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CENTRO DE TECNOLOGIA E GEOCIÊNCIAS
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A utilização dos diferentes habitats do estuário do Rio Goiana pelas diferentes fases ontogenéticas das espécies *Cathorops spixii*, *Cathorops agassizii*, *Stellifer brasiliensis* e *Stellifer stellifer* (Actinopterygii, Teleostei).

Estudo de caso: Caracterização das áreas utilizadas como berçário.

David Valença Dantas

Recife – PE

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Orientador: Dr. Mário Barletta
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Não é o mais forte que sobrevive, nem o mais inteligente, mas o que melhor se adapta as mudanças.

“Charles Darwin”

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RESUMO

A utilização dos habitats está relacionada à variações na dieta ao longo do ciclo de vida. A análise da dieta das diferentes fases ontogenéticas em diferentes habitats pode gerar informações a respeito dos padrões de movimento entre os habitats utilizados como berçário e os dos adultos. O presente estudo descreve a utilização sazonal dos habitats e hábitos alimentares de diferentes fases ontogenéticas das espécies *Cathorops spixii*, *Cathorops agassizii*, *Stellifer brasiliensis* e *Stellifer stellifer* ao longo do canal principal do estuário do Rio Goiana. Neste estudo, foram utilizados dados referentes à amostragens realizadas com rede de arrasto no canal principal entre dezembro de 2005 e novembro de 2006. O canal principal do estuário foi dividido em três áreas (superior, intermediária e inferior), de acordo com o gradiente de salinidade e a geomorfologia do estuário. As espécies foram divididas em diferentes classes de tamanho, de acordo com o seu respectivo estágio de desenvolvimento, em jovens, sub-adultos e adultos. Além da distribuição, em termos de densidade e biomassa, também foram analisados o conteúdo estomacal dos indivíduos com o objetivo de observar a variação sazonal na dieta e possíveis sobreposições alimentares entre as diferentes fases ontogenéticas das espécies simpátricas. A sobreposição alimentar entre *C. spixii* e *C. agassizii* foi testada quando as diferentes fases ontogenéticas ocorreram no mesmo local. A precipitação sazonal das chuvas foi importante para definir a utilização dos habitats pelas diferentes fases ontogenéticas destas espécies ao longo do canal principal do estuário. A porção intermediária do estuário foi importante como local de berçário e alimentação para jovens, além de ser importante para alimentação de todas as espécies estudadas. Os bagres marinhos *C. spixii* e *C. agassizii* são predominantemente zoobentívoros, mas ao longo do seu ciclo de vida, e entre os diferentes locais e estações do ano, esta guilda trófica pode mudar para zooplanctívoro ou até mesmo oportunista. No início da estação seca, nas porções superior e intermediária do estuário, sub-adultos e adultos de *C. spixii* demonstraram sobreposição alimentar, principalmente pela elevada ingestão de Polychaeta e Ostracoda. No final da seca, no estuário superior, os adultos da espécie *C. spixii* apresentaram sobreposição alimentar com os jovens e adultos da espécie *C. agassizii*, devido à elevada ingestão de Gastropoda, Ostracoda e Calanoida. No início da chuva, na porção superior do estuário, foram observadas sobreposições na dieta de jovens e sub-adultos das duas espécies, e entre jovens e sub-adultos de *C. agassizii*, influenciadas pela alta ingestão de Ostracoda e Calanoida. No final da chuva, no estuário intermediário, essa sobreposição foi observada para jovens e sub-adultos de *C. spixii* e *C. agassizii*, devido à alta ingestão de Gastropoda, Calanoida e Harpacticoida. Durante este período, na porção inferior do estuário, *C. spixii* e *C. agassizii* jovens e sub-adultos demonstraram sobreposição alimentar, resultado da elevada ingestão de Gastropoda, Calanoida e Ostracoda. As espécies *S. brasiliensis* e *S. stellifer* são especialmente zoobentívoras, mas ao longo do ciclo de vida, entre as estações do ano e diferentes habitats, sua guilda trófica pode variar para oportunista ou até mesmo zooplanctívora. No final da estação chuvosa, na porção inferior do estuário, todas as fases ontogenéticas de ambas as espécies, com exceção de jovens de *S. brasiliensis* e adultos de *S. stellifer*, apresentaram sobreposição alimentar indicando a similaridade na utilização das presas. Esta sobreposição foi influenciada pelo consumo de Calanoida, Polychaeta e Eucarida por todas as fases das duas espécies. A ingestão de fragmentos azuis de nylon por todas as espécies estudadas foi observada como sendo um problema ambiental que deve ser discutido pelas autoridades e levado à comunidade. O conhecimento dos hábitos alimentares e a utilização dos habitats pelas diferentes fases ontogenéticas é essencial para entender o papel ecológico das populações de peixes, sendo uma ferramenta fundamental para o desenvolvimento de planos de manejo e conservação.

Palavras chave: Dieta; Coexistência; Nicho alimentar; Fases ontogenéticas; Variabilidade espaço-temporal; Movimentos de peixes; Papel de berçário; Qualidade da água.

ABSTRACT

Habitat use by fish is related to diet shifts during the species life-cycles. Diet analysis of different ontogenetic phases from different habitats provides information on movement patterns between nursery and adult habitats. This study described the seasonal habitat utilization and feeding habits of ontogenetic phases of *Cathorops spixii*, *Cathorops agassizii*, *Stellifer brasiliensis* and *Stellifer stellifer* along the Goiana Estuary main channel. In this study, samples were taken from December of 2005 to November 2006 with an otter trawl net. The estuary main channel was divided in three different areas (upper, middle and lower) according to their different salinity gradients and geomorphologies. The species were distributed into different size classes according to their ontogenetic stages (juveniles, sub-adults and adults). The distribution, in terms of density and biomass, and the diet of each ontogenetic phases were analized to determine the seasonal movements and diet shifts of each ontogenetic phases along the estuarine ecocline. The diet overlap between *C. spixii* and *C. agassizii* was tested when different ontogenetic phases occurred together. The same hypothesis was tested for the species *S. brasiliensis* and *S. stellifer*. Seasonal freshwater discharge was important to define the habitat utilization of different ontogenetic phases of these species along the estuarine ecocline. The middle estuary was important as a nursery and feeding ground for juveniles, and a feeding ground for sub-adults and adults of all studied species. The ariid species are expected to be zoobenthivorous, but along their life-cycle and between different habitats and seasons, their trophic guild can change to zooplanktivore. During the early dry season, in the upper and middle estuary, sub-adults and adults of *C. spixii* showed a diet overlap, mainly by the high ingestion of Polychaeta and Ostracoda. During the late dry season, in the upper estuary, adults of *C. spixii* showed diet overlap with juveniles and adults of *C. agassizii*, mainly due to the high ingestion of Gastropoda, Ostracoda and Calanoida. During the early rainy season, in the upper estuary, significant diet overlaps was observed between juveniles of both species, sub-adults of both species and between juveniles and sub-adults of *C. agassizii*, determined by the high ingestion of Ostracoda and Calanoida. During the late rainy season, in the middle estuary, diet overlap was observed between juveniles and sub-adults of *C. spixii* and *C. agassizii*, with high ingestion of Gastropoda, Calanoida and Harpacticoida. At this time, in the lower estuary *C. spixii* and *C. agassizii* juveniles, and sub-adults showed remarkable diet overlap, with high ingestion of Gastropoda, Ostracoda and Calanoida. *Stellifer brasiliensis* and *S. stellifer* are expected to be zoobenthivorous, but along their life-cycle and between different habitats and seasons, their trophic guild can change to opportunist or zooplanktivore. During the late rainy season, in the lower estuary, all phases of both species, except juveniles of *S. brasiliensis* and adults of *S. stellifer*, showed a diet overlap indicating similarity in prey utilization. This overlap was influenced by the consumption of Calanoida, Polychaeta and Eucarida by all phases of both species. The ingestion of blue nylon fragments by all species studied here was observed as an environmental problem, which demands solutions by authorities and communities alike. The knowledge of feeding habits and habitat utilization by different ontogenetic phases is essential to understand the ecological role of fish populations, a critical tool in the development of conservation and management plans.

Keywords: Diet; Coexistence; Food niche; Ontogenetic phases; Spatial-temporal variability; Fish movement; Nursery role; Water quality.

Capitulo 1

Introdução geral

Introdução

Os ecossistemas costeiros promovem uma série de funções ecológicas vitais em águas costeiras, como proteção da costa, produtividade pesqueira e circulação de nutrientes (Beck et al. 2003). Diversos autores têm demonstrado a importância desses ambientes como locais de proteção, alimentação, reprodução e crescimento para um grande número de espécies de peixes e invertebrados (Nagelkerken et al. 2000, Laegdsgaard & Johnson 2001, Beck et al. 2003, Ikejima et al. 2003, Barletta et al. 2000, 2003, 2005, 2008, Chícharo et al. 2006, Barletta & Blaber 2007). Além disso, diversos estudos descreveram a importância e a função de possíveis habitats berçários (e.g. canais de maré, canal principal, prados de capim marinho e manguezais), para espécies de peixes ou invertebrados, além da conectividade existente entre estas áreas e os sistemas estuarinos (Perkins-Visser et al. 1996, Laegdsgaard & Johnson 2001, Nagelkerken et al. 2000, Sheridan & Hays 2003, Jenkins & King 2006, Barletta-Bergan et al. 2002a e b, Barletta et al. 2003, 2005, 2008, Ramos et al. 2011, Dantas et al. 2010, 2012a). A importância dos ambientes costeiros como berçário vem sendo discutida para peixes recifais em Curaçao, Mar do Caribe (Nagelkerken & van der Velde 2002, Cocheret de la Morinière et al. 2003), Nova Caledônia, sudoeste do Pacifico (Mellin et al. 2007), e para peixes estuarinos residentes em um estuário tropical do Nordeste do Brasil (Dantas et al. 2012a). O conceito de berçário se baseia no sucesso do assentamento das pós-larvas no habitat berçário, onde elas se desenvolvem para jovens e posterior migração dos sub-adultos para os habitats utilizados pelos adultos (Beck et al. 2003). Este ciclo de vida e os movimentos de espécies de peixes em estuários e águas costeiras adjacentes estão associados à variações de fatores bióticos (*e.g.* predação, suprimento larval, disponibilidade de alimento) e abióticos (*e.g.* salinidade, temperatura da água, oxigênio dissolvido) (Barletta et al. 2005, 2008, Dantas et al.

2010, 2012a), podendo ser inferido a partir da análise da utilização espaço-temporal dos habitats pelas diferentes fases ontogenéticas das espécies de peixes (Cocheret de la Morinière et al. 2003, Mellin et al. 2007, Dantas et al. 2012a). A utilização destes habitats pode estar relacionada a mudanças na dieta das espécies durante seu ciclo de vida, e a análise do conteúdo estomacal das diferentes fases ontogenéticas em diferentes habitats pode gerar informações a respeito dos padrões de movimentos entre os habitats utilizados como berçário e os habitats dos adultos (Cocheret de la Morinière et al. 2003).

Além das variações nos habitats e na dieta, outra importante função ecológica exercida por espécies de peixes é a de estarem aptos a compartilhar, ou competir por recursos, em uma população com alta densidade em um ambiente dinâmico (Mariani et al. 2011). Espécies simpátricas provavelmente devem consumir presas diferentes para minimizar a sobreposição alimentar (Schoener 1974), e diversos estudos testaram esta hipótese para espécies de peixes que habitam ecossistemas costeiros, *e.g.* em uma praia costeira no Mediterrâneo (Darnaude et al. 2001), na enseada de Wilson, um estuário sazonal no oeste da Austrália (Platell et al. 2006), e na Baía de Dublin, no Mar da Irlanda (Russo et al. 2008). Além disso, a competição por alimento pode afetar padrões de seleção do habitat, sobreposição do nicho e distribuição (David et al. 2007, Hilderbrand & Kershner 2004). Quando recursos alimentares são compartilhados, a coexistência de espécies de peixes tem sido relacionada à seleção de padrões diferenciados na utilização do espaço (Hesthagen et al. 2004, Sandlund et al. 2010). Além disso, o conhecimento dos hábitos alimentares e da utilização dos habitats pelas diferentes fases ontogenéticas é essencial para se entender o papel ecológico das populações de peixes (Blaber 2000). Ainda segundo Blaber (2000), para a realização de estudos científicos, gerenciamento de estoques pesqueiros e por razões conservacionistas, o conhecimento sobre dieta, ecologia alimentar e reprodução de peixes estuarinos é de extrema importância. O autor salienta ainda que, sem o conhecimento detalhado dessas informações, não é possível descrever como as comunidades de peixes estuarinos funcionam, nem é possível prever mudanças que possam resultar de qualquer intervenção natural ou antrópica, ou mesmo planejar seu manejo ao testar a eficiência dessas ações.

Estudos no canal principal do estuário do Rio Goiana sobre os movimentos espaciais e temporais das assembléias de peixes são realizados desde 2005 (Projeto FACEPE Nº: APQ-0586-1.08/06; Projeto Universal CNPq Nº 474736/2004; CT-Hidro 29/2007/CNPq Nº 552896/2007-1), para uma melhor compreensão da função deste habitat (canal principal do rio) para as diferentes fases ontogenéticas das espécies de peixes. Dentro desta linha de pesquisa, é de vital importância a realização de estudos mais detalhados nestes habitats do canal principal (superior, intermediário e inferior) para se conhecer melhor a função desses habitats como berçário e como fonte de alimento para as diferentes espécies de vertebrados e invertebrados (FACEPE: APQ-0586-1.08/06; CNPq: 37384/2004-7, 474736/2004 e 482921/2007-2; CNPq/CT-Hidro: 552896/2007-1).

Espécies estudadas

Cathorops spixii e *Cathorops agassizii* (Siluriformes, Ariidae)

Em estuários de regiões tropicais e subtropicais, os bagres marinhos da família Ariidae podem ser considerados o grupo mais importante em termos de número de espécies, densidade e biomassa (Lowe-McConnell 1987, Araújo 1988, Barletta et al. 2005, 2008, Dantas et al. 2010). Os bagres marinhos do gênero *Cathorops* estão distribuídos em ecossistemas estuarinos e águas costeiras adjacentes no Atlântico Sul ocidental da costa da Colômbia ao sul do Brasil, e na costa do Pacifico Oriental, do México ao Equador (Burgess 1989, Marceniuk & Menezes 2007). Nestes ecossistemas, os bagres marinhos são importantes não apenas para a pesca artesanal ou de subsistência (Barletta & Costa 2009), mas também com recurso alimentar para outros animais em diferentes níveis da cadeia trófica (Bittar & Di Beneditto 2009). Devido à grande abundância em estuários tropicais e subtropicais, os bagres marinhos estão disponíveis como recurso alimentar para peixes de importância comercial que visitam os estuário, *e.g. Trichiurus lepturus* Linnaeus e *Bairdiella ronchus* (Cuvier) (Bittar & Di Beneditto 2009, Castro et al. 2004). A distribuição dos bagres da família Ariidae em ecossistemas estuarinos é influenciada pela sazonalidade das chuvas e, consequentemente pelas flutuações dos parâmetros abióticos, *e.g.* salinidade, temperatura da água e oxigênio dissolvido (Barletta et al. 2005, 2008, Dantas et al. 2010). As diferentes fases ontogenéticas respondem diferentemente a estas flutuações (Dantas et al. 2012a). Além disso, as espécies *Cathorops spixii* (Agasiiz) e *Cathorops agassizii* (Eigenmann & Eigenmann) (Figura 1) são bentófagas (Barletta & Blaber 2007), alimentando-se especialmente de pequenos crustáceos e outros invertebrados que vivem no sedimento, e os estuários representam um ecossistema dinâmico e complexo para a reprodução, desova, incubação e berçário para ambas as espécies (Dantas et al. 2012a).

