age of maturity and slow growth (Koslow, 2000).

The first list of deep-sea Brazilian fishes was published by Seret and Andreata, (1992), based on sampling done by trawling between the Abrolhos seamounts and around Trindade and Martin Vaz islands, during an oceanographic cruise, in 1987. From the 1990s a wide research project named REVIZEE, to evaluate the fishing potential of marine living resources of Brazilian Economic Exclusive Zone, raised new information on deep water species from the entire Brazilian coast. The results from the northeast coast showed a low fish biomass and consequently a reduced potential for commercial fishing (Nobrega and Lessa, 2007).

Nevertheless, fishing mortality is not the only anthropic threat to fish stocks. The risk of marine oil spills resulting from exploration in deep-sea areas, for instance, can directly affect several fish species, especially when close to nursery areas, spawning grounds or egg and larval drift regions (Hjermann et al., 2007; Rooker et al., 2013); Sørhus et al., 2015). Recently, a huge amount of crude oil waste of unknown origin reached 2,500 kilometers of Brazil's northeast coast, contaminating hundreds of beaches, estuaries, reefs, and mangroves (Escobar, 2019). This recent accident, still unclarified, demonstrates that even in the absence of any significant fishing pressure, other anthropogenic impacts make it important to study the deep-sea biodiversity.

Due to its much higher fisheries potential, the south and southeast Brazilian coast traditionally have received much more research attention and consequently produced much more information about deep-sea species (Haimovici et al., 1994; Figueiredo et al., 2002; Bernardes et al., 2005; Costa et al., 2005; Braga et al., 2007; Costa et al., 2007; Melo, 2007) than the northeast coast. More recently, however, new studies have shed light on the deep-sea fauna from Brazilian northeast coast (Paiva et al., 2011, Oliveira et al., 2015; Eduardo et al., 2018; Eduardo et al., 2018b; Mincarone et al., 2019).

Aiming to contribute to the knowledge of the depth fauna in oligotrophic waters from the equatorial Atlantic, Brazilian northeast coast, this study examined the population structure related to the depth and reproductive biology of *Physiculus kaupi*, the most abundant teleost in a series of fishing surveys performed on the Pernambuco continental slope, northeast Brazil, from 2014 through 2018.

Material and Method

Study Area and Sampling

From October 2014 to March 2018, twenty-four bottom-trap fishing sets were carried out along Pernambuco coast, northeast Brazil, on the continental slope, between 200 and 600m depth. *Physiculus kaupi* specimens were caught in 11 of the 39 fishing sets (Table 1) (Figure 1), ranging from 290 m to 430 m. For more information about the fishing method see Pires et al., 2020, *in press*.

Table 1- Data, depth and number of fish sampled during the cruises with *Physiculus kaupi* catch on Pernambuco coast, Brazil.

Data	Depth	Number of fish sampled
05 December 2014	300	1
17 April 2015	401	10
11 June 2015	291	2
16 July 2015	301	15
26 August 2015	321	11
11 November 2015	405	4
24 August 2016	424	2
12 October 2016	411	1
23 November 2016	400	3
28 April 2017	300	2
27 September 2017	300	4

The Pernambuco coast, located in the equatorial region of the southwestern Atlantic Ocean, is 187 km long (Pereira et al., 2007), with a shelf break around 55 to 65 m depth and an average width of 33.3 km (Araújo et al. 2004). The suspended material concentration in platform waters is generally low (less than 0.5 mg/l), with exception of areas in front of large rivers (Manso et al., 2006). It has two well defined seasons throughout the year: the rainy season, with the highest rainfall from April to July, and the dry season. The average air temperature ranges from 21 to 30°C, with a sea surface temperature from 26.9 to 29.0°C (Manso et al., 2006).

After gear retrieval, the fish caught were refrigerated on ice and transported to laboratory where they were processed. Each fish was measured for total length from the tip of the mouth to the edge of the tail (TL) to the nearest 0.1 cm and weighed whole (Wt), to the nearest 0.1 g. They were then dissected for the collection of the gonads, which were also weighed to the nearest 0.01 g. Once collected, the gonads were fixed in 10% formaldehyde and stored in 70% ethanol. The gutted weight of the fish (Wg) was also measured.

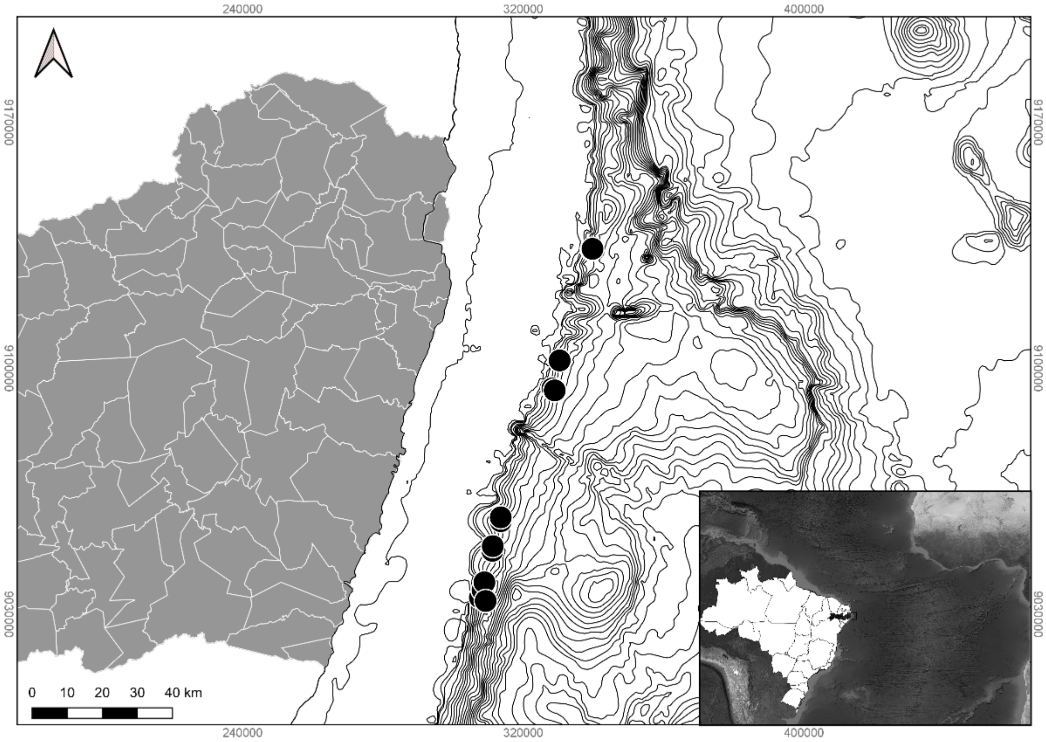

Figure 1- Continental slope off Pernambuco, highlighting the sampling points of *Physiculus kaupi* and Pernambuco location in relation to the equatorial Atlantic.

Reproduction Analyses

Sex was determined by macroscopic examination and confirmed by histology. The sex ratio was defined as the proportion of the number of females by the number of males. Gonadosomatic index was calculated over the year by the formula:

$$GSI = \left(W_g / \left(W_t - W_g\right)\right) \text{ x } 100,$$

where W_g is the gonad weight and W_t is the total fish weight.

For the histological processing, a portion of fixed gonads were dehydrated, embedded in Technovit resin, sectioned at 4 mm thickness and stained with toluidine blue. The developing phases for both sexes were described according to Brown-Peterson et al. (2011). The female reproductive cycle was evaluated based on the monthly variation of the mean GSI values and frequency of developing phases.

The size at first maturity (L_{50}), defined as the body length at which 50% of the individuals were mature, was calculated for the sample using the linear form of a logistic curve describing the relationship between the fish length and proportion of mature fish at this length (ICCAT, 2006–2016):

$$\text{Ln } \frac{P}{1-P} = a + b \text{ x TL}$$

where P is the observed proportion of mature fish, a and b are the linear regression parameters of the linear model, TL: central value of each 2.5 cm bin size class (15 – 31.5 cm TL), L_{50} is the size of fish corresponding to P ¼ 0.5, which means that L_{50} ¼ 2a/b. The predicted proportion of mature fish was estimated using a logistic model (ICCAT, 2006–2016):

$$\% \text{ Matures} = \frac{1}{1 + \exp(-b \text{ x } (\text{TL} - \text{L50}))}$$

where TL is the total length in cm, L_{50} is the size at first sexual maturity in cm, b ¼ slope of the linear regression line of the logistic model.

To study follicle size-frequency distribution and ovarian development organization, the average size range of 100 oocytes with a visible nucleus was measured from twelve ovaries in different developing phases, 3 in each phase (immature, developing, spawning capable and regressing) using NDP.view 2 program.

Batch fecundity was calculated by the gravimetric method from the average count of advanced yolked oocytes from three aliquots of 0.1g of 4 ovaries in capable spawning phase. Total number of oocytes was estimated a following Hunter (1985) and Murua et al. (2003) by the formula:

$$F = \frac{[\sum_i O_i / P_i]}{n} \text{ x } Wg$$

where O_i is the number of each aliquot, P_i is the aliquot weight, *n* is the number of aliquots repetitions taken from each ovary and Wg is the gonad weight.

Statistical Analyses

Vertical distribution of the species was analyzed according to the relative abundance, calculated as the catch per unit effort (CPUE) in number of individuals caught per immersion time of traps and number of traps used (Pires et al., 2020 in press).

The sex ratio was calculated monthly, for size class and for 2 different depth classes: shallower (between 290 to 360 m) and deeper (between 361 to 430 m). Furthermore, the absolute frequency of each sex was also compared according to the depth classes, to detect possible segregation.

The sex ratios were tested by chi-square test (χ^2) calculated with the mathematical equation: $\chi^2 = \sum d^2/e$, in which d is the expected frequency for that depth class and o= observed frequency for that depth class.

Since the distribution of gonadosomatic index by sex and by development phase in females was not normal, according to a normality test of Shapiro-Wilk, they were tested through non-parametric Wilcoxon paired and Kruskal-Wallis tests, to verify whether there were any relationship between reproduction and ontogeny against depth.

Results

A total of 55 individuals of *Physiculus kaupi* were caught between 290 to 430 m, with higher relative abundance (CPUE), between 300 and 400 m (Fig. 2). The total length of *P. kaupi* varied from 15,1 to 31,5 cm. Females had a broader size range, from 15,1 to 31,5 cm (22,15 ± SD 3,85), while males measured from 16,5 to 24,4 cm (21,5 ± SD 2,54). The size class with highest frequency (n= 19) was 20.0-22.5 cm, with a high female dominance (n= 14). (Fig. 3). The total weight also varied more in females (Max.= 328 g; Min.= 26 g; mean= 122.5 g ± SD 31.7) than in males (Max.= 135 g; Min.= 32.4 g; mean= 79.7 g ± SD 31.2).

Of the 55 specimens caught, 36 were female, 14 were male, and in 5 of them the sex could not be identified. The total sex ratio showed a statistically significant predominance of females: 1F:0.4M (χ^2= 9.1). The monthly sex ratio, however, was significantly different only in July (χ^2= 4.6) and August (χ^2= 5.3). Considering depth distribution, females were significantly predominant only in the shallower strata (χ^2= 8.8), as well as in the size classes of 20.1- 22.5 (χ^2= 4.3) and of 25.1- 27.5 (χ2= 5) (Table 2).

The size of first maturation (L_{50}) for females was estimated at 17.9 cm of total length (Fig. 4). It was not possible to calculate the L_{50} for males due the lack of immature specimens. Based on this result, 33 of the 36 females sampled (92%) were above the first maturation size.

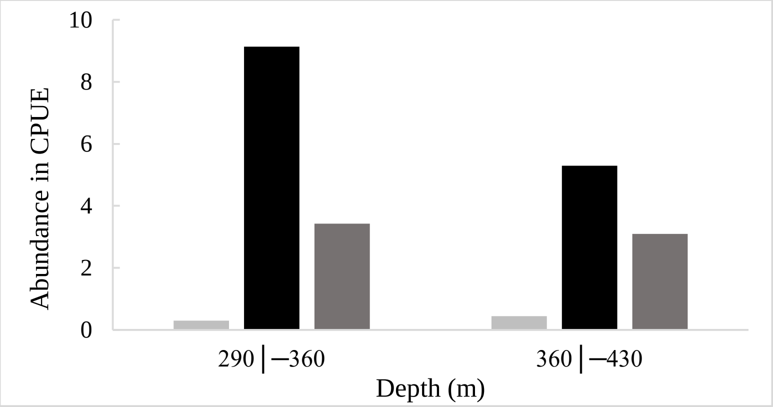

Figure 2- CPUE of *P. kaupi* caught on continental slope off Pernambuco by depth strata.