Stellifer brasiliensis **e** ***Stellifer stellifer*** **(Perciformes, Sciaenidae)**

As espécies simpátricas *Stellifer brasiliensis* (Schultz) e *Stellifer stellifer* (Bloch) (Figura 2) são mais abundantes em águas interiores rasas e quentes de estuários, sobre fundos arenosos ou lamosos (Carpenter 2002). Estas espécies podem ser classificadas como zoobentívoras ou zooplanctívoras, alimentando-se principalmente de pequenos crustáceos, peixes e outros invertebrados associados ao substrato ou que vivem logo acima do sedimento (Carpenter 2002, Barletta & Blaber 2007). As espécies do gênero *Stellifer* apresentam grande abundância em estuários tropicais e subtropicais da costa do Oceano Atlântico da América do Sul (Barletta et al. 2005, 2008). Estudos no estuário do Rio Caeté, na região tropical-úmida na Amazônia Oriental, no norte do Brasil, demonstraram que as espécies desse gênero, especialmente *S. rastrifer* (Jordan) and *S. microps* (Steindachner), são as espécies de peixes mais abundantes da família Sciaenidae em termos de densidade e biomassa (Barletta et al. 2005). No estuário de Paranaguá, na região de transição entre os climas tropical-subtropical, no sul do Brasil, Barletta et al. (2008) descreveram a estrutura da comunidade de peixes demersais em relação as variações sazonais das variáveis abióticas e também encontraram uma grande abundância, em termos de densidade e biomassa, das espécies do gênero *Stellifer*. Devido a esta grande abundância em ecossistemas estuarinos, especialmente como jovens, *Stellifer* spp. são importantes recursos alimentares para espécies de peixes de importância ecologica e comercial, que visitam o estuário em busca de alimento, *e.g. Trichiurus lepturus* L. (Bittar & Di Beneditto 2009), *Hexanematichthys proops* (Valenciennes, 1840), *Trachurus symmetricus* (Ayres, 1855) *Merluccius gayi gayi* (Guichenot, 1848), *Carcharhinus porosus* (Ranzani, 1839) e *Pterengraulis atherinoides* (Linnaeus, 1766) (Froese & Pauly 2011).

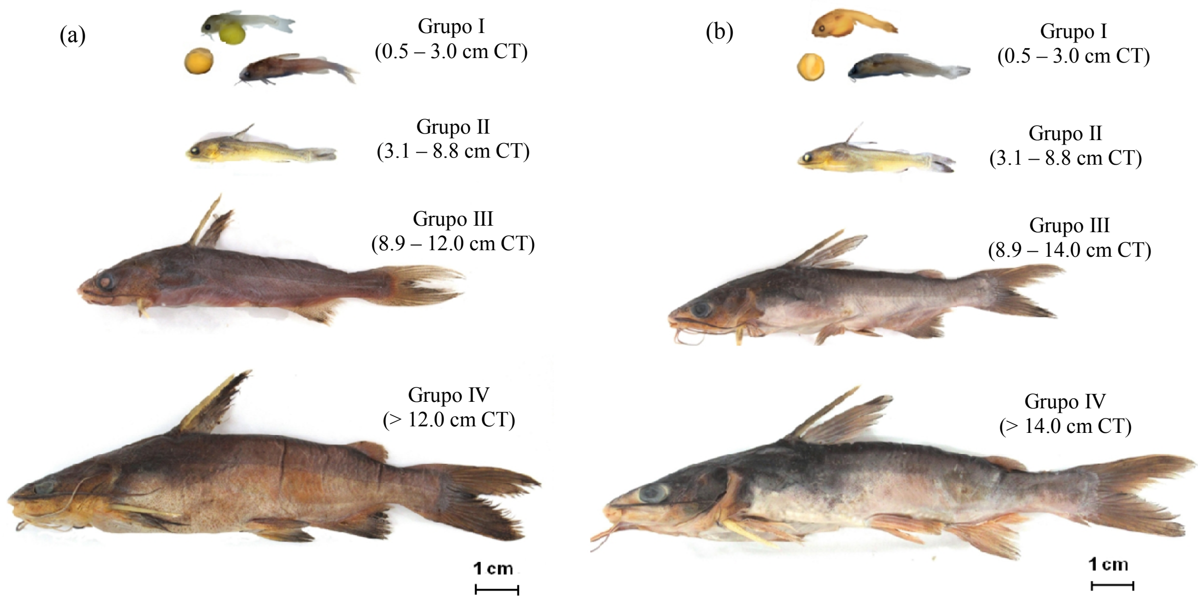

Figura 1. Bagres marinhos da família Ariidae. (a) *Cathorops spixii* e (b) *Cathorops agassizii*. Grupo I: ovos, larvas vitelínicas e pré-juvenis; Grupo II: jovens; Grupo III: sub-adultos; Grupo IV: adultos.

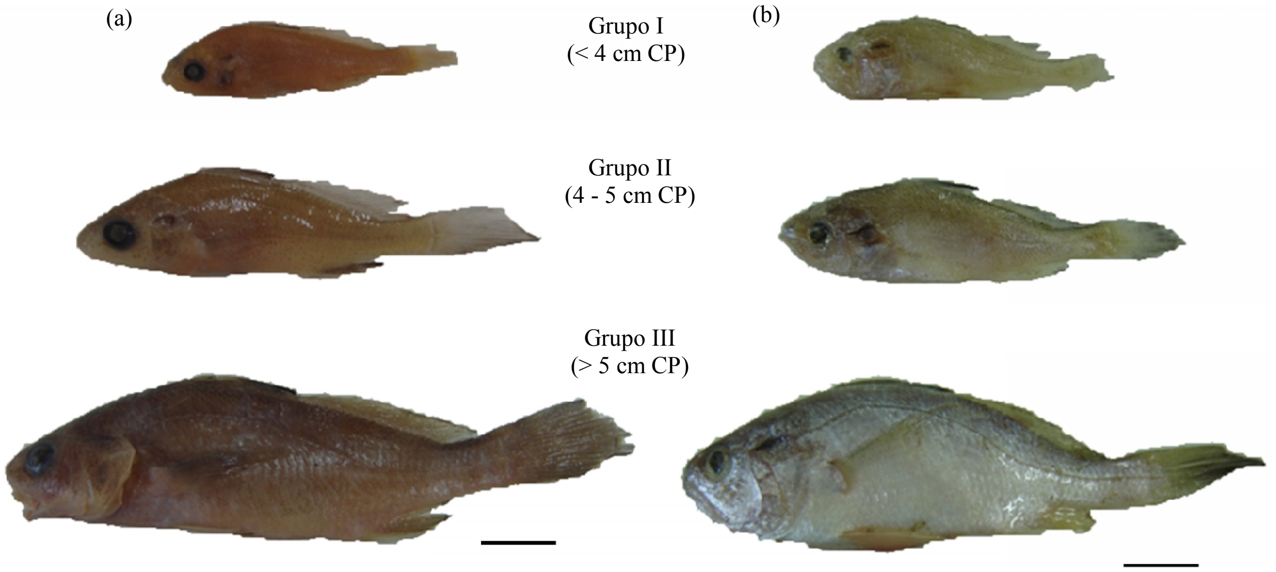

Figura 2. Espécies da família Sciaenidae. (a) *Stellifer brasiliensis* e (b) *Stellifer stellifer*. Grupo I: jovens; Grupo II: sub-adultos; Grupo III: adultos.

Objetivos

Objetivo geral

Esse projeto teve como objetivo geral determinar as variações sazonais das diferentes fases ontogenéticas das espécies *Cathorops spixii* (Agassiz, 1829), *Cathorops agassizii* (Eigenmann & Eigenmann, 1888), *Stellifer brasiliensis* (Schultz, 1945) e *Stellifer stellifer* (Bloch, 1790) em relação à densidade e biomassa. Além disso, este estudo determinará as variações sazonais da dieta e a ingestão de plástico pelas diferentes fases ontogenéticas das espécies estudadas no canal principal do estuário do Rio Goiana.

Objetivos específicos

- Identificar os possíveis habitats utilizados como berçário pelas espécies *Cathorops spixii*, *Cathorops agassizii*, *Stellifer brasiliensis* e *Stellifer stellifer* no estuário do Rio Goiana.
- Associar as variáveis ambientais que influenciam na distribuição das espécies estudadas, com os movimentos sazonais e espaciais das diferentes fases ontogenéticas destas espécies.
- Identificar a variação sazonal da dieta e possíveis sobreposições alimentares das diferentes fases ontogenéticas das espécies estudadas no canal principal do estuário.
- Caracterizar a ingestão sazonal de plástico pelas diferentes fases ontogenéticas das espécies estudadas no canal principal do estuário.

Material e método

Área de estudo

A Bacia Hidrográfica do Rio Goiana localiza-se na região Nordeste do Brasil, na divisa dos estados de Pernambuco e Paraíba (07°32’-07°35’ S e 034°50’-034°58’ W), possuindo uma área de 2900 km^2 (Barletta & Costa 2009). O Rio Goiana é formado pela confluência dos rios Capibaribe Mirim e Tracunhaém (Figura 3), e a cobertura vegetal é predominantemente de florestas de manguezal na faixa de influência das marés. O clima é tropical úmido do tipo As, segundo a classificação de Köppen (A: temperatura média do mês mais frio superior a 18ºC; s: mês menos chuvoso com precipitação inferior a 60 mm).

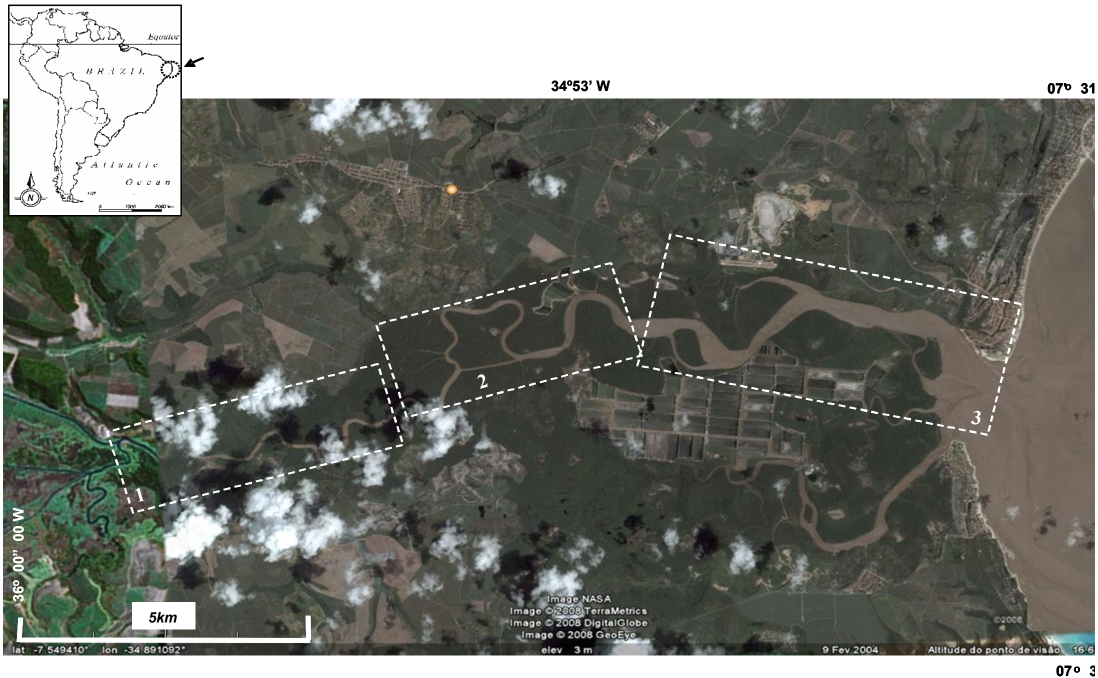

Figura 3. Estuário do Rio Goiana, localizado na divisa entre os estados de Pernambuco e Paraíba, no nordeste do Brasil. A área demarcada (⬚) representa as porções do estuário (1. superior, 2. intermediária e 3. inferior) onde foram realizados os arrastos no canal principal.

A temperatura média do ar é de 25ºC, e oscila entre 27ºC nos meses de verão e 24ºC nos meses de inverno. Apresenta quatro estações bem definidas: início da chuva (março à maio), final da chuva (junho à agosto), início da seca (setembro à outubro) e final da seca (dezembro à fevereiro) (Barletta & Costa 2009).

O estuário possui uma área de 4700 ha incluindo o canal principal, planícies inundadas e a floresta de manguezal. Este estuário ainda se mantém preservado, embora a poluição hídrica de origem industrial e doméstica, além do corte e aterros de manguezais para a implantação de grandes projetos de carcinicultura, e a atividade da cana de açúcar, representem uma ameaça à sua preservação (Barletta & Costa 2009). Uma outra ameaça à conservação deste estuário é decorrente da intensa pesca exploratória da lagosta na região, principalmente durante os meses de pico da estação chuvosa (maio à agosto), que além de ameaçar o importante recurso, aumenta consideravelmente a poluição decorrente de resíduos sólidos que são descartados sem nenhum tratamento nas águas do estuário e habitats adjacentes.

Os municípios costeiros de Goiana (PE), Caaporã e Pitimbu (PB) margeiam o estuário do Rio Goiana, utilizando diretamente os recursos disponíveis neste ecossistema. O município de Goiana, em 2007, foi responsável por 29% da produção de Pernambuco, com 19% referente ao desembarque pesqueiro (IBAMA 2009). Além disso, recentemente pelo decreto presidêncial s/nº de 26 de setembro de 2007, foi criada a Resex Acaú-Goiana. Essa Resex é uma unidade de conservação federal categorizada como reserva extrativista, e se estende por uma área de 6.678ha, abrangendo os municípios de Caaporã e Pitimbu na Paraíba e Goiana em Pernambuco. Esses dados demonstram a importância deste estuário, e das áreas adjacentes, para a produtividade pesqueira artesanal. Além disso, é importante destacar que esse estuário também apresenta um papel importante para a pesca de subsistência, pois, muitos ribeirinhos dependem diretamente desse ecossistema para a sua sobrevivência.

Método amostral

Parâmetros abióticos

Neste estudo foram coletados dados referentes às variáveis ambientais, salinidade, temperatura da água (ºC), oxigênio dissolvido (mg l^{-1}) e transparência (disco de Secchi - cm). Os dados referentes à precipitação estão sendo compilados desde 2005 da estação meteorológica Curado 82900 localizada em Recife-PE (INMET, 2009). Os dados das variáveis ambientais referentes ao canal principal do estuário estão sendo obtidos desde 2005, antes de cada amostra de fauna, através de projetos realizados pelo LEGECE (Projeto FACEPE Nº: APQ-0586-1.08/06; Projeto Universal CNPq Nº 37384/2004-7, 474736/2004 e 482921/2007-2; CT-Hidro 29/2007/CNPq Nº 552896/2007-1).

Amostragem da ictiofauna

Neste estudo foram utilizados dados referentes à capturas realizadas no canal principal do estuário do Rio Goiana, entre dezembro de 2005 e novembro de 2006, para os estudos dos movimentos espaciais e temporais das assembléias de peixes. De acordo com o gradiente de salinidade e a geomorfologia, o estuário do Rio Goiana foi dividido em três áreas (superior, intermediária e inferior). A metodologia utilizada para a amostragem no canal principal está descrita em Barletta et al. (2005), Barletta et al. (2008) e Dantas et al. (2010).

Em cada uma das áreas do canal principal do Rio Goiana foram realizadas seis réplicas mensais com rede de arrasto com portas. A rede tem 7,72 m de abertura e 8,72 m de comprimento (tralha superior com 7,1 m e inferior com 8,5 m). A malha da rede varia entre 35 mm nas asas e corpo da rede, e 22 mm no saco (entre os nós). Para obter-se uma amostragem representativa para todos os intervalos de comprimento dos peixes, foi utilizado um sobre-saco com um tamanho de malha de 5 mm. A rede foi arrastada no canal principal do estuário por um barco de 40 hp de potência e o tempo de arrasto foi de 5 minutos, sendo as posições iniciais e finais registradas com um sistema de posicionamento global (GPS). Também foram registrados os valores de profundidade durante o arrasto, com a utilização de uma ecossonda. A área arrastada **(A)** foi estimada através da equação abaixo:

$$A = D * h * X_2 \tag{1}$$

Onde, **D** é a extensão percorrida pela rede, **h** é o comprimento da tralha superior, e $\mathbf{X_2}$ é a fração do comprimento da tralha superior **(**$\mathbf{h * X_2}$**)** que corresponde à largura do percurso arrastado pela abertura da rede (Sparre & Venema 1997). O valor de $\mathbf{X_2}$ utilizado para esse estudo foi de 0,5 (Barletta et al. 2005). A captura por unidade de área (CPUA) foi utilizada para estimar a densidade e biomassa, sendo o número de indivíduos e o peso, divididos pela área, respectivamente (Sparre & Venema 1997).

$$\text{Densidade} = n/A \ (\text{ind.m}^{-2}) \tag{2}$$

$$\text{Biomassa} = p/A \ (\text{g.m}^{-2}) \tag{3}$$

Onde, **n** é a captura em número, **p** é a captura em peso de peixe e **A** é a área percorrida pela rede durante cada arrasto.