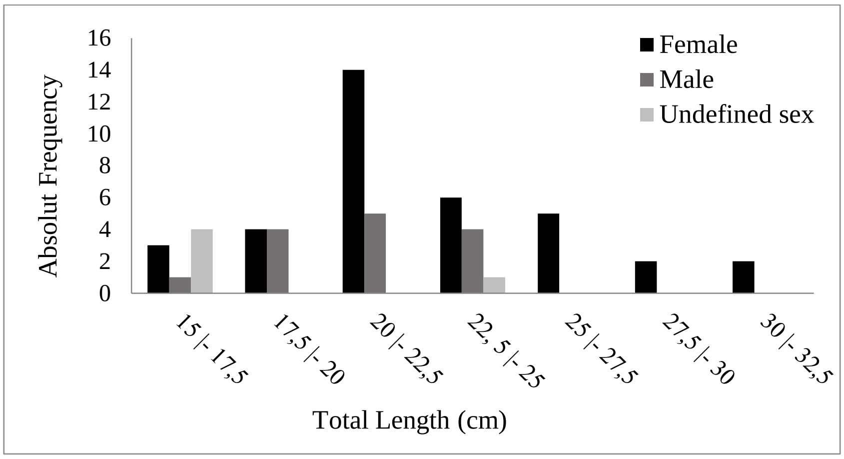

Figure 3- Total length-frequency distribution of *P. kaupi* on continental slope off Pernambuco.

Table 2- Sex ratio by month, size class and bathymetric distribution (Upper *x* Lower depth) of *Physiculus kaupi*, and results of the chi-square test (χ2). Shallower depth class: 290 to 360 m; deeper depth class: 361 to 430 m.

Month	**Female**	**Male**	**Total**	**χ2 Test**
April	5	5	10	0
June	2	0	2	2.0
July	11	3	14	4.6*
August	10	2	12	5.3*
September	2	2	4	0.0
October	1	0	1	1.0
November	4	2	6	0.7
December	1	0	1	1
Size Classes				
15-17,5	3	1	4	1.0
17,6-20	4	4	8	0.0
20,1-22,5	14	5	19	4.3*
22,6-25	6	4	10	0.4
25,1-27,5	5	0	5	5.0*
27,6-30	2	0	2	2.0
30,1-32,5	2	0	2	2.0
Depth Classes				
Shallower	25	8	33	8.8*
Deeper	11	6	17	1.5
Total	**36**	**14**	**50**	**9.7***

* Statistical difference, 5% significance level

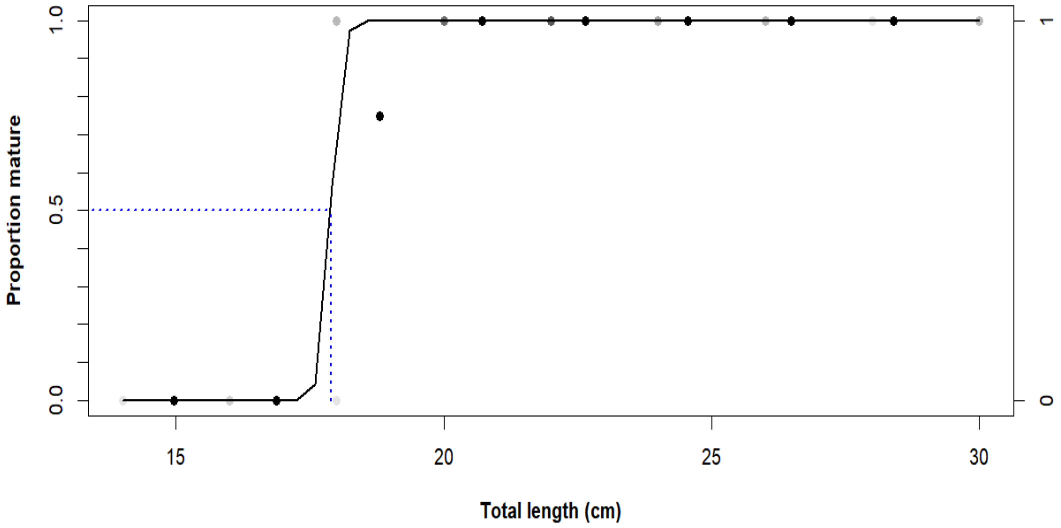

Figure 4- Size of first maturation estimated for *Physiculus kaupi* females, caught with bottom traps off Pernambuco, northeast Brazil.

The distribution of *P. kaupi* by size and sex in relation to the depth (Fig. 5) shows that only females were found in deeper waters, besides being also more abundant in shallower depths (p <0.02). However, when the total length was plotted in relation to the depth classes, there was no statistical difference between sex (p> 0.14).

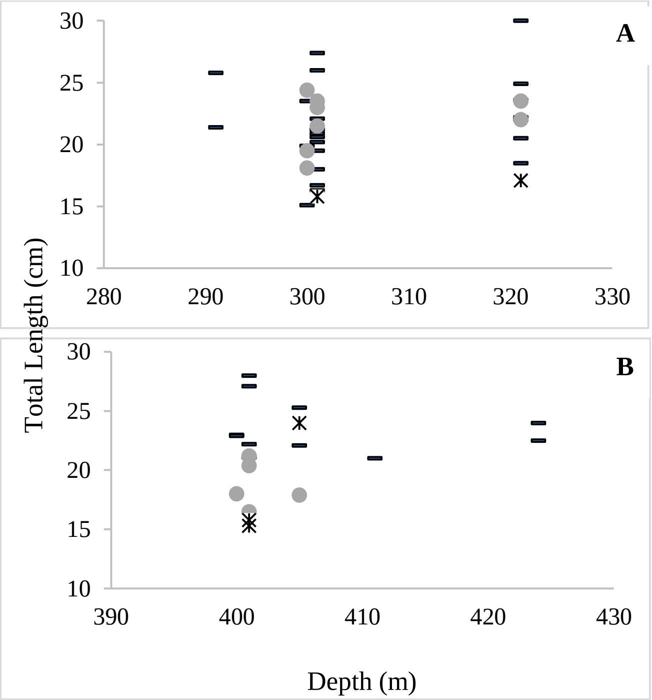

Figure 5 – Distribution of the total length (cm) of *Physiculus kaupi* in the Shallower depth (A) and Deeper depth (B). Small lines represent females, gray points males and asterisks individuals with undefined sex.

The depth distribution by development phase (Immature, Developing, Spawning capable and Regressing) for females indicate that Immature and Regressing females occurred only in the shallower depth (Fig 6). Additionally, all the females found in the deeper stratum measured above the L_{50} size, indicating a possible depth segregation by size.

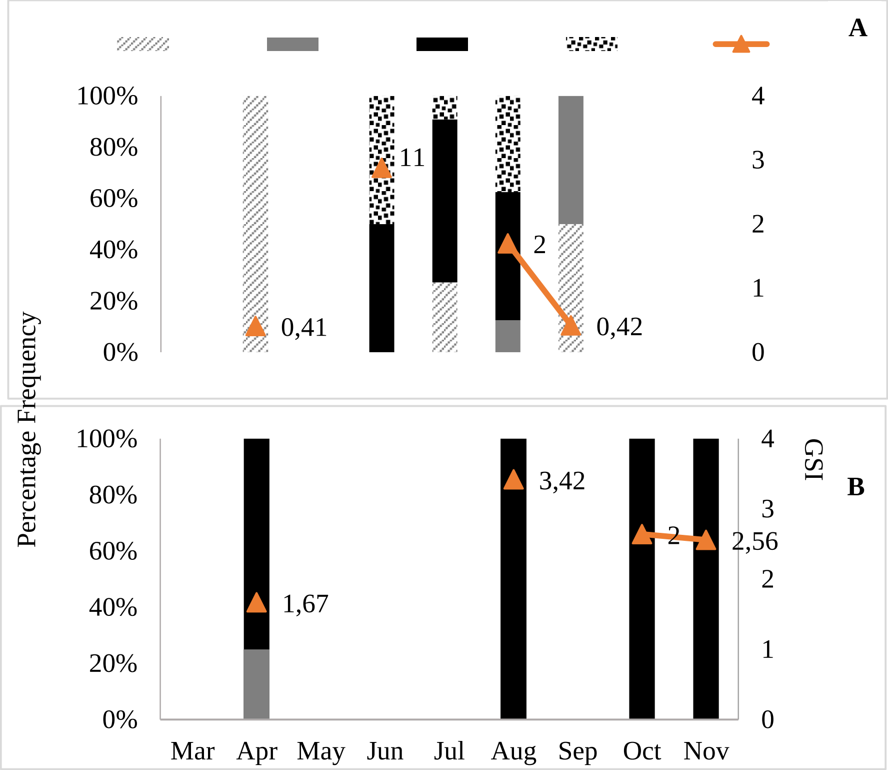

Figure 6 – Percentage Frequency of development phase of female *Physiculus kaupi* and GSI in the Shalower depth (A) and Deeper depth (B).

Reproductive Biology

From the microscopic analysis of *Physiculus kaupi* gonads, it was possible to identify four development phases in females: Immature, Developing, Spawning capable and Regressing; and only three phases in males: Developing, Spawning Capable and Regressing (Fig. 7 and 8).

Immature females only contained oogonia and primary growth (PG) oocytes, and a thin ovarian wall. The developing phase was characterized by the presence of oogonia, PG, cortical alveolar (CA) and primary vitellogenic oocytes (Vtg1). It was also possible to observe old atresia. The spawning capable phase showed cells in all developing stages, from oogonia to the latest stages of oocyte maturation, such as germinal vesicle migration and hydrated oocytes, prominent blood vessel, postovulatory follicle (POFs) and atresia.

Regressing phase was markedly featured by a flaccid ovarian wall and high quantity of atresia of all oocyte stages, presence of POFs, a great number of oogonia, PG, earlier vitellogenic oocytes and still oocytes in late maturation (Fig. 7, Table 3).

Only three development phases of *Physiculus kaupi* testis were observed: Developing, Spawning capable and Regressing. The weight of male gonads showed a slight variation (from 0.01 to 0.9 g) and macroscopic distinction between phases was very difficult. The main characteristic in the development testis was the lack of spermatozoa in the lumen, and all the spermatogenesis cells in spermatocysts. The spawning capable phase contained sometimes elongated lobules, reduced amount of spermatogonia in comparison with development phase, presence of spermatozoa in the lumen and in the spermatic ducts, and a generally discontinuous germinal epithelium near the spermatic duct in the late ripening. Regressing phase was also characterized by elongated lobules, a discontinuity in the germinal epithelium, and a reasonable amount of sertolli cells to phagocyte the residual spermatozoa (rSz), together with a major quantity of spermatogonia (Fig 8, Table 3).

The monthly distribution of the development phases of females suggests they may spawn all year round, but with a peak of reproductive activity from October to December. However, even the period from July to August, the only one with females in Regression, also had females in spawning capable phase (Fig. 9A). The monthly mean Gonadosomatic index, as well, was rather high for all months sampled, except for September, but only one developing female was caught during this month (together with an immature specimen that was not included in this analysis). The monthly mean GSI values for males follow those for females, despite the lower proportion of males in the sample (Fig. 9B). Despite of a lack of samples from most of the first half of the year, the monthly distribution of development phases together with the GSI variation suggest a continuous reproduction of *Physiculus kaupi* on Pernambuco coast, at least for the months sampled.

Batch Fecundity ranged from 8,565 to 13,160, with an average of 11,517 oocytes per gonad. The lowest fertility was observed in a 22.1 cm specimen with a gonad weight of 2.83 g and the highest fertility was found in a specimen with 21.2 cm, with a gonad weight of 4.96 g.

Oocyte diameter varied from 12.5 to 659.0 µm. Immature ovaries had oocytes up to 83.5 µm in diameter, developing ovary oocytes measured up to 255.5 µm, and ovaries in Spawning capable and in Regression phases had ovaries with oocyte diameter with greater amplitude, with a maximum of 659.0 µm and 591.5 µm, respectively. The Spawning capable ovaries had less oocytes in primary growth and more oocytes in advanced vitellogenesis compared to the Regression phase. The dynamics of oocyte organization (Fig. 10), i.e. the presence of oocytes in all development stages without a dominant population, indicates that *Physiculus kaupi* has an asynchronous ovarian development.