Processamento e classificação das amostras

Após cada arrasto, todos os peixes capturados foram congelados e, no laboratório, triados, identificados, pesados, contados e medidos (comprimento padrão). As espécies utilizadas neste estudo foram identificadas de acordo com os critérios taxonômicos propostos por Figueiredo & Menezes (1978), Menezes & Figueiredo (1980) e Marceniuk (2005). A nomenclatura científica seguiu àquela proposta por Menezes & Figueiredo (1980) e Marceniuk & Menezes (2007). As espécies estudadas foram agrupadas em diferentes classes de comprimento de acordo com as fases ontogenéticas. Para separar as diferentes fases ontogenéticas foram utilizados o ponto de inflexão da curva peso *vs.* comprimento, para separar indivíduos jovens de sub-adultos, e o comprimento de primeira maturação (L_{50}) para separar indivíduos sub-adultos dos adultos (ANEXOS). Os dados de comprimento de primeira maturação foram obtidos a partir de análise macroscópica das gônadas, segundo a metodologia proposta por Vazzoler (1996). No caso dos bagres marinhos da família Ariidae, *C. spixii* e *C. agassizii*, que realizam cuidado parental, foi adicionado outro grupo que inclui os ovos, larvas vitelínicas e pré-juvenis, carregados na cavidade bucal dos machos.

Análise do conteúdo alimentar

Os conteúdos estomacais de cada indivíduo foram removidos e analisados separadamente através de microscópio estereoscópico ZEISS Stemi 2000-C. Os conteúdos foram separados em itens alimentares e identificados ao menor nível taxonômico possível. Em seguida, foram contados e pesados com o uso de uma balança analítica digital (± 0,001g). A identificação foi feita com base em Stachowitsch (1992) e Ruppert et al. (2005). Além disso, durante a análise dos conteúdos, os plásticos encontrados nos estômagos dos indivíduos também foram separados e quantificados para posterior análise.

Índices alimentares

Para a análise dos itens, utilizou-se de três métodos tradicionais de análise de dietas em peixes. Índice de porcentagem por frequência de ocorrência (%F), por número (%N) e peso (%P) (Hynes 1950, Hyslop 1980). Cada uma dessas medidas proporciona diferentes tipos de informações do hábito alimentar do predador. Portanto foi utilizado um índice composto, o Índice de Importância Relativa (IIR) proposto por Pinkas et al. (1971), o qual é composto pelos três índices acima e fornece uma descrição mais precisa da importância dos itens, podendo ser expresso em porcentagem %IIR facilitando a comparação entre estudos (Cortés 1997).

A frequência de ocorrência (%F), possivelmente é a maneira mais simples de se obter dados de conteúdo alimentar, o número de peixes em qual cada item alimentar ocorre é obtido em porcentagem. Para tal utiliza-se a fórmula abaixo:

$$\%F_i = (F_i / F_t) * 100 \qquad (4)$$

Onde, F_i é o número de estômagos contendo o item *i* e F_t é o número total de estômagos (incluindo os vazios).

No método numérico (%N), o número total de cada item alimentar é expresso como porcentagem do número total de itens encontrados em todos os estômagos analisados, utilizando a fórmula:

$$\%N_i = (N_i / N_t) * 100 \qquad (5)$$

Onde, N_i é o número do item alimentar *i* e N_t é o número total de itens nos estômagos.

No método por peso (%P) o peso de cada categoria de item alimentar é expresso como porcentagem do peso total dos itens encontrados em todos os estômagos. Para tal utiliza-se a fórmula abaixo:

$$\%P_i = (P_i / P_t) * 100 \qquad (6)$$

Onde, P_i é o peso do item alimentar *i* e P_t é o peso total dos itens nos estômagos.

O índice de importância relativa de cada item é dado pela combinação da frequência de ocorrência (%F) de cada item alimentar multiplicada pelo somatório da porcentagem em número (%N) e em peso (%P), como segue a fórmula abaixo:

$$IIR_i = \%F_i * (\%N_i + \%P_i) \qquad (7)$$

Sendo expresso em porcentagem de cada item utilizando a seguinte fórmula:

$$\%IRI = 100 \text{ x } IRI / \sum_{i=1}^{n} IRI \qquad (8)$$

Onde, *n* é o número total de categorias de itens alimentares.

O índice de Schoener (*C*) foi utilizado para avaliar se houve sobreposição da dieta entre as espécies e fases ontogenéticas (Schoener 1970). O índice foi calculado a partir da seguinte fórmula:

$$C = 1 - 0.5 \left(\sum | W_{xi} - W_{yi} |\right) \qquad (9)$$

Onde W_{xi} é a proporção média do peso do item i utilizado pela fase especifica da espécie x e W_{yi} é a proporção média do peso do item i utilizado pela fase especifica da espécie y (Wallace 1981). Valores iguais a zero indicam que não houve sobreposição, enquanto que valores iguais a 1 indicam total sobreposição. O índice é geralmente considerado biologicamente significante quando fica acima de 0.6 (Wallace 1981).

Análise estatística

Variação sazonal da densidade e biomassa

A análise de variância (ANOVA) foi utilizada para determinar se a densidade e biomassa total das diferentes fases ontogenéticas de cada uma das espécies apresentaram diferenças significativas entre as diferentes áreas do estuário e entre as estações do ano. Para aumentar a normalidade em todas as análises os dados foram transformados utilizando o método Box-Cox (Box & Cox 1964). O teste de Levene foi utilizado para testar a homocedasticidade dos dados (Underwood 1997) e, *a posteriori*, foi aplicado o teste de Bonferroni ($p < 0,05$) sempre que diferenças significativas foram detectadas. Um teste não-paramétrico de Kruskal-Wallis foi utilizado sempre que as premissas da homocedasticidade não foram atendidas (Zar 1996).

Uma análise canônica de correspondência (CCA) foi utilizada para se observar as possíveis interações ecológicas entre as comunidades de peixes (variáveis dependentes) e as condições ambientais (variáveis independentes) (ter Braak 1986). A análise canônica de correspondência (CCA) é um método de ordenação direta onde a composição das espécies, ou distribuição, é diretamente relacionada às variáveis ambientais (Palmer 1993).

Conteúdo estomacal

A Análise de Variância (ANOVA) foi utilizada para testar diferenças significativas entre número e peso total dos itens (e componentes) encontrados nos estômagos entre os fatores: fase ontogenéticas, áreas do estuário e estações do ano. Com o objetivo de aumentar a normalidade nas análises, os dados originais foram transformados *a priori* pelo método Box-Cox (Box & Cox 1964). O teste de Levene foi utilizado para testar a homocedasticidade dos dados (Underwood 1997) e, *a posteriori*, quando detectadas diferenças significativas, o teste de comparação de Bonferroni ($p < 0,05$) foi utilizado para detectar as fontes de variância (Quinn & Keough 2002). Uma análise canônica de correspondência (CCA) foi utilizada para se observar as possíveis interações ecológicas entre as comunidades de peixes (variáveis dependentes), as principais presas ingeridas e as condições ambientais (variáveis independentes) (ter Braak 1986).

Estrutura da tese

De acordo com os objetivos do projeto proposto e os resultados obtidos ao longo da realização do estudo, a tese foi dividida em seis capítulos. Os capítulos referentes aos artigos científicos seguem as normas de publicação das revistas escolhidas para publicação.

Capítulo 1: Introdução geral. Apresenta uma introdução geral destacando a importância dos estuários para as espécies estudadas além de apresentar os objetivos do estudo e a metodologia empregada para a realização do mesmo.

Capítulo 2: Este capítulo apresenta o artigo "**Nursery habitat shifts in an estuarine ecosystem: patterns of use by sympatric catfish species** (doi: 10.1007/s12237-011-9452-0)" referente à aula de qualificação realizada em fevereiro de 2010 e publicado na revista científica Estuaries and Coasts (ISSN 1559-2731) em 2011. Este artigo descreve o movimento espaço-temporal das diferentes fases ontogenéticas das espécies *C. spixii* e *C. agassizii* no canal principal do estuário do Rio Goiana, com o objetivo de identificar os habitats utilizados como berçário por estas duas espécies.

Capítulo 3: Este capítulo apresenta o artigo "**Seasonal diet shifts and overlap between two sympatric catfishes in an estuarine nursery**", que foi submetido à revista científica Estuaries and Coasts (ISSN 1559-2731), tendo como objetivo descrever as variações espaço-temporais na dieta das diferentes fases ontogenéticas das espécies *C. spixii* e *C. agassizii* no canal principal do estuário do Rio Goiana, além de apresentar informações sobre possíveis sobreposições alimentares entre as espécies. Além disso, esse artigo descreve a ingestão espaço-temporal de plástico pelas diferentes fases ontogenéticas destas espécies.

Capítulo 4: Este capítulo apresenta o artigo "**Spatial and seasonal patterns of resources partitioning between sympatric fish species that use nursery habitats along an estuarine ecocline**" que foi submetido à revista científica Marine Ecology Progress Series (ISSN 1616-1599), descrevendo o movimento e a dieta espaço-temporal das diferentes fases ontogenéticas das espécies *S. brasiliensis* e *S. stellifer* no canal principal do estuário do Rio Goiana, para identificar os habitats utilizados como berçário por ambas as espécies e os padrões sazonais de alimentação das diferentes fases ontogenéticas. Além disso, apresenta informações sobre possíveis sobreposições alimentares entre as duas espécies.

Capítulo 5: Este capítulo refere-se ao artigo “**The seasonal and spatial patterns of ingestion of polyfilament nylon fragments by estuarine drums (Sciaenidae)** (doi: 10.1007/s11356-011-0579-0) publicado em 2011 na revista científica Environmental Science and Pollution Research (ISSN 1614-7499), descrevendo a variação espaço-temporal da ingestão de fragmentos de nylon pelas espécies *S. brasiliensis* e *S. stellifer* no canal principal do estuário do Rio Goiana.

Capítulo 6: Conclusões. Este capítulo apresenta as principais conclusões descrtitas a partir das informações geradas pelo presente estudo.

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Capitulo 2

Nursery habitat shifts in an estuarine ecosystem: patterns of use by sympatric catfish species

Nursery habitat shifts in an estuarine ecosystem: patterns of use by sympatric catfish species.

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Abstract The seasonal and spatial distribution (density and biomass) of five size classes (based on total length (TL) and ontogenetic phases) of two catfish species (*Cathorops spixii* and *C. agassizii*) were studied in an estuary of the Northeastern Brazilian coast. Group I (0.8 – 3 cm TL for both species) includes the eggs, free embryos and young juveniles; Group II includes the mouth-brooder males (> 12 cm TL) with eggs, free embryos and young juveniles in their mouths; Group III includes the free juveniles (3.1 – 8.8 cm TL for both species); Group IV includes the sub-adults (8.9 – 12 cm TL for *C. spixii*, and 8.9 – 14 cm TL for *C. agassizii*); and Group V includes the adults (> 12 cm TL for *C. spixii*, and 14 cm TL for *C. agassizii*). Distribution patterns of total density and biomass for each group throughout the different habitats of the Goiana Estuary main channel (upper, middle, lower) were analysed to test the relative importance of the nursery function of each habitat. Seasonal *vs.* area interactions were significant for all groups of both species. Seasonal variation affecting environmental conditions influenced the specific use of a given habitat by each group of *C. spixii* and *C. agassizii*. During the early rainy season, the middle estuary is an important nursery habitat for juveniles of both species (*C. spixii*: 0.4 individuals m^{-2}, 0.15 g m^{-2}; *C. agassizii*: 0.1 individuals m^{-2}, 0.03 g m^{-2}); however, when environmental conditions change during the late rainy season, the *C. spixii* estuarine primary nursery habitat shifts to the lower estuary (0.2 individuals m^{-2}, 0.08 g m^{-2}). During this period, juveniles of *C. agassizii* remain in the middle estuary (0.0005 individuals m^{-2}, 0.0003 g m^{-2}). Another important ecological area is the upper estuary, which becomes a breeding, spawning and hatchery area during the late dry season for both species (*C. spixii*: 0.06 individuals m^{-2}, 0.1 g m^{-2}; *C. agassizii*: 0.04 individuals m^{-2}, 0.21 g m^{-2}). The nursery function of habitats within the main channel shifts according to the seasonal fluctuation of salinity and dissolved oxygen, and each species responds differently to this change.

Keywords Spatial-temporal variability; Fish movement; Nursery role; Estuary; Water quality.

Introduction

The distribution of estuarine fishes and the migration of juveniles into adult populations are subject to a number of biotic (*e.g.,* predation, food availability, recruitment), abiotic (*e.g.*, salinity, dissolved oxygen, temperature) and landscape factors (*e.g.,* habitat size and habitat connectivity) (Beck et al. 2003; Barletta et al. 2005, 2008). Patterns of fish distribution in coastal and estuarine ecosystems, according to the seasonal fluctuation of environmental variables, are of ecological and socioeconomic interest (Lugendo et al. 2007; Nakamura and Tsuchiya 2007; Barletta et al. 2008; Dantas et al. 2010). However, studies on the observation and modelling of movements and on the habitat use of the different ontogenetic phases of ecologically important fish species in tropical estuaries remain scarce. On occasions, the movement from juvenile to adult habitats has been studied in attempts to determine the particular value of a habitat as nursery grounds, but these efforts have principally been aimed at coral reefs and their adjacent habitats (Nagelkerken et al. 2002; Mellin et al. 2007). According to Beck et al. (2003), a habitat is a nursery for juveniles of a particular species if its contribution per unit area to the production of individuals that recruit to adult populations is greater, on average, than the production from other habitats in which juveniles occur.

The nursery function of habitats in estuarine and coastal ecosystems (*e.g.*, seagrass meadows, mangrove forests, wetlands and sandy beaches) for fishes and invertebrates has been generally accepted among scientists (Perkins-Visser et al. 1996; Nagelkerken et al. 2000; Sheridan and Hays 2003; Jenkins and King 2006), conservation groups and the general public as fundamental to species development and survival. However, there is an ongoing need to test the nursery hypothesis (Beck et al. 2003) for particular estuarine habitats (main channel, mangrove tidal creeks) and seasons using different sets of data and statistical tools. Estuaries are highly dynamic environments and can be altered by both natural and anthropogenic factors. Therefore, the ecological services of estuarine habitats may also change along different time scales (Barletta et al. 2010), generating the need for continuous re-evaluation.

In tropical and subtropical estuaries, catfish species can be considered the most important group in terms of number of species, density and biomass (Lowe-McConnell

1987; Araújo 1988; Barletta et al. 2003, 2005, 2008; Dantas et al. 2010). The marine catfishes from the Genera *Cathorops* are distributed along tropical and subtropical estuaries and adjacent coastal ecosystems of the Western South Atlantic coast from Colombia to South Brazil and on the Pacific coast from Mexico to Equator (Burgess 1989; Marceniuk and Menezes 2007). In these ecosystems, the Ariidae are important not only for the artisanal and subsistence fisheries (Barletta and Costa 2009) but also as a food resource for other animals at different levels of the food chain. Because of their high abundance in estuarine ecosystems, especially as juveniles, catfishes are available as food resources for commercial marine fishes that visit the estuary in search of food (*e.g., Trichiurus lepturus* Linnaeus and *Bairdiella ronchus* (Cuvier)) (Bittar and Di Beneditto 2009; Castro et al. 2004). Moreover, the distribution of catfish in estuarine ecosystems has been shown to be affected by seasonal rainfall and consequent fluctuations of abiotic parameters (*e.g.*, salinity, water temperature and dissolved oxygen) (Barletta et al. 2005, 2008; Dantas et al. 2010).

The study of estuarine habitats (main channel, mangrove creeks, sandy beaches and adjacent coastal areas) used by juveniles and adult fish can provide a better understanding of the ecological function of each estuarine habitat for catfishes, some of which spend their entire life history within these systems (Barletta and Blaber 2007; Dantas et al. 2010). The identification of habitats that perform as efficient nurseries for a particular species is crucially important in the planning of environmental management, directly affecting conservation or restoration of individual areas or even of an entire ecosystem (Beck et al. 2003). According to the authors, the choice of the right area to receive conservation status is crucial for estuarine species.