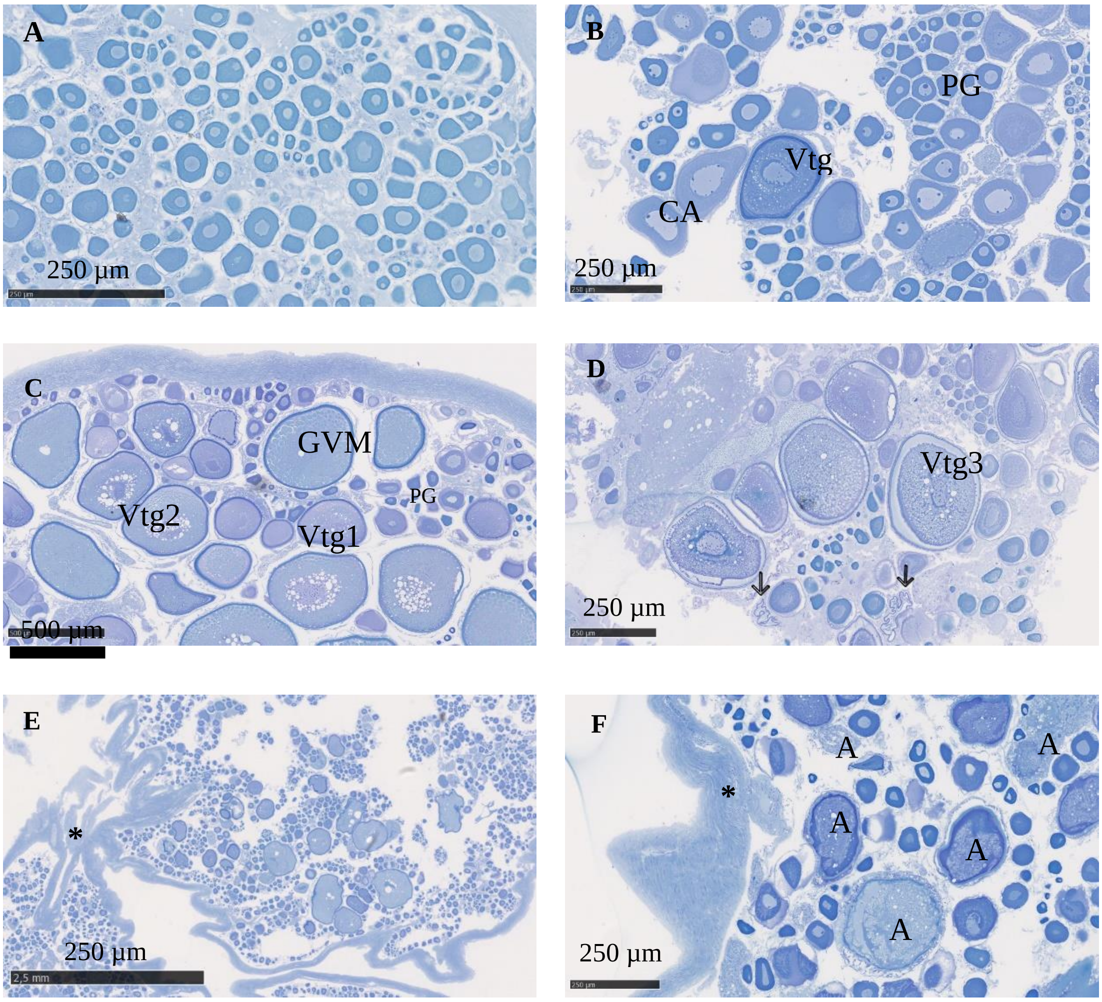

Figure 7- Photomicrographs of *Physiculus kaupi* ovarian, illustrating the appearance of different development phases: (A) Immature phase containing only oogonia and primary growth oocytes; (B) Developing phase with oogonia, primary growth, cortical alveolar and initial vitellogenic oocytes (PG = primary growth, CA= cortical alveolar, Vtg1 = primary vitellogenic oocyte); (C) Spawning capable phase with oocytes in different developing stages (Vtg2 = secondary vitellogenic oocyte, GVM = germinal vesicle migration); (D) Spawning capable phase containing oocytes in different developing stage and with Vtg3 as the most mature oocyte (Vtg3 = tertiary vitellogenic oocyte, arrows indicating postovulatory follicle); (E and F) Regressing phase highlighting the oocytes in atresia and the ovarian wall with muscle bundles (*).

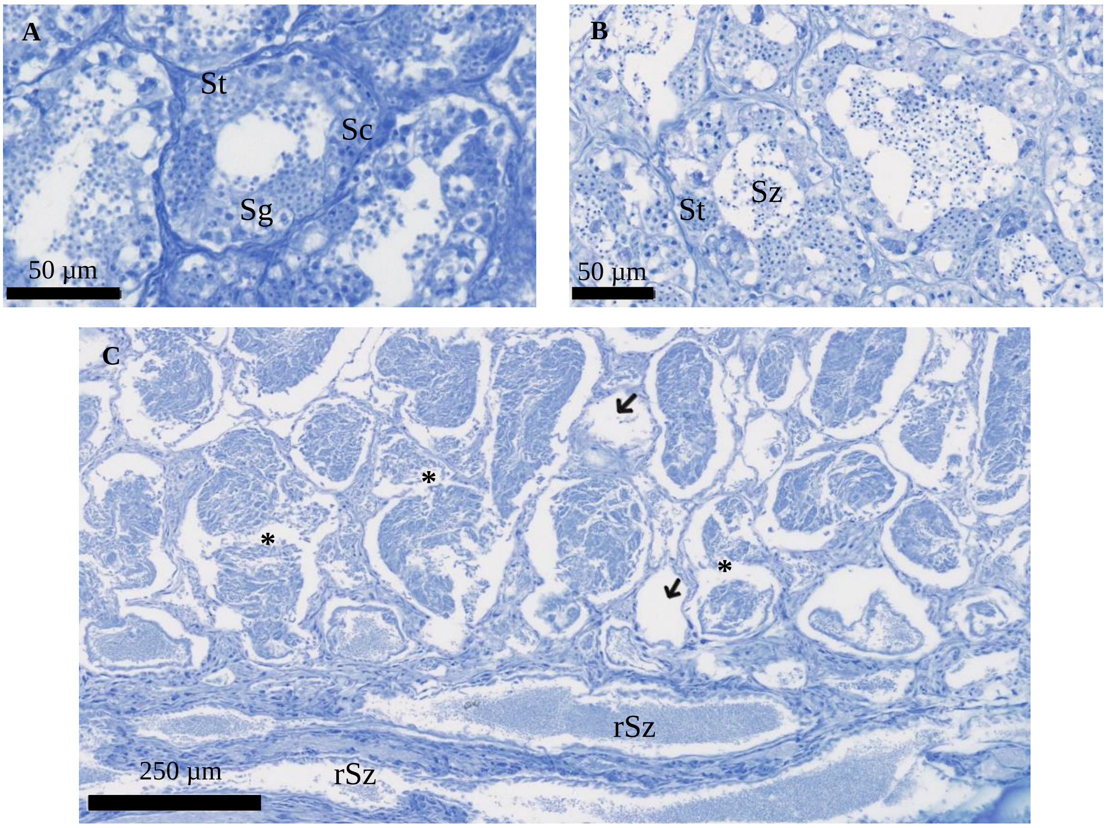

Figure 8- Photomicrographs of *Physiculus kaupi* testis, illustrating the appearance of different development phases: (A) Developing phase do not containing spermatozoa cell in the lumen, but various stages of spermatogenesis cells are organizing in cysts around the seminiferous lobules (SG = spermatogonia, Sc= spermatocytes, St= spermatids); (B) Spawning capable phase containing spermatozoa in the lumen and a smaller amount of other spermatogenic cells in the lobules periphery; (C) Regressing phase shows empty lumen indicated by the arrow, anastomosing regions indicated by asterisks and residual spermatozoa and sertolli cells in the spermatic ducts (rSz= residual spermatozoa).

Table 3- Description of histological characters of male and female *Physiculus kaupi* gonads from Pernambuco coast, Brazil.

Phase	**Ovary**	**Testis**
Immature	Present only oogonia and PG oocytes. Little space between oocytes. Ovarian wall width ranging from 49 to 98 µm. GSI: 0.04 – 0.43	No fish identified in this phase.
Developing	Presence of PG, CA, Vtg1 and Vtg2 oocytes. May be identified old atresia of oocytes and POFs. The size of the ovaries and the ovarian wall width increase. The later ranges between 99,5 to 344 µm. GSI: 0.34 – 0.87	Presence of all spermatogenesis cells in the gonad, but a few quantities of Sz in the lumen, therefore the lumen is usually empty. Lobules may have elongated shape. The GE is continuous. GSI: 0.02 – 0.12

Spawning capable	All stages of oocytes present, including GVM, GVBD e OH. POFs and a big amount of vitellogenic oocytes in atresia are possible to observe. The ovaries are larger and blood vessels are prominent. GSI: 1.39 – 4.76	All stages of spermatogenesis cells can be presented, but Spermatozoa is finding in a major quantity in the lumen of the lobule and in the sperm ducts. The Germinal epithelium can be continuous or discontinuous. GSI: 0.14 – 1.19
Regressing	Flaccid ovaries, blood vessels prominent. Atresia of all oocytes stages and POFs present. CA oocytes and oocytes in primary and second vitellogenesis present. GSI: 1.1 – 2.55	Presence of residual Spermatozoa in the lumen and in sperm duct, big space between the residual spermatozoa and the interstitial tissue. Big amount of Sertoli cells. GSI: 0.12 – 0.28
Regenerating	No fish identified in this phase.	No fish identified in this phase.