Studies on the movement of juvenile fishes to adult habitats in estuarine and coastal ecosystems based on distribution have been conducted in Florida (Faunce and

Serafy 2007; Jones et al. 2010), Australia (Blaber et al. 1989; Gillanders 1997), Rhode Island (Dorf and Powell 1997), Portugal (Henriques and Almada 1998), and Curaçao, Caribbean Sea (Verweij et al. 2007). However, there are few studies on seasonal migrations of estuarine species during ontogenetic development. Such a study would help to determine which estuarine habitats are important nurseries for tropical and subtropical Western South Atlantic regions (Barletta et al. 2010).

The aim of this study was to describe the seasonal and spatial variation in density and biomass of the different groups of the main Ariidae species in the Goiana Estuary main channel in regard to seasonal fluctuations of environmental variables (salinity, water temperature and dissolved oxygen). This study assesses the importance of each area as a juvenile habitat to determine which habitats of the Goiana Estuary main channel function as nurseries for these two sympatric catfish species.

Materials and Methods

Study Location

The Goiana Estuary, Northeast Brazil, has a total area of 4700 ha (Fig. 1). The climate is tropical and semi-arid (mean air temperature ~ 25 ºC), with a dry season from September to February (< 50 mm) and a rainy season from March to August (> 400 mm). These two seasons can be further divided into early dry (September to November), late dry (December to February), early rainy (March to May) and late rainy (June to August) (Barletta and Costa 2009). Estuaries on tropical semi-arid coasts tend to reflect the inland conditions of the river basin and show a strong seasonal pattern marked by short but intense periods of rainfall (Barletta and Costa 2009). This study considered three habitats of the estuary main channel (upper, middle and lower estuary), divided according to their different salinity gradients and geomorphologies (Fig. 1). The main channel of Goiana Estuary presents a sharp salinity gradient between the upper reaches of the estuary, which have more freshwater input, and the mouth of the estuary (lower estuary), which lies in the coastal marine environment. This change occurs along the length of the 20-km river, and it is largely affected by seasonal rainfall and consequently by river discharge. This seasonal variation also affects the fluctuation of other abiotic factors such as water temperature and dissolved oxygen in the estuary main channel. The characteristics of the estuarine boundaries are described in detail by Barletta and Costa (2009). The Goiana Estuary supports estuarine and costal fisheries (mollusks, fishes and crustaceans) that are important to the local traditional communities. Poorly managed land use (e.g., sugarcane plantations and unplanned urban areas) and predatory fisheries are threats to the sustainability of this ecosystem (Barletta and Costa 2009; Barletta et al. 2010).

Experimental Design

Between December 2005 and November 2006, water temperature (ºC), salinity (WTW LF 197, Wissenschaftlich Technische Werkstätten, Wellhein, Germany) and dissolved oxygen (mg l^{-1}) were recorded at the bottom and surface of the water column before each trawl. For the fish samples, six replicate trawls were made per month in each estuary habitat (upper, middle and lower) with an otter trawl net. The net was 8.72 m long with a mesh size of 35 mm in the body and 22 mm in the cod-end. The length of the ground-rope was 8.5 m, and the head-rope was 7.1 m long. To guarantee a representative sample of all the fish sizes, a cover with a smaller mesh-size (5 mm) was used over the cod-end (Barletta et al. 2005, 2008; Dantas et al. 2010).

The position was recorded by GPS before and after net deployment and was used to calculate the swept area. The swept area (A) was calculated from: $A = D*h*X2$, where D is the length of the path, h is the length of the head-rope and $X2$ is the fraction of the head-rope ($h*X2$) that is equal to the width of the path swept by the trawl (Sparre and Venema 1997). Estimations of the density (D) and biomass (B) were made using CPUA (catch per unit area), which was calculated by dividing the catch by the swept area (ha): $D = CnA^{-1}$ (Individuals*m^{-2}) and $B = CmA^{-1}$ (g*m^{-2}), where Cn is the catch in number and Cm is the catch in fish biomass (Sparre and Venema 1997). In the case of a trawl net, the length of the head rope can be controlled by the velocity of the boat that pulls the net, minimizing the effect of the tide current. In accordance with Barletta et al. (2005), the otter trawl width was measured at the level of the otter boards at different trawl velocities while deployed. The ideal velocity was recorded between 3.7 km h^{-1} (2.0 knots) (h=3.4m; X_2=0.4787) and 6.5km h^{-1} (3.5 knots) (h=3.8m; X_2=0.5352). Above and below this optimal velocity range, the otter trawl net does not work to its maximum efficiency. The fraction of the head-rope that was close to the width of the swept area by the net during a haul was assumed to be X_2=0.5.

Laboratory procedures

Each captured fish was identified, counted, weighed and measured (TL: total length in cm). Individuals from the most abundant (by density and biomass) Ariidae species in the Goiana Estuary (*Cathorops spixii* (Agassiz) and *C. agassizii* (Eigenmann & Eigenmann)) were distributed into five different groups by size class and ontogenetic phase. Group I corresponded to the ontogenetic phases found in the mouth of the male, which includes the eggs, free embryos and young juveniles (size classes between 0.8 and 3 cm TL for both species); Group II included the mouth-brooder males (size classes higher than 12 cm TL) with the eggs, free embryos and young juveniles; Group III included free juveniles recently released from the mouth of the male (size classes between 3.1 and 8.8 cm TL for both species); Group IV included the sub-adults (individuals with adult characteristics that are still immature, with size classes between 8.9 and 12 cm TL for *C. spixii*; 8.9 and 14 cm TL for *C. agassizii*); and Group V included recently matured individuals (L_{50}) (size classes greater than 12 cm TL for *C. spixii* and greater than 14 cm TL for *C. agassizii*).

Data Analysis

Two-way ANOVA was used to test differences in distribution (density and biomass) of the *C. spixii* and *C. agassizii* groups and their correlation to the factors “areas” (upper, middle and lower estuary) and “seasons” (early dry, late dry, early rainy and late rainy). A Box-Cox transformation was performed to increase the normality of the data (Box-Cox 1964). Whenever significant differences were detected, the Bonferroni test was used *a posteriori* (Quinn and Keough 2003). Canonical Correspondence Analysis (CCA) was performed (ter Braak and Smilauer 2002) to observe ecological correlations between the groups (dependent variables) and environmental conditions (independent variables). CCA is a direct gradient analysis in which the species composition or distribution is directly related to environmental variables (Palmer 1993). To perform the CCA, a multiple least-squares regression was computed with the site scores (derived from weighted averages of both species and of the groups) as the dependent variables and the environmental parameters as the independent variables (ter Braak 1986; Palmer 1993).

The densities of the different groups of *C. spixii* and *C. agassizii* in each season (early and late dry; early and late rainy) were analysed to extract patterns of variation in relation to environmental data (direct gradient analysis). These analyses focused on symmetric and biplot scaling, and a Monte Carlo Permutation Test was used to determine which environmental variables were significant to the variability of the dependent variable. An ordination diagram was also computed (Triplots: with environmental variables). The positions of the density values of groups of both species and sites in each season were represented by different geometric shapes. Environmental variables (salinity, water temperature and dissolved oxygen) were represented by vectors.

Results

Environmental variables

The upper estuary was principally characterised by the lowest salinity values (0 – 8) during the rainy season (March to August) (Fig. 2a, b). During the dry season, the middle estuary showed salinity values similar to those presented by the lower estuary during the late rainy season (8 – 17) (Fig. 2b). In contrast, during the rainy season, the middle estuary showed salinity values similar to those presented by the upper estuary during the late dry season (0 – 6). Despite this seasonality, the lower estuary always showed the highest salinities values throughout the year (8 – 36).

Water temperature showed the same seasonal trend as salinity, with the highest values (27 – 31 ºC) during the dry season and lowest (26 – 27 ºC) during the late rainy season (Fig. 2c). Dissolved oxygen showed the highest values in the lower estuary (5.0 – 7.9 mg l^{-1}), whereas the upper and middle estuaries presented the lowest values (3.0 – 5.1 mg l^{-1} and 1.1 – 5.2 mg l^{-1}, respectively) (Fig. 2d).

Distribution of Ontogenetic Phases Along the Estuarine Gradient

The most abundant ariid species in the main channel was *C. spixii* (0.147 ind. m^{-2} and 1.550 g m^{-2}) (Table 1). The highest density of this species was observed in the middle estuary (0.230 ind. m^{-2}), while the highest biomass occurred in the upper estuary (2.467 g m^{-2}). The highest density of mouth-brooder males (0.021 ind. m^{-2}), eggs, free embryos and young juveniles (0.021 ind. m^{-2}) was observed in the middle estuary. The highest biomass of these phases was observed in the upper estuary (0.025 g m^{-2}) (Table 1). The juvenile phase was predominant (0.077 ind. m^{-2}). For this phase, the highest density and biomass occurred in the middle estuary (0.152 ind. m^{-2} and 0.072 g m^{-2}) (Table 1). The highest density and biomass of sub-adults (0.029 ind. m^{-2} and 0.424 g m^{-2}) and adults (0.054 ind. m^{-2} and 2.035 g m^{-2}) of *C. spixii* were observed in the upper estuary (Table 1).

C. agassizii was the second-most abundant ariid in the upper estuary (0.039 ind. m^{-2} and 1.063 g m^{-2}) (Table 1). Mouth-brooder males with eggs, free embryos and young juveniles of *C. agassizii* were most abundant in the upper estuary (Table 1). Juveniles (0.026 ind. m^{-2} and 0.009 g m^{-2}) were most abundant in the middle estuary, while the sub-adults (0.0003 ind. m^{-2} and 0.051 g m^{-2}) and adults (0.019 ind. m^{-2} and 1.007 g m^{-2}) were most abundant in the upper estuary (Table 1).

Ontogenetic Phases and Seasonal Variation

A two-way ANOVA showed that the total mean density and biomass differed significantly ($p < 0.01$) among areas and seasons for *C. spixii* and *C. agassizii* (Table 2 & 3). This difference was detected principally during the rainy season (Fig. 3 – 6, Table 2 & 3). The season *vs.* area interaction term was significant ($p < 0.05$) for the variables “density” and “biomass” for all groups of both species (Table 2 & 3). This result indicates that the seasonal variations affecting environmental conditions influence how *C. spixii* and *C. agassizii* use particular habitats during specific ontogenetic phases in the main channel of Goiana Estuary.

The density and biomass of juveniles differed significantly ($p < 0.05$) among areas and seasons for *C. spixii*, with the highest values (0.41 ind. m^{-2} and 0.15 g m^{-2}) observed in the middle estuary during the early rainy season (Figs. 3 & 4, Table 2 & 3). The density of *C. agassizii* juveniles differed significantly among areas and seasons, while the biomass in this case differed only among seasons (Table 2). The highest values of density and biomass of *C. agassizii* juveniles (0.1 ind. m^{-2} and 0.03 g m^{-2}) were observed in the middle estuary during the early rainy season (Figs. 5 & 6). For the variables “density” and “biomass” for the sub-adults and adults of both species, significant differences were observed among areas and seasons ($p < 0.01$), with the highest values of density and biomass (0.09 ind. m^{-2} and 1.33 g m^{-2} for *C. spixii*; 0.01 ind. m^{-2} and 0.15 g m^{-2} for *C. agassizii*) occurring in the upper estuary during the rainy season (Figs. 3 – 6, Table 2 & 3). The incubation phase of *C. spixii* and *C. agassizii* occurred in the late dry season at the upper estuary, where high density and biomass of mouth-brooder males with eggs, free embryos or young juveniles (0.06 ind. m^{-2} and 0.1 g m^{-2} for *C. spixii*; 0.04 ind. m^{-2} and 0.21 g m^{-2} for *C. agassizii*) were observed (Figs. 3

– 6). Juveniles were observed in the middle estuary during the early rainy season for both species. However, the *C. spixii* juveniles moved to the lower estuary during the late rainy season, while the *C. agassizii* juveniles remained in the middle estuary during this time (Figs. 3 – 6).

Correlation between Ontogenetic Phases and Environmental Variables

A canonical correspondence analysis (CCA) was performed to determine the influence of environmental gradient variation on the distribution of the ontogenetic phases of *C. spixii* and *C. agassizii* throughout the year (Fig. 7a – d, Table 4). For the graph depicting data from the early dry seasons, the second axis is dominated by the salinity gradient (Fig. 7a, Table 4). During this period, the presence of adults of both species, as well as mouth-brooder males with eggs, free embryos or young juveniles of *C. agassizii* was correlated with low salinity (3.1 ±3.7) and low dissolved oxygen levels (3.1 mg l^{-1} ±1.7 mg l^{-1}) in the upper estuary. In addition, during the early dry season, the presence of juveniles and sub-adults of both species was correlated with higher salinity (11.9 ±3.7) and dissolved oxygen levels (4.2 mg l^{-1} ±0.5 mg l^{-1}) in the middle estuary.

For the graph depicting data from the late dry season, the first axis represents salinity ($p < 0.05$) and dissolved oxygen ($p < 0.01$) (Fig. 7b, Table 4). In this period, a correlation of all ontogenetic periods of both species with low salinity (3.4 ±2.3) and high dissolved oxygen levels (4.9 mg l^{-1} ±0.3 mg l^{-1}) in the upper estuary was observed. During this period, high densities of mouth-brooder males with eggs, free embryos or young juveniles were observed in the upper estuary, characterizing the beginning of the reproductive period of both species. Additionally, free juveniles released by the males were observed at this portion of the estuary. Juveniles then began their migration/movement to the adult habitats of the middle estuary. For the graph depicting data from the early rainy season, dissolved oxygen ($p < 0.05$) is the most important variable on Axis 2 (Fig. 7c, Table 4). During this period, mouth-brooder males with eggs, free embryos or young juveniles and free juveniles of both species were correlated with low salinity (3.2 ±2.8) and dissolved oxygen levels (3.2 mg l^{-1} ±0.4 mg l^{-1}) in the middle estuary, characterizing the nursery function of this habitat during the early rainy season. The presence of sub-adults and adults of both species was correlated with stressful conditions in the upper estuary, with very low salinity (0.1 ±0.04) and dissolved oxygen levels (2.8 mg l^{-1} ±0.1 mg l^{-1}). The salinity of the late rainy season ($p < 0.01$) was responsible for the formation of Axis 1 (Fig. 7d, Table 4). At this time, the presence of mouth-brooder males with eggs, free embryos or young juveniles and free juveniles of *C. agassizii* was correlated with low salinity (1.9 ±1.4) and high dissolved oxygen levels (4.2 mg l^{-1} ±0.5 mg l^{-1}) at the middle estuary. On the other hand, these phases of *C. spixii* were correlated with high salinities (13.4 ±5.4) and very high dissolved oxygen levels (6.2 mg l^{-1} ±1.2 mg l^{-1}) at the lower estuary. The presence of sub-adults and adults of *C. agassizii* was correlated with stressful conditions in the upper estuary, where very low salinity (0.0 ±0.02) and dissolved oxygen levels (4.0 mg l^{-1} ±0.4 mg l^{-1}) prevailed. Meanwhile, the presence of adults and sub-adults of *C. spixii* was correlated with low salinity (1.9 ±1.4) and high dissolved oxygen levels (4.2 mg l^{-1} ±0.5 mg l^{-1}) at the middle estuary. The environmental variables “salinity” and “dissolved oxygen” are represented on Axes 1 and 2; these variables define the patterns of use of each habitat of the estuary main channel by the ontogenetic phases of *C. spixii* and *C. agassizii*.

Discussion

Several studies have demonstrated that the seasonal fluctuations in the salinity gradient in the main channel of estuaries were the main factor responsible for structure in these fish assemblages (Cyrus and Blaber 1992; Barletta-Bergan et al. 2002a; Barletta et al. 2005, 2008; Lugendo et al. 2007; Barletta and Blaber 2007). Seasonal variations on environmental conditions play a significant role in the specialised use of a habitat, i.e., as nursery grounds for fish species (Beck et al. 2003; Mellin et al. 2007). Moreover, salinity appears to have the strongest effects on site-specific variation in the nursery function of an estuarine habitat (Beck et al. 2003). In the Goiana Estuary, the variations in the seasonal ecocline, principally the salinity gradient, defined the distribution and movements of the estuarine species from the Ariidae Family along a large-scale (~20 km) spatial gradient (Dantas et al. 2010). In the present study, it was observed that the salinity gradient and dissolved oxygen influenced the seasonal distribution not only of adults but also all the different ontogenetic phases of *Cathorops spixii* and *C. agassizii* in the three habitats of the main channel of the estuary (upper, middle and lower). Moreover, the seasonal fluctuations in salinity (late dry and late rainy) and dissolved oxygen (early rainy and late dry) defined the nursery role for *C. spixii* and *C. agassizii*. A significantly higher density and biomass of juveniles of both species were observed in the middle estuary during the early rainy season. The importance of this habitat for *C. spixii* and *C. agassizii* juveniles is determined by the environmental conditions at this site at this time of the year.

According to Beck et al. (2003), there must be some difference between juvenile and adult habitats for a species to be considered to have a nursery habitat. In the Goiana Estuary during the early dry season, the middle estuary, with high salinity and dissolved oxygen values, was characterised as nursery habitat for both species. Meanwhile, adults of both species were found in the upper estuary, where the environmental conditions were more stressful, with low salinity and dissolved oxygen values. During the late dry season, all phases of both species were concentrated in the upper estuary. During this period, the upper estuary played an important role in reproduction, hatchery and pre-settlement for both species. During the early rainy season, with the increase in the freshwater inflow, the middle estuary showed low values for salinity and dissolved oxygen. High densities of mouth-brooder males with eggs, free embryos or young juveniles and free juveniles of both species were found in this section of the estuary. Therefore, during this period, the middle estuary can be characterised as an egg-laying, hatchery, pre-settlement and nursery area for both species. Moreover, at this time, sub-adults and adults of both species used preferably the upper estuary, where the environmental conditions were highly stressful for estuarine or marine fishes. Most likely, fish in these phases remained in this area to avoid competition for food with other fish. During the late rainy season, the upper estuary becomes a feeding grounds only for adults and sub-adults of *C. agassizii*. However, the middle estuary becomes a nursery for *C. agassizii* juveniles and a feeding area for adults and sub-adults of *C. spixii*. On the other hand, mouth-brooder males with eggs, free embryos or young juveniles and free juveniles of *C. spixii* used the lower estuary as a reproduction, hatchery, pre-settlement and nursery area. Based on this information, it is clear that the variation in the environmental conditions that juveniles and adults preferred by both species results in a separation of the habitats characteristic of each ontogenetic phase, as proposed by Beck et al. (2003).

Previous studies on the migration of juvenile fish to adult habitats in estuarine and coastal environments detected migration of juveniles from the nursery habitat to adult habitats. According to Beck et al. (2003), the migration of individuals from juveniles to adult habitats must be measured to test the nursery hypothesis. In addition, the authors suggest that nursery habitats not only change in space but their importance also changes with time and that tracking this change will make management and conservation efforts more effective. The present study has shown that juveniles move from the middle to lower estuary during the late rainy season, changing the distribution of the ontogenetic phases and, thus, the ecological function of the main channel habitats. During the dry season, these juveniles were observed transferring to adult habitats in the upper estuary, where the salinity was lowest.

In conclusion, the upper estuary (especially during the end of the dry season) has functions in reproduction, hatchery, pre-settlement and protection for these species. According to Barletta et al. (2005), the increased presence of organic matter, turbidity and low salinity values in upstream sections of the estuary may provide shelter from predation by marine predator species for estuarine resident species such as catfishes. With increased rainfall, physical and chemical changes begin to occur in the middle estuary. The juveniles of both species then begin to follow the upper boundary of the salinity ecocline, while *C. agassizii* juveniles use the middle estuary as a nursery and *C. spixii* occupy the lower estuary. Studies differ in their estimation of the importance of salinity gradients for distribution of fish assemblages (Barletta et al 2008). These disagreements can be attributed to seasonal alterations in large-scale salinity gradients and the sequential recruitment of species throughout the year (Barletta et al 2005).

The recognition of a habitat as a nursery for a species or group of species should be one of the fundamental values accounted for by state or federal environmental agencies and fishery management councils to make better regulatory decisions for fisheries, management, habitat conservation, habitat restoration, and impact mitigation.

The Goiana Estuary is an important site on the Northeast Brazilian coast for commercial, artisanal and subsistence fisheries because of the high productivity and nursery role of the different habitats within and surrounding the system. However, the nursery function can be severely impacted by natural or man-made alterations to the habitats, with consequent effects on the hydrological conditions at each site. According to Barletta and Costa (2009), inappropriate land use and dredging operations in the Goiana Estuary main channel are threats to the sustainability of this ecosystem and could eliminate the nursery function of these habitats in the estuarine ecosystem. Identification of those habitats that function as nurseries for invertebrates and fishes in this estuary is an important first step in decision-making about the sustainable use of all Goiana Estuary's living and non-living resources.

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Figure Legends

Figure 1. Goiana Estuary. ⬚ = upper (1), middle (2) and lower (3) estuaries, where the samples were taken with an otter trawl net. Modified from Barletta and Costa, 2009.

Figure 2. Monthly total rainfall (a) and mean (± standard deviation) salinity (b), temperature (c) and dissolved oxygen (d) in the upper (○), middle (□) and lower (Δ) Goiana Estuary between December 2005 and November 2006.

Figure 3. Mean (+ standard error) density (m^{-2}) of the different groups and total of *Cathorops spixii* in each season (early dry, late dry, early rainy and late rainy) at three areas of the Goiana Estuary (upper, middle and lower estuary). Total = total density of all ontogenetic phases.

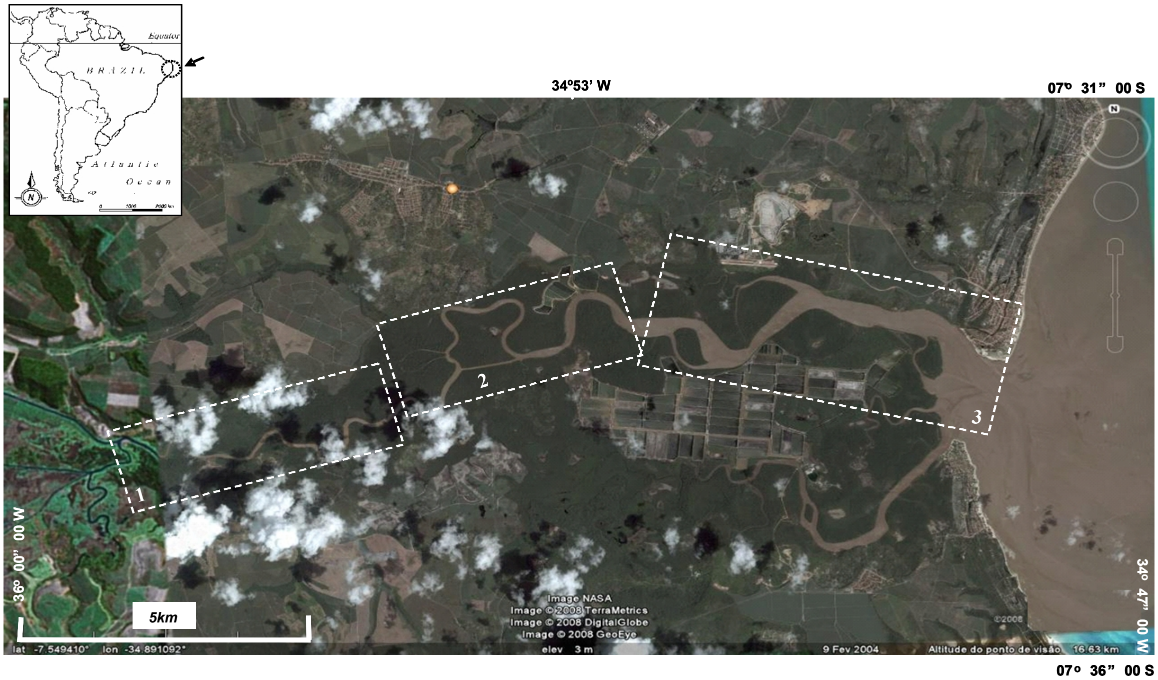
Figure 4. Mean (+ standard error) biomass (g m^{-2}) of the different groups and total of *Cathorops spixii* in each season (early dry, late dry, early rainy and late rainy) at three areas of the Goiana Estuary (upper, middle and lower estuary). Total = total biomass of all ontogenetic phases.

Figure 5. Mean (+ standard error) density (ind. m^{-2}) of the different groups and total *Cathorops agassizii* density during each season (early dry, late dry, early rainy and late rainy) at three areas of the Goiana Estuary (upper, middle and lower estuary). Total = total density of all ontogenetic phases.

Figure 6. Mean (+ standard error) biomass (g m^{-2}) of the different groups and total *Cathorops agassizii* biomass in each season (early dry, late dry, early rainy and late

rainy) in three areas of the Goiana Estuary (upper, middle and lower estuary). Total = total biomass of all ontogenetic phases.

Figure 7. Canonical correspondence analysis triplots for the density (ind. m^{-2}) of different groups of *Cathorops spixii* and *Cathorops agassizii* in the three areas (upper, middle and lower) of the main channel of the Goiana Estuary for each season: (a) early dry; (b) late dry; (c) early rainy; (d) late rainy. (Δ) Species *C. spixii* (*Cs*) and *C. agassizii* (*Ca*), and groups (E, eggs, free-embryo and young-juveniles; M, mouth-brooder males with eggs, free-embryo or young-juveniles; J, juveniles; S, sub-adults; A, adults). (○) Season (ED, early dry; LD, late dry; ER, early rainy; LR, late rainy), area (U, upper; M, middle; L, lower) and month (1, 2, 3) were represented by points, and the environmental variables (salinity, water temperature and dissolved oxygen) were represented by arrows (→).



Equator
BRAZIL
Atlantic
Ocean
N
34º53' W
07º 31" 00 S
N
1
2
3
36º 00" 00 W
34º 47" 00 W
5km
Image NASA
Image © 2008 TerraMetrics
Image © 2008 DigitalGlobe
Image © 2008 GeoEye
©2008
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elev 3 m
9 Fev 2004
Altitude do ponto de visão 16.63 km
07º 36" 00 S

Figure 1.

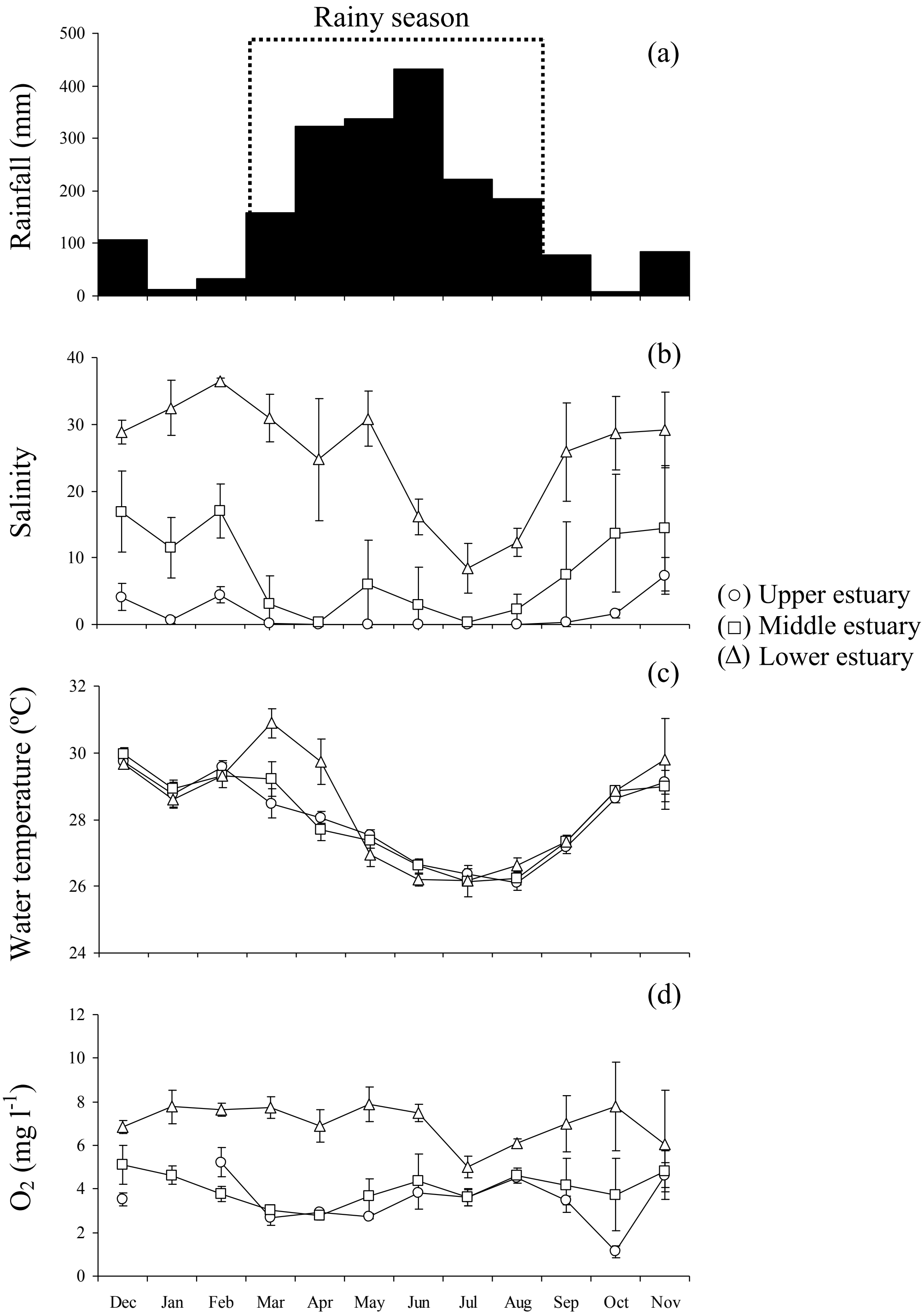

Rainy season
(a)
Rainfall (mm)
500
400
300
200
100
0
(b)
Salinity
40
30
20
10
0
(○) Upper estuary
(□) Middle estuary
(Δ) Lower estuary
(c)
Water temperature (ºC)
32
30
28
26
24
(d)
O_2 (mg l^{-1})
12
10
8
6
4
2
0
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov

Figure 2.

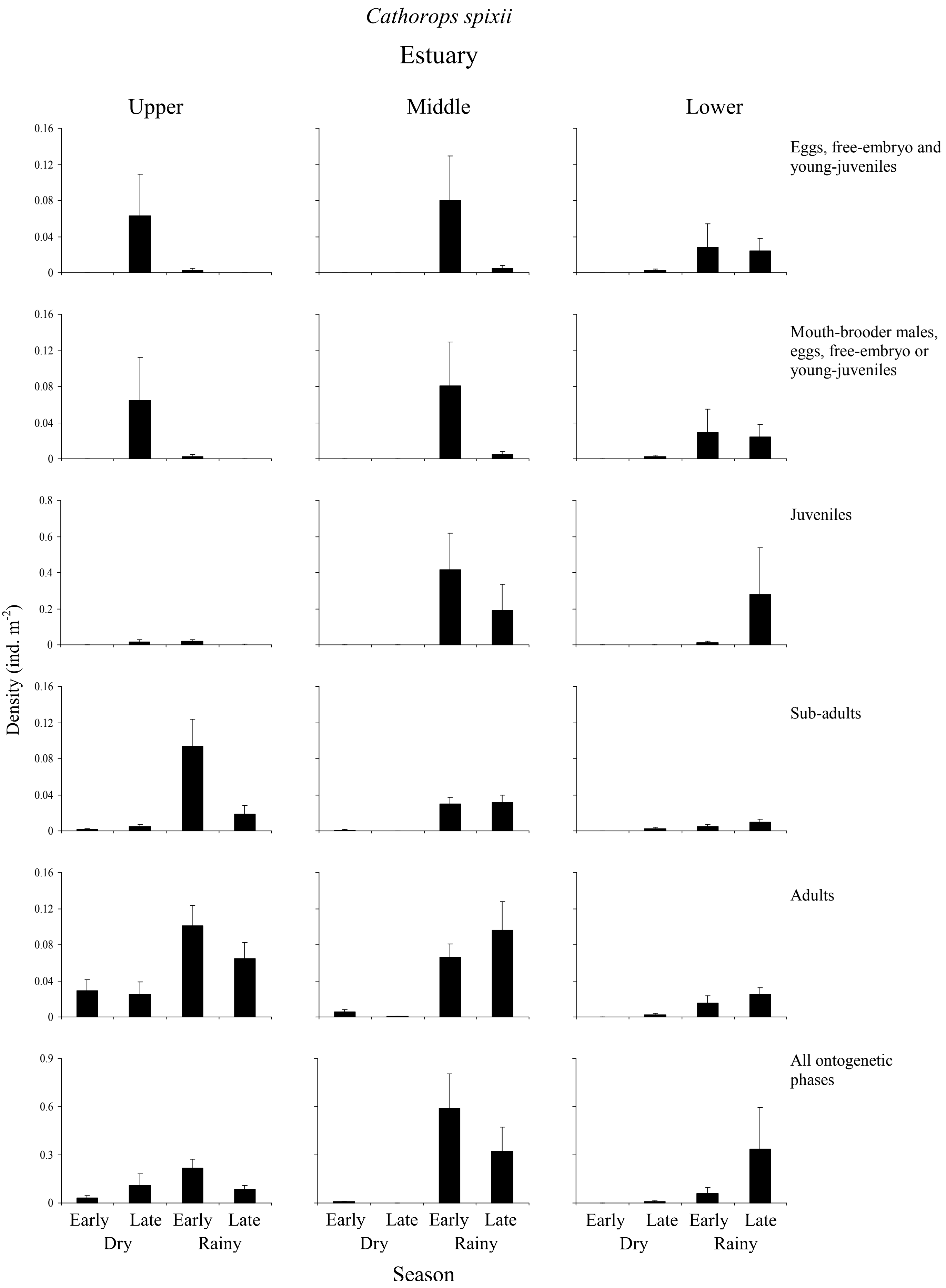

Cathorops spixii
Estuary
Upper
Middle
Lower
Eggs, free-embryo and young-juveniles
Mouth-brooder males, eggs, free-embryo or young-juveniles
Juveniles
Sub-adults
Adults
All ontogenetic phases
0.16
0.12
0.08
0.04
0
0.8
0.6
0.4
0.2
0.9
0.3
Density (ind. m-2)
Early
Late
Early
Late
Dry
Rainy
Season

Figure 3.

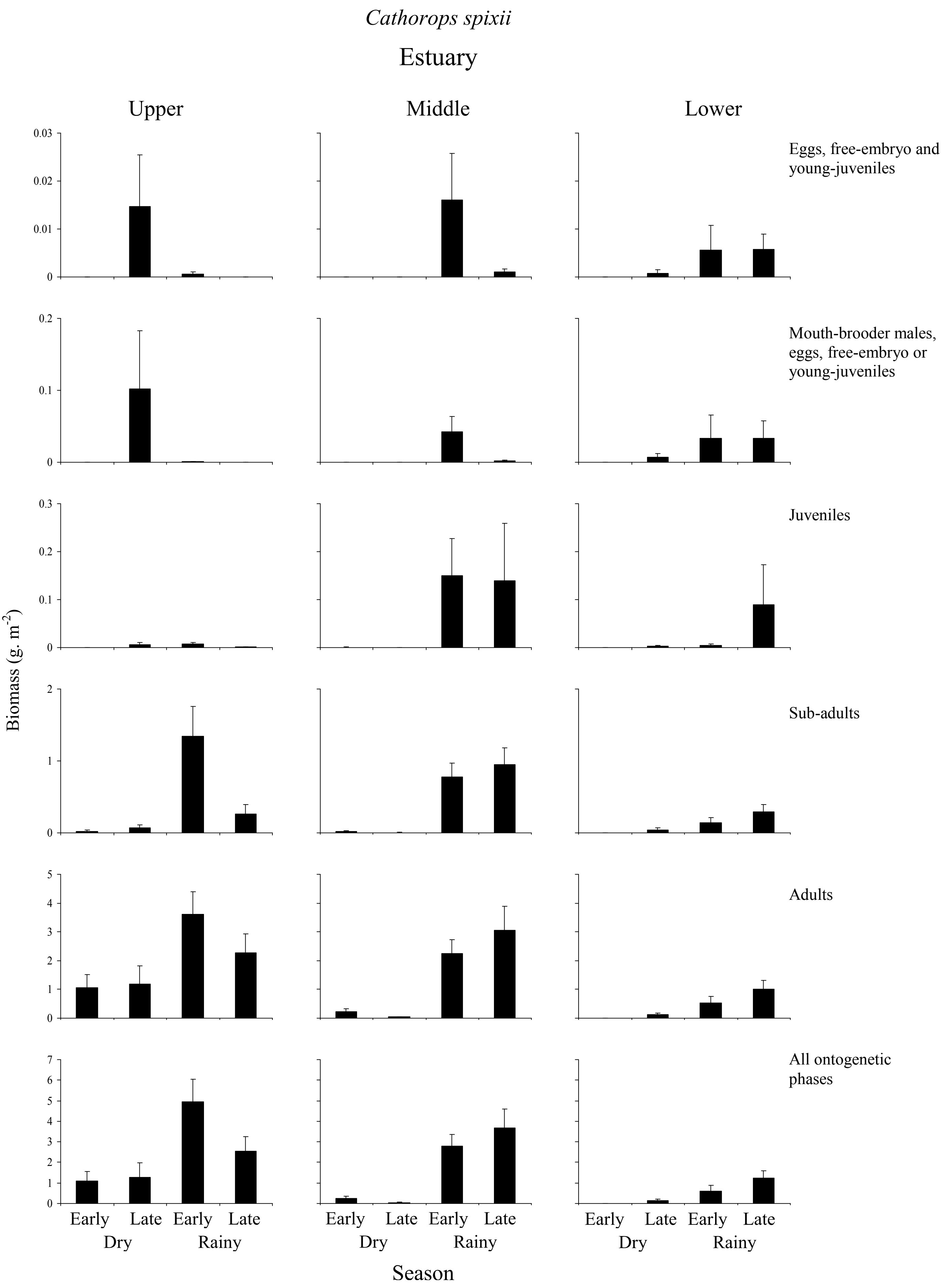

Cathorops spixii
Estuary
Upper
Middle
Lower
Eggs, free-embryo and young-juveniles
Mouth-brooder males, eggs, free-embryo or young-juveniles
Juveniles
Sub-adults
Adults
All ontogenetic phases
0.03
0.02
0.01
0
0.2
0.1
0
0.3
0.2
0.1
0
2
1
0
5
4
3
2
1
0
7
6
5
4
3
2
1
0
Biomass (g. m^{-2})
Early
Late
Early
Late
Dry
Rainy
Season

Figure 4.

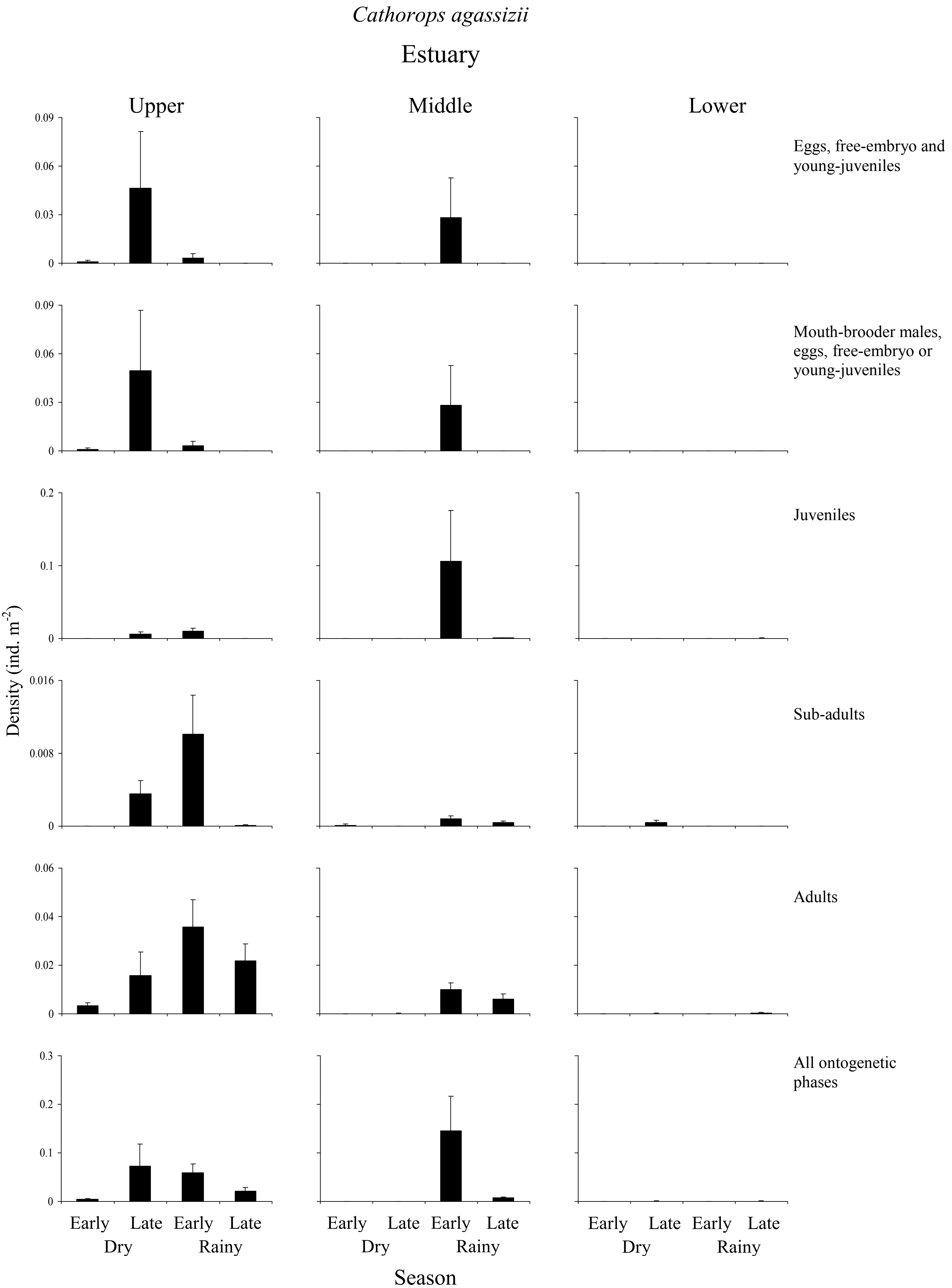
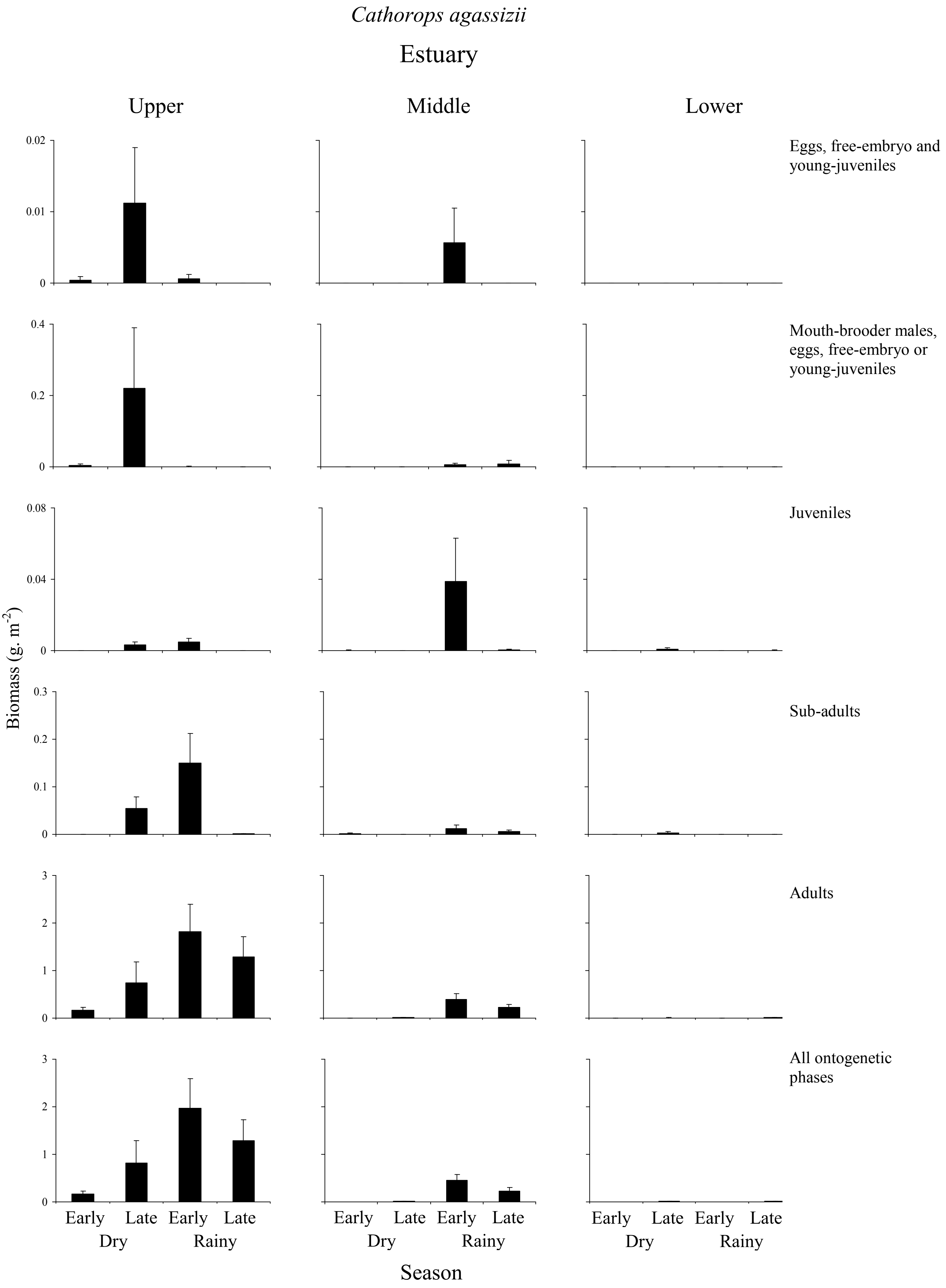

Cathorops agassizii
Estuary
Upper
Middle
Lower
Eggs, free-embryo and young-juveniles
Mouth-brooder males, eggs, free-embryo or young-juveniles
Juveniles
Sub-adults
Adults
All ontogenetic phases
Density (ind. m^{-2})
0.09
0.06
0.03
0
0.2
0.1
0.016
0.008
0.06
0.04
0.02
0.3
Early
Late
Dry
Rainy
Season

Figure 5.

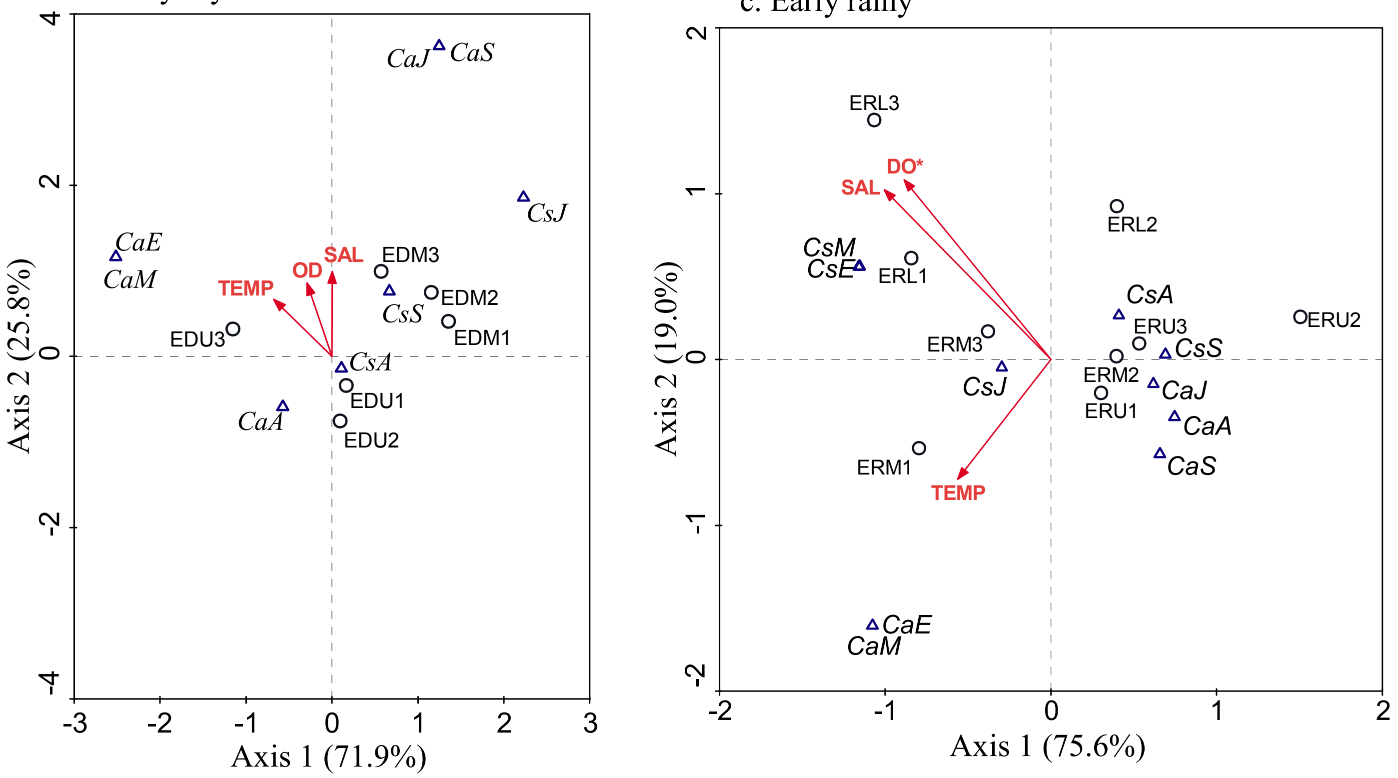


Cathorops agassizii
Estuary
Upper
Middle
Lower
Eggs, free-embryo and young-juveniles
Mouth-brooder males, eggs, free-embryo or young-juveniles
Juveniles
Sub-adults
Adults
All ontogenetic phases
Biomass (g. m^{-2})
0.02
0.01
0
0.4
0.2
0
0.08
0.04
0
0.3
0.2
0.1
0
3
2
1
0
3
2
1
0
Early
Late
Early
Late
Dry
Rainy
Season

Figure 6.

a. Early dry

c. Early rainy



b. Late dry

d. Late rainy

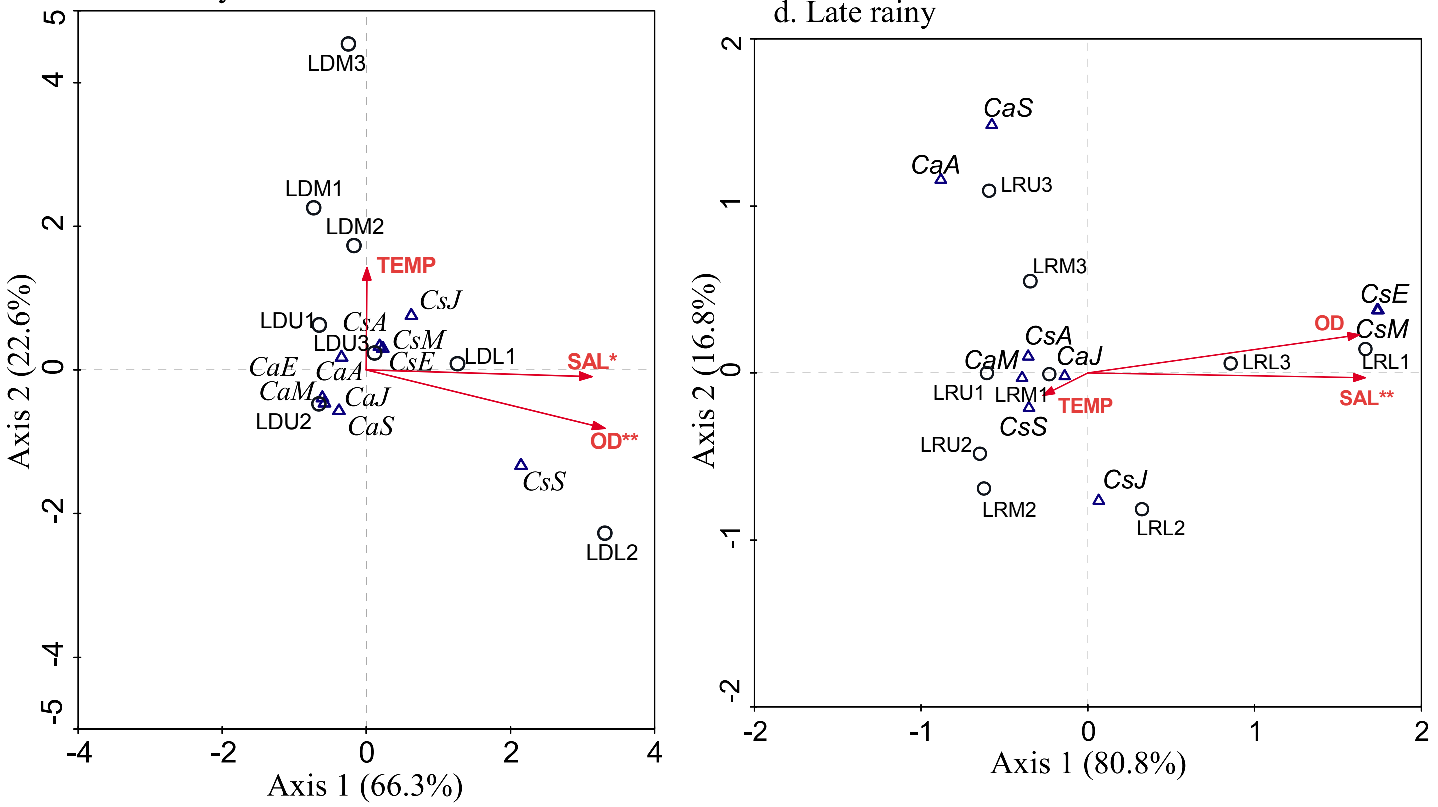


Figure 7

Table 1. Total density (ind. m^{-2}) and biomass (g m^{-2}); density (ind. m^{-2}) and biomass (g m^{-2}) for each area (upper, middle and lower) and size classes of the different groups of *Cathorops spixii* and *Cathorops agassizii* in the Goiana Estuary. TL: total length.

	Size classes	Total density	Total biomass	Density (ind. m^{-2})			Biomass (g m^{-2})		
Parameters	TL (cm)	ind. m^{-2}	g m^{-2}	Upper	Middle	Lower	Upper	Middle	Lower
A. *C. spixii*									
I. Egg, free-embryo & young-juvenile	0.5 – 3	0.017	0.003	0.016	0.021	0.013	0.003	0.004	0.003
II. Mouth-brooder male	12.1 – 22	0.017	0.013	0.016	0.021	0.013	0.025	0.005	0.009
III. Juvenile	3.1 – 8.8	0.077	0.033	0.009	0.151	0.072	0.003	0.072	0.024
IV. Sub-adult	8.9 – 12	0.016	0.234	0.029	0.015	0.004	0.424	0.219	0.060
V. Adult	12.1 – 22	0.035	1.278	0.054	0.042	0.011	2.035	1.386	0.413
Total		0.147	1.550	0.110	0.230	0.101	2.467	1.683	0.501
B. *C. agassizii*									
I. Egg, free-embryo & young-juvenile	0.5 – 3	0.006	0.001	0.012	0.007	0	0.003	0.001	0
II. Mouth-brooder male	14.1 – 21	0.006	0.019	0.013	0.007	0	0.056	0.003	0
III. Juvenile	3.1 – 8.8	0.010	0.004	0.004	0.026	0.0001	0.002	0.009	0.0002
IV. Sub-adult	8.9 – 14	0.001	0.019	0.003	0.0003	0.00009	0.051	0.005	0.0008
V. Adult	14.1 – 21	0.007	0.389	0.019	0.004	0.0001	1.007	0.155	0.004
Total		0.025	0.413	0.039	0.038	0.0003	1.063	0.171	0.005

Table 2. Summary of the ANOVA test results for total (and component) density for the different groups (group I, group II, group III, group IV, group V and total) of *Cathorops spixii* and *C. agassizii*. Analysis performed on Box-Cox transformed data. Differences among areas and seasons were determined by Bonferroni's test *post hoc* comparisons (underline indicates homogeneous groups:——). NS, not significant; ED, early dry season; LD, late dry season; ER, early rainy season; LR, late rainy season; Areas of the Goiana Estuary (upper, middle and lower).

Parameters	Source of variance			Interactions
	Season (1)	Month (2)	Area (3)	
A. ***Cathorops spixii***				
I. Egg, free-embryo & young-juvenile	* ED LR LD ER	NS	NS	1 x 3 **
II. Mouth-brooder males	* ED LR LD ER	NS	NS	1 x 3 ** 1 x 2 x 3 *
III. Juvenile	** ED LD LR ER	NS	* U L M	1 x 3 **
IV. Sub-adult	** ED LD LR ER	* 3 2 1	** L M U	1 x 2 * 1 x 3 ** 2 x 3 *
V. Adult	** LD ED ER LR	NS	** L M U	1 x 3 *
Total	** ED LD ER LR	NS	** L M U	1 x 3 ** 1 x 2 x 3 **
B. ***Cathorops agassizii***				
I. Egg, free-embryo & young-juvenile	NS	NS	NS	1 x 3 *
II. Mouth-brooder males	NS	NS	NS	1 x 3 *
III. Juvenile	** ED LR LD ER	NS	* L U M	1 x 2 * 1 x 3 ** 2 x 3 * 1 x 2 x 3 **
IV. Sub-adult	** ED LR LD ER	NS	** L M U	1 x 2 ** 1 x 3 ** 1 x 2 x 3 **
V. Adult	** ED LD LR ER	NS	** L M U	NS
Total	** ED LR LD ER	NS	** L M U	1 x 2 * 1 x 3 ** 1 x 2 x 3 *

* $p < 0.05$; ** $p < 0.01$.

Table 3. Summary of the ANOVA test results for total (and component) biomass for the different groups (group I, group II, group III, group IV, group V and total) of *Cathorops spixii* and *C. agassizii*. Analysis performed on Box-Cox transformed data. Differences among areas and seasons were determined by Bonferroni's test *post hoc* comparisons (underline indicates homogeneous groups: ——). NS, not significant; ED, early dry season; LD, late dry season; ER, early rainy season; LR, late rainy season; Areas of the Goiana Estuary (upper, middle and lower).

Parameters	Source of variance			Interactions
	Season (1)	Month (2)	Area (3)	
A. ***Cathorops spixii***				
I. Egg, free-embryo & young-juvenile	NS	NS	NS	1 x 3*
II. Mouth-brooder males	NS	NS	NS	1 x 3*
III. Juvenile	* ED LD LR ER	NS	* U L M	1 x 3*
IV. Sub-adult	** ED LD ER LR	NS	** L M U	1 x 3** 1 x 2 x 3**
V. Adult	** LD ED ER LR	NS	** L M U	1 x 3** 2 x 3* 1 x 2 x 3**
Total	** ED LD ER LR	NS	** L M U	1 x 3 ** 2 x 3 * 1 x 2 x 3 **
B. ***Cathorops agassizii***				
I. Egg, free-embryo & young-juvenile	NS	NS	NS	NS
II. Mouth-brooder males	* ED ER LR LD	NS	** L M U	1 x 3** 2 x 3*
III. Juvenile	** ED LR LD ER	NS	NS	1 x 3* 2 x 3* 1 x 2 x 3**
IV. Sub-adult	** ED LR LD ER	NS	** L M U	1 x 2** 1 x 3** 1 x 2 x 3**
V. Adult	** ED LD LR ER	NS	** L M U	1 x 2* 1 x 3** 1 x 2 x 3**
Total	** ED LD LR ER	NS	** L M U	1 x 3** 1 x 2 x 3**

* $p < 0.05$; ** $p < 0.01$.

Table 4. Summary of canonical correspondence analysis using three environmental parameters and density of *Cathorops spixii* and *Cathorops agassizi* groups in the Goiana Estuary main channel for each season: (a) early dry; (b) late dry; (c) early rainy; (d) late rainy. Correlations with environmental variables are presented. (** $p < 0.01$; * $p < 0.05$).

a. Early Dry	Axis 1	Axis 2	Axis 3	
Eigenvalue	0.210	0.075	0.007	
Species-environmental correlation	0.992	0.915	0.601	
Cumulative % variance				
of species data	56.9	77.2	79.0	
of species environmetal relation	71.9	97.7	100	
Correlation with environmental variables				*p*-value
Salinity	0.0026	0.8779*	0.1697	0.1060
Dissolved oxygen (mg l^{-1})	-0.2138	0.7573*	-0.3115	0.0920
Water temperature (ºC)	-0.5012	0.5888	0.3456	0.3020
b. Late Dry	Axis 1	Axis 2	Axis 3	
Eigenvalue	0.154	0.052	0.026	
Species-environmental correlation	0.949	0.852	0.930	
Cumulative % variance				
of species data	52.3	70.1	78.8	
of species environmental relation	66.3	88.9	100	
Correlation with environmental variables				*p*-value
Salinity	0.8538**	-0.0296	0.4046	0.0340*
Dissolved oxygen (mg l^{-1})	0.9029**	-0.2609	-0.0274	0.0020**
Water temperature (ºC)	0.0019	0.4558	-0.7857	0.1880
c. Early Rainy	Axis 1	Axis 2	Axis 3	
Eigenvalue	0.285	0.072	0.020	
Species-environmental correlation	0.945	0.932	0.393	
Cumulative % variance				
of species data	47.3	59.2	62.5	
of species environmental relation	75.6	94.6	100	
Correlation with environmental variables				*p*-value
Salinity	-0.5177	0.7329*	0.1125	0.1040
Dissolved oxygen (mg l^{-1})	-0.4560	0.7768*	0.1061	0.0380*
Water temperature (ºC)	-0.2892	-0.5176	0.3039	0.3880

Table 4. Continued.

d. Late Rainy	Axis 1	Axis 2	Axis 3	
Eigenvalue	0.346	0.072	0.010	
Species-environmental correlation	0.970	0.594	0.361	
Cumulative % variance				
of species data	49.8	60.0	61.5	
of species environmental relation	80.8	97.6	100	
Correlation with environmental variables				*p*-value
Salinity	0.9692**	-0.0153	-0.0072	0.0020**
Dissolved oxygen (mg l^{-1})	0.9484	0.1202	-0.0181	0.2120
Wate temperature (ºC)	-0.1573	-0.0712	0.3533	0.8680

**$p < 0.01$; *$p < 0.05$.

Capitulo 3

Seasonal diet shifts and overlap between two sympatric catfishes in an estuarine nursery

Seasonal diet shifts and overlap between two sympatric catfishes in an estuarine nursery.

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Abstract This study describes the seasonal feeding habits of different size classes of *Cathorops spixii* and *Cathorops agassizii* along the Goiana Estuary main channel, and the food overlap when different size classes occur together. These species are expected to be zoobenthivorous, but along their life-cycle and between different habitats and seasons, the trophic guild can change to zooplanktivore. During the early dry season, in the upper and middle estuary, sub-adults and adults of *C. spixii* showed a diet overlap, mainly by the high ingestion of Polychaeta and Ostracoda. During the late dry season, in the upper estuary, adults of *C. spixii* showed diet overlap with juveniles and adults of *C. agassizii*, principally due to the high ingestion of Gastropoda, Ostracoda and Calanoida. During the early rainy season, in the upper estuary, significant diet overlaps between juveniles of both species were observed, sub-adults of both species and between juveniles and sub-adults of *C. agassizii*, influenced by the high ingestion of

Ostracoda and Calanoida. During the late rainy season, in the middle estuary, diet overlap was observed between juveniles and sub-adults of *C. spixii* and *C. agassizii*, with high ingestion of Gastropoda, Calanoida and Harpacticoida. At this time, in the lower estuary *C. spixii* and *C. agassizii* juveniles, and sub-adults showed remarkable diet overlap, with high ingestion of Gastropoda, Ostracoda and Calanoida. During the rainy season juveniles of both species using the middle estuary as nursery and feeding ground. Feeding habits and habitat utilization by different ontogenetic phases is an essential information to understand the ecological role of fish populations, critical in the development of conservation and management strategies.

Keywords Spatial-temporal diet variability; Diet overlap; Fish movement; Nursery role; Coexistence.

Introduction

In tropical and subtropical estuaries, catfish species can be considered the most important group in terms of number of species, density and biomass (Lowe-McConnell 1987; Araújo 1988; Barletta et al. 2005, 2008; Dantas et al. 2010). The marine catfishes of the genus *Cathorops* are distributed along tropical and subtropical estuaries and adjacent coastal ecosystems of the Western South Atlantic coast, from Colombia to South Brazil and on the Pacific coast from Mexico to Ecuador (Burgess 1989; Marceniuk and Menezes 2007). In these ecosystems, the ariid catfishes are important not only for the artisanal and subsistence fisheries (Barletta and Costa 2009) but also as a food resource for other animals at different levels of the food chain (Bittar and Di Beneditto 2009). Because of their high abundance in tropical estuarine ecosystems, especially as juveniles, ariid catfishes are available as food resources for commercial marine fishes that visit the estuary in search of food (*e.g., Trichiurus lepturus* Linnaeus and *Bairdiella ronchus* (Cuvier)) (Bittar and Di Beneditto 2009; Castro et al. 2004). The distribution of ariid catfish in tropical estuarine ecosystems has been shown to be affected by seasonal rainfall and consequent fluctuations of abiotic parameters (*e.g.*, salinity, water temperature and dissolved oxygen) (Barletta et al. 2005, 2008; Dantas et al. 2010) and the different ontogenetic phases respond differently to these fluctuations (Dantas et al. 2012a). Moreover, the species *Cathorops spixii* (Agassiz) and *Cathorops agassizii* (Eigenmann & Eigenmann) were benthophagous (Barletta and Blaber 2007), feeding mainly small crustaceans and others invertebrates that live in the sediment, and the estuaries represent a dynamic and complex ecosystem for breeding, spawning, hatchery and nursery for both species (Dantas et al. 2012a).

The identification of habitats that perform efficient nurseries for a particular species is crucially important in the planning of environmental management, directly affecting conservation or restoration of individual areas or even of an entire ecosystem (Beck et al. 2003). The nursery concept is based on the success of the settlement of post-larvae in the nursery habitat where they grow to juvenile and posterior migration of sub-adults from the juvenile nursery to adult habitats (Beck et al. 2003). These life-cycle patterns and movements of fish species in estuaries and adjacent coastal waters are subject to a variety of biotic (*e.g.* predation, larval supply, food availability) and abiotic (*e.g.* salinity, water temperature) factors (Barletta et al. 2008; Barletta et al. 2010; Dantas et al. 2010). These movements can be inferred from the spatial and temporal habitat utilization by the different ontogenetic phases of fish species (Cocheret de la Morinière et al. 2003; Mellin et al. 2007; Dantas et al. 2012a). These habitats utilization could be related to diet shifts during the life-cycle, and the stomach content analysis of the different ontogenetic phases in the different habitats can, therefore, provide information on the movement patterns between the nursery and adult habitats (Cocheret de la Morinière et al. 2003).

Another important ecological challenge faced by fish species is to be able to share or compete for resources in a densely populated and frequently variable environment (Mariani et al. 2011). Many studies on trophic ecology infer mechanisms for fish coexistence using diet overlap data (Sánchez-Hernández et al. 2011; Schoener 1974; Darnaude et al. 2001; Platell et al. 2006; Russo et al. 2008), and the increasing amount of information on diverse habitat and behavioral of fish diets may as well shed new light on the feeding strategy of fishes (Sánchez-Hernández et al. 2011). Thus, trait analysis has been proposed as a functional approach to understand mechanisms involved in predator-prey relationships (de Crespin de Billy and Usseglio-Polatera 2002; de Crespin de Billy et al. 2002), and consequently it may be useful for understanding inter-species interactions and the mechanisms that determine food partitioning between them. Sympatric species will likely consume slightly different prey to minimize niche overlap (Schoener 1974), and a number of studies tested this hypothesis for fish that inhabiting coastal ecosystems (Darnaude et al. 2001; Platell et al. 2006; Woodland et al. 2010; Spilseth and Simenstad 2011). Moreover, competition for food can affect patterns of habitat selection, niche overlap and distribution (David et al. 2007; Hilderbrand and Kershner 2004). When food resources are shared, coexistence of fish species has been suggested to be related to selection for different activity patterns or differential use of space (Hesthagen et al. 2004; Sandlund et al. 2010). Moreover, knowledge of feeding habits and habitat utilization by different ontogenetic phases is essential to understand the ecological role of these to fish population and a critical requirement to develop conservation and management plans (Mellin et al. 2007; Teixeira and Cortes 2006).

The Goiana Estuary supports a rich fauna of fish, crustaceans and mollusks that play an important role in subsistence, artisanal and commercial fisheries. However, raw sewage and solid wastes are discharged into the estuary and pose a threat to the living resources that use this ecosystem (Barletta and Costa 2009; Dantas et al. 2012b; Possatto et al. 2011; Ramos et al. 2011). Small commercial, artisanal and subsistence fisheries account for approximately half of all finfish landings in Brazil, especially in the Northeast (Diegues 2008). These fisheries therefore represent an important economic activity that has so far received little official attention in terms of capacity building, access to financial credit and new technologies. The aim of this study was to describe the seasonal and spatial variation in the feeding habits of the different size classes of two sympatric catfish species in the Goiana Estuary main channel in regard to seasonal fluctuations of environmental variables (rainfall, salinity, water temperature, dissolved oxygen and Secchi depth). Moreover, this article investigated if their food niches are partitioned when the different size classes of this two species occur together in the same estuarine habitat.

Materials and Methods

Study Location

The Goiana Estuary, Northeast Brazil, has a total area of 4700 ha (Fig. 1). The climate is tropical and semi-arid (mean air temperature ~ 25 ºC), with a dry season from September to February (< 50 mm) and a rainy season from March to August (> 400 mm). These two seasons can be further divided into early dry (September to November), late dry (December to February), early rainy (March to May) and late rainy (June to August) (Barletta and Costa 2009). This study considered three habitats of the estuary main channel (upper, middle and lower estuary), divided according to their different salinity gradients and geomorphologies (Fig. 1). The main channel of Goiana Estuary presents a sharp salinity gradient between the upper reaches of the estuary, which have more freshwater input, and the mouth of the estuary (lower estuary), which lies in the coastal marine environment. This change occurs along the length of the 20-km river, and it is largely affected by seasonal rainfall and consequently by river discharge. This seasonal variation also affects the fluctuation of other abiotic factors such as water temperature and dissolved oxygen in the estuary main channel. The characteristics of the estuarine boundaries and uses are described in detail by Barletta and Costa (2009).

Experimental Design

Between December 2005 and November 2006, water temperature (ºC), salinity, dissolved oxygen (mg l^{-1}) and Secchi depth (cm) were recorded before each trawl. For the fish samples, six replicate trawls were made per month in each estuarine habitat (upper, middle and lower) with an otter trawl net. The net was 8.72 m long with a mesh size of 35 mm in the body and 22 mm in the cod-end. The length of the ground-rope was 8.5 m, and the head-rope was 7.1 m long. To guarantee a representative sample of all the fish sizes, a cover with a smaller mesh-size (5 mm) was used over the cod-end (Barletta et al. 2005, 2008; Dantas et al. 2010).

The position was recorded by GPS before and after net deployment and was used to calculate the swept area. The swept area (A) was calculated from: $A = D$ x h x X_2, where D is the length of the path, h is the length of the head-rope and X_2 is the fraction of the head-rope (h x X_2) that is equal to the width of the path swept by the trawl (Sparre and Venema 1997). Estimations of the density (D) and biomass (B) were made using CPUA (catch per unit area), which was calculated by dividing the catch by the swept area (ha): $D = C_nA^{-1}$ (Individuals per square meter) and $B = C_mA^{-1}$ (grams per square meter), where C_n is the catch in number and C_m is the catch in fish mass (Sparre and Venema 1997). In the case of a trawl net, the length of the head rope can be controlled by the velocity of the boat that pulls the net, minimizing the effect of the tide current. In accordance with Barletta et al. (2005), the otter trawl width was measured at the level of the otter boards at different trawl velocities while deployed. The ideal velocity was recorded between 3.7 km h^{-1} (2.0 knots) ($h=3.4m$; $X_2=0.4787$) and 6.5km h^{-1} (3.5 knots) ($h=3.8m$; $X_2=0.5352$). Above and below this optimal velocity range, the otter trawl net does not work to its maximum efficiency. The fraction of the head-rope that was close to the width of the swept area by the net during a haul was assumed to be $X_2=0.5$.

Laboratory procedures

In the laboratory, each fish was identified, weighed and measured (standard length - cm). Each of the Ariidae species (*C. spixii* and *C. agassizii*) was grouped in different size classes corresponding different ontogenetic stages. Three different size classes were attributed to the captured individuals of the target species. The *C. spixii* and *C. agassizii* individuals in the samples were divided into juveniles (3.1 – 8.8 cm in total length; n(*C.*

spixii) = 40; n(*C. agassizii*) = 40), sub-adults (8.9 – 12 cm for *C. spixii* in total length (n = 73); and 8.9 – 14 cm for *C. agassizii* in total lenght (n = 33)), and adults (12.1 - 22 cm for *C. spixii* in total length (n = 93); and 14.1 – 21 cm for *C. agassizii* (n = 60)). The stomach contents of each size classes, for each area (upper, middle and lower estuaries) and season (early and late dry; early and late rainy seasons), were examined and analysed using a stereomicroscope (Zeiss 50x), and all dietary and non-dietary items (*e.g.,* plastics, nylon) were separated. Prey were sorted and identified to the lowest possible taxonomic level. The items found in the stomachs were washed with distilled water, dried with tissue paper and weighed with a precision scale (0.001 g). To perform the analyses, some food items were grouped in major groups due to their low occurrence in the diet. Crabs and shrimps were grouped in the Superorder Eucarida, Mytilidae and Lucinidae were grouped under Class Bivalvia, and Lepidoptera, Plecoptera, Formicidae Orthoptera, Coleoptera and Diptera were grouped under Class Insecta. The quantification of food items ingestion followed three criteria (Hynes 1950; Hyslop 1980):

1. The frequency of occurrence (%F) is expressed the percentage of each prey according to the equation:

$$\%F_i = (F_i / F_t) \times 100$$

Where F_i is the number of stomachs containing the food item i and F_t is the total number of stomachs examined. The advantages of the frequency of occurrence method are that, provided food items are readily identitifiable, it is quick and requires the minimum apparatus (Hyslop 1980);

2. The percent of prey abundance in numbers (%N) according to the equation:

$\%N_i = (N_i / N_t) \times 100$

Where N_i is the numbers of food item i and N_t is the total number of food item in the stomachs examined. The numerical method is relatively fast and simple to operate providing identification of prey items is feasible (Hyslop 1980);

3. The percent of prey abundance in weight (%W) according to the equation:

$\%W_i = (W_i / W_t) \times 100$

Where W_i is the weights of food item i and W_t is the total weight of food item in the stomachs examined. The volumetric techniques (weight) probably give the most representative measure of bulk and may be applied to all food items (Hyslop 1980).

It seems realistic to base assessment of dietary importance upon these unrelated methods, and indices combining values from different sources are more representative (Hyslop 1980). Such a measure is the Index of Relative Importance (IRI) (Pinkas et al. 1971, Prince 1975) which incorporates frequency of occurrence ($\%F_i$), percentage by number ($\%N_i$) and percentage by weight ($\%W_i$) expressed by the equation:

$IRI_i = \%F_i \times (\%N_i + \%W_i)$

This index was expressed in percentage of each prey according to the following equation proposed by Pinkas et al. (1971) and Prince (1975):

$$\%\text{IRI} = 100 \times \text{IRI} / \sum_{i=1}^{n} \text{IRI}$$

Where n is the total number of categories of food items (Cortés 1997).

Schoener's index (C) was used to evaluate food niche overlap between the different size classes of both species (Schoener 1970). The index was calculated following the equation:

$$C = 1 - 0.5\ (\sum |\ W_{xi} - W_{yi}\ |)$$

Where W_{xi} is the mean proportion of the biomass of food item i used by the specific size classes of *Cathorops* sp. x and W_{yi} is the mean proportion of biomass of food item i used by the specific size classes of *Cathorops* sp. y (Wallace 1981). Zero values indicate no overlap, while 1 indicates complete overlap. The index value is generally considered biologically significant when exceeds 0.6 (Wallace 1981).

Data Analysis

Factorial ANOVA (STATISTICA 8$^{®}$ software) was used to test differences in the number and weight of each category of food item for each species (*C. spixii* and *C. agassizii*) in relation to the factors "area", "season" and "size classes". Box-Cox transformation was performed to increase the normality of the data (Box-Cox 1964). Levene's test was used to check the homogeneity of the variances. Whenever significant differences were detected, the Bonferroni test was used *a posteriori* (Quinn & Keough 2003). Canonical Correspondence Analysis (CCA) (CANOCO for Windows 4.5) was performed (ter Braak & Smilauer 2002) to observe ecological correlations between the index of relative importance (%IRI) of the ingested prey items of each species (dependent variables) for each area and season to extract patterns of diet variation in relation to environmental data (independent variables). To perform the CCA, a multiple least-squares regression was computed with the site scores (derived from weighted averages of %IRI of both species and of the groups) as the dependent variables and the environmental parameters as the independent variables (ter Braak 1986; Palmer 1993). These analyses focused on symmetric and biplot scaling. A Monte Carlo Permutation Test was used to determine which environmental variables were significant to the variability of the dependent variable. An ordination diagram was computed (Triplots: with environmental variables). The positions of the %IRI values of the ingested food items of both species and sites in each season were represented by different geometric shapes. Environmental variables (Rainfall, salinity, water temperature, dissolved oxygen and Secchi depth) were represented by vectors.

Results

Environmental variables

The upper estuary was characterized principally by low salinity values (0 – 8) all year, but especially during the rainy season (March to August) (Fig. 2a, b). During the dry season the salinity values in the middle estuary ranged from 8 to 17, and during the rainy season 0 to 6 (Fig. 2b). Despite seasonality, the lower estuary always showed the highest salinities values throughout the year (8 – 36). Water temperature showed a seasonal trend, with the highest values (27 – 31 ºC) during the dry season and lowest

(26 – 27 ºC) during the late rainy season (Fig. 2c). Dissolved oxygen showed the highest values in the lower estuary (5.0 – 7.9 mg l^{-1}), whereas the upper and middle estuaries presented the lowest values (3.0 – 5.1 mg l^{-1} and 1.1 – 5.2 mg l^{-1}, respectively) (Fig. 2d). The highest values of Secchi depth were observed during the dry season in all areas (39 – 171 cm) and the lowest values during the rainy season (14 – 108 cm) (Fig. 2e).

Seasonal and spatial diet shifts of ontogenetic phases along the estuarine ecocline

Factorial ANOVA showed that for *C. spixii* and *C. agassizii* significant interactions among the factors area and phase ($p < 0.01$) were observed for the ingestion of Polychaeta (number), and for *C. agassizii* for the ingestion of Polychaeta (weight) and Gastropoda (number) (Table 1). Moreover, significant interactions were observed for both species among the factors season, area and phase ($p < 0.01$) for the ingestion of Gastropoda, Bivalvia and Eucarida (number), and Ostracoda and Calanoida (number and weight) (Table 1). For *C. spixii* significant differences ($p < 0.01$) were observed for the ingestion of Gastropoda, Bivalvia, Ostracoda and Eucarida (number), and for *C. agassizii* for the ingestion of Ostracoda (number and weight), Bivalvia and Eucarida (number) for the factors season, area and phase (Table 1). For *C. spixii* the ingestion of Calanoida (number and weight), Eucarida and Ostracoda (weight) showed significant differences ($p < 0.01$) for the factor season, and the ingestion of Ostracoda (weight) and Polychaeta (number) for the factor area ($p < 0.01$). For *C. agassizii* the ingestion of Gastropoda (number and weight), Polychaeta and Actinopterygii (number) showed significant differences ($p < 0.01$) for the factors area and phase (Table 1). The ingestion of Polychaeta (weight) by *C. agassizii* showed significant differences for the factor area

($p < 0.01$), and Calanoida (number and weight) for the factor season ($p < 0.01$) (Table 1). Moreover, the ingestion of Actinopterygii (weight) by *C. agassizii* showed significant differences ($p < 0.05$) for the factors season and phase (Table 1).

The highest ingestion of Polychaeta by *C. spixii* was observed in sub-adults (2 ± 0.6 ind) during the early dry season in the upper estuary (Fig. 3). This item was important in weight for juveniles of *C. spixii* (late rainy season) in the middle estuary, for sub-adults (early rainy season) in the upper estuary, and for adults (early dry season) in the upper and middle estuary (Tables 2 & 3). The highest