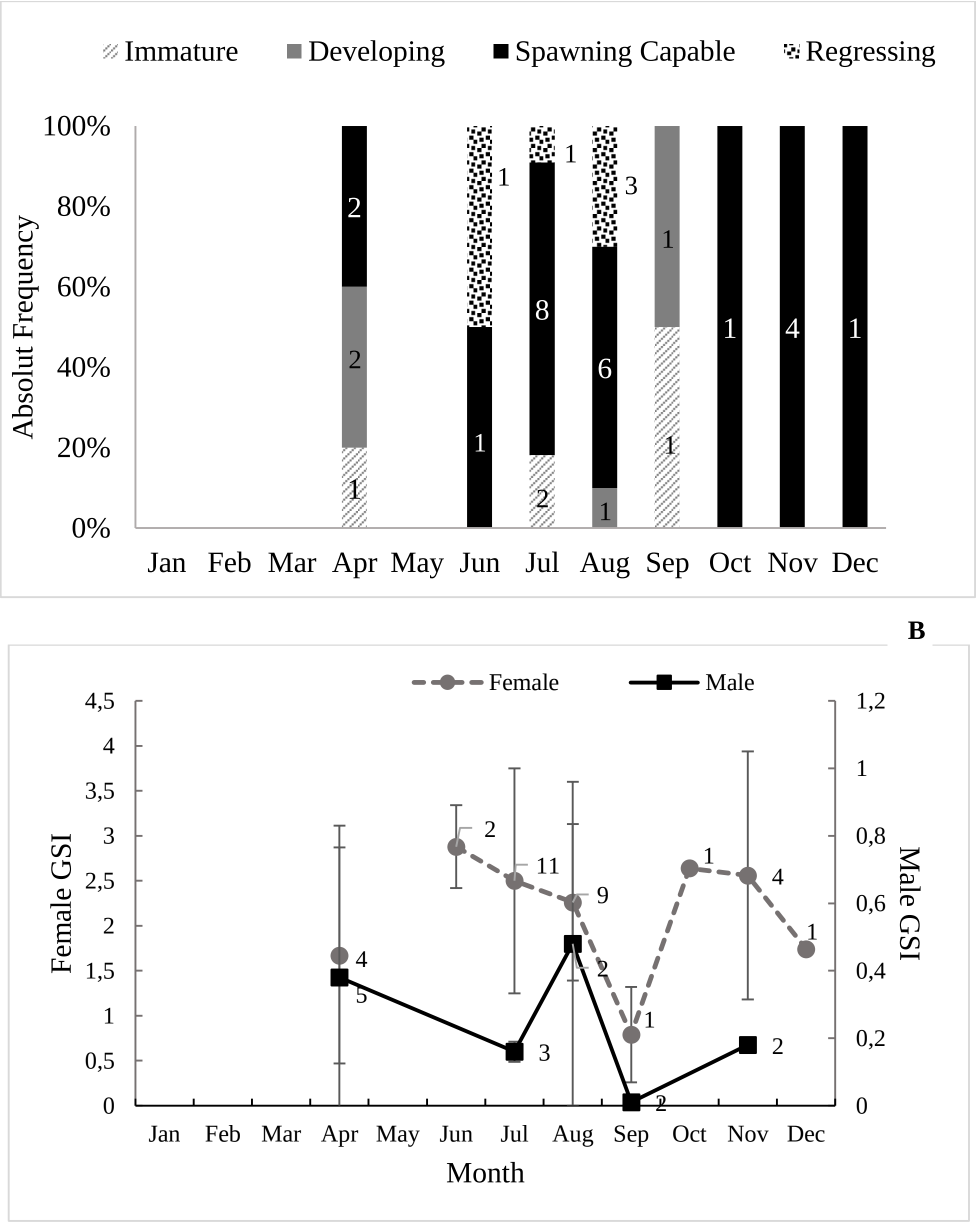

Figure 9- Monthly distribution of the development phases in females (A) and monthly variation of female and male GSI of *Physiculus kaupi* (B).

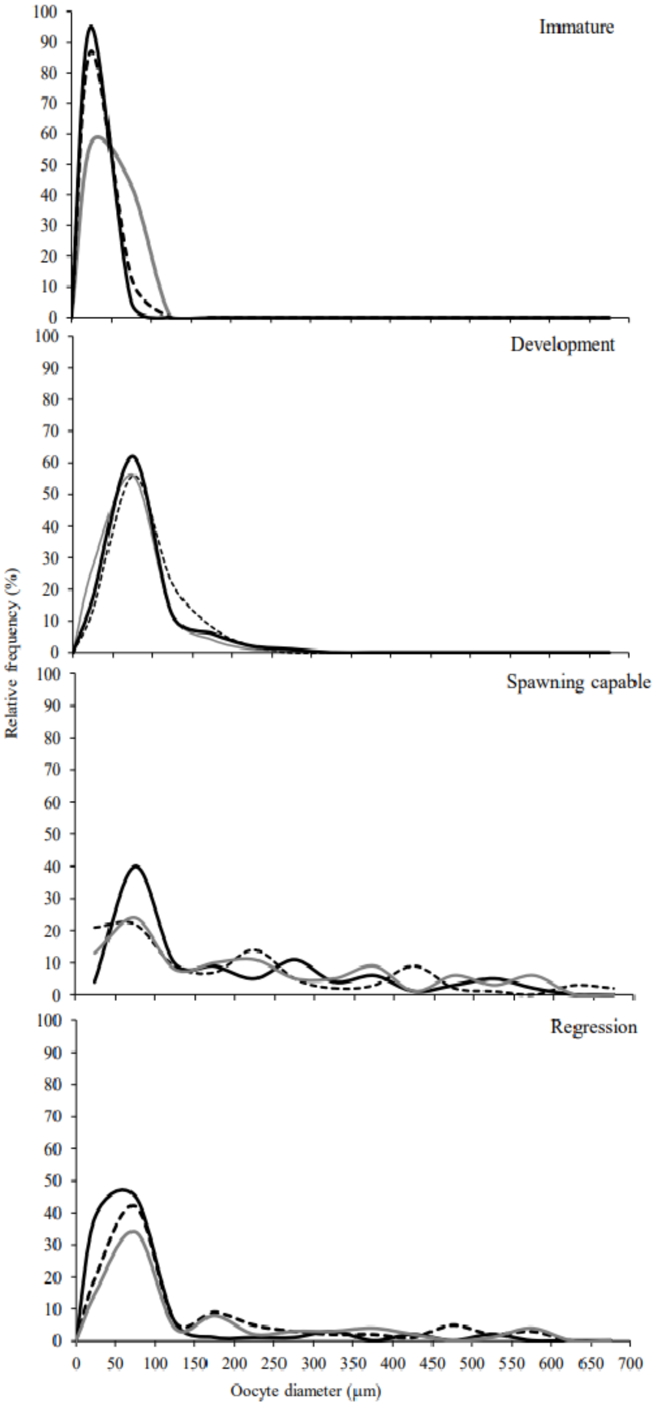

Figure 10- Distribution of oocyte diameter (µm) frequency of *Physiculus kaupi* females caught on Pernambuco coast, northeast Brazil.

Discussion

Species from Moridae and Macrouridae family, both Gadiforms, usually are the dominant biomass in deep-sea studies worldwide (Snelgrove e Haedrich, 1985; Meléndez e Pequeño, 1999; D'Onghia et al., 2004; Capezzuto et al., 2010). On Pernambuco coast, *Physiculus kaupi* was the most caught Teleostei species during a series of fishing sets with bottom traps (Pires et al. *in press*). This large abundance confirms their ecological importance in local demersal communities (Stefanescu et al., 1994, Fernandez-Arcaya et al., 2013a).

The predominance of females found in the present work is often reported from demersal fish communities, including *Physiculus maximoczi* (Kitagawa and Nigahora, 1982) and *Physiculus cyanostrophus* (Triay-Portella et al., 2019). This phenomenon may be because the species studied shows a marked sexual dimorphism, where females are bigger and more abundant than males; a common strategy in deep-water species to avoid intraspecific competition for resources (Shine, 1989; Fairbairn, 1997).

Differences in sex ratio have also been attributed to ontogenic migration for feeding purposes, with mature females usually being found in deeper waters and immature specimens in shallower areas, where food availability may be greater (Cohen et al., 1990, Massutí et al., 1995, D´Onghia et al., 1999; Fernandez-Arcaya et al., 2012). Although the differences in depth distribution by stage of development was not statistically significant, the fact that most of the females found in deeper waters were in developing and spawning capable phases, together with all immature females being found in shallower depths, seems to corroborate the hypothesis of a vertical migration to deeper areas to spawn (Romeu et al., 2016).

Genetic and environmental factors play different roles in reproduction. While the former controls gonad morphology and gametogenesis (Eckelbarger and Watling, 1995), environmental factors, for example, the organic flux from the surface and the arrival of water masses, may shape reproductive strategies, such as the timing and duration of gametogenesis and the spawning season (Company et al., 2001, 2003; Wigham et al., 2003). Several studies have been conducted to assess the temporal pattern and depth variation in the reproductive process (Gordon e Duncan, 1985; Rotllant et al., 2002; D'Onghia et al., 2006; Fernandez-Arcaya et al., 2013; Mecho et al., 2015). Nevertheless, in the deep-sea environment, seasonality and effects of environmental variables on reproduction biology has been difficult to assess due to sampling difficulties.

Fecundity measurements are of particular importance to elucidate the reproductive dynamics and the spawning energetics of a fish population, and to estimate annual reproductive output (Ganias et al., 2014). Studies on gadoid species have shown that egg production can vary with female size, age and/or condition (Merret, 1994; Hislop, 1988; Kjesbu et al., 1991). Deep water species, however, are generally reported as having a low fecundity (Merret, 1987; Fernandez-Arcaya et al., 2012). With an average of 11,517 oocytes per gonad, the fecundity of *Physiculus kaupi* was indeed relatively low. *P. kaupi*, however, displayed asynchronous development and were sampled throughout spawning periods, hence, it is possible that some fish had already released at least one batch of eggs before the fecundity estimates, resulting in underestimations (Murua et al., 2013). Until now, the only fecundity data published to another congener are those of *Physiculus cyanostrophus* from Cape Verde Archipelago, caught at depths of 66 m and 458 m, which batch fecundity varied between 4,561 to 44,959 (Triay-Portela et al., 2009), with the fecundity of *P. kaupi*, therefore, being within that range.

The distribution of the developmental stages of *P. kaupi* females, despite the discontinuity of the sampling, indicates an asynchronous development of vitellogenic oocytes and continuous oogenesis throughout the year. Mature females were present in almost every month but in larger concentration in the last three months of the year, while the highest GSI values were found in June-August and October-December. Continuous reproduction is in line with what is reported for other species in the upper slope and over a broad depth gradient (D’Onghia et al., 2008; Fernadez-Arcaya et al., 2013). Allain (2001) proposed that prolonged spawning periods and asynchrony in maturation is associated with the lack of pronounced cycles in environmental factors in the deep sea. This fits well with the environment of the Pernambuco coast, where *P. kaupi* were sampled in this study, where primary production is low and stable. In addition, Fernadez-Arcaya et al. (2013) suggested that species in the upper slope (300- 800 m) do not face energetic constraints, therefore continuously spawning throughout the year.

In conclusion, this study shows that the sex ratio of *Physiculus kaupi* changes with depth, with a higher proportion of females in deeper waters. Total length was not correlated to depth, but the vertical distribution of female developing phases suggest a migration of adult females to spawn in deeper waters. The low fecundity, asynchronous ovarian development and likely continuous reproduction all year round shown by the species, are in agreement with several Gadiformes reproduction, but also with the typical low productivity from the western equatorial Atlantic and the deep-sea environment.

Although this species is currently not targeted by commercial fishing and the small number of captured specimens does not allow robust conclusions on the extension of their reproductive period, the results help to understand the biology of the *P. kaupi* and, in the long run, to understand the dynamics of deep-sea fish populations in relation to depth in equatorial and oligotrophic environments. They also contribute to improve the understanding of the factors that shape their vulnerability to natural and anthropogenic changes.

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6. Considerações Finais

O conhecimento sobre a dinâmica de populações de espécies que habitam os ambientes marinhos profundos tem avançado bastante, motivado especialmente pela preocupação em assegurar a conservação da biodiversidade diante do crescimento na exploração do mar profundo, seja ele pela expansão da pesca para atender à demanda do mercado, uma vez que muitos estoques de peixes costeiros têm colapsado (Coll et al., 2008; Pontecorvo e Schranck, 2014), seja pelo desenvolvimento de tecnologias capazes de minerar o assoalho marinho.

Alguns peixes de profundidade são K-estrategistas e exibem história de vida excepcionalmente duradoura. O *orange roughy* e oreosomatídeos, por exemplo, aparentemente vivem até mais de 100 anos (Tracey e Horn, 1999; Smith e Stewart, 1994), enquanto os Sebastes spp., família Scorpeanidae, também de águas profundas, vivem mais de 50 anos (Chilton e Beamish, 1982; Campana et al., 1990). Além da grande longevidade, essas espécies exibem uma taxa de mortalidade natural baixa, crescimento lento e maturidade tardia, características que aumentam consideravelmente a sua vulnerabilidade, reduzindo concomitantemente a sua resiliência à sobre pesca.

A grande diversidade de estratégias de vida já encontradas entre as espécies de profundidade, porém, indicam claramente que não há um modelo único de história evolutiva resultante de adaptações ao ambiente. Portanto, estudar a distribuição das populações, compreender a sua produtividade e conhecer as estratégias de vida de diferentes espécies, é um elemento crucial para aumentar o poder preditivo e consequentemente o manejo e conservação dos ecossistemas marinhos de águas profundas.

Nesse estudo, as espécies de teleósteos presentes no talude continental do estado de Pernambuco, na costa nordeste do Brasil, no Atlântico equatorial, foram estudadas, quanto a sua composição e distribuição vertical, incluindo a possível formação de assembleias e zonas de transição, com foco na estrutura da população e biologia do teleósteo mais abundante, o *Physiculus kaupi*. Apesar de estudos anteriores terem sido efetuados no talude do estado de Pernambuco, na maioria das vezes os dados reportam as ocorrências de forma genérica, estendidas para toda a região Nordeste, não havendo, em muitos casos, qualquer especificação sobre local e profundidade de coleta, sem descrição detalhada dos espécimes coletados, informações sobre a sua biologia ou tombamento em coleções ictiológicas.

Ao aportar informações inéditas sobre os teleósteos de profundidade na costa pernambucana, espera-se que o presente trabalho possa contribuir para a compreensão da diversidade e distribuição da fauna profunda em regiões equatoriais e oligotróficas e eventual adoção de medidas de manejo e conservação frente a um possível impacto. No caso de futuros estudos, sugere-se a utilização de malhas menores, de forma a permitir a coleta de espécies de tamanho menor, além da coleta de um maior número de variáveis ambientais, de forma a permitir uma análise mais aprofundada da influência do ambiente na distribuição das espécies.

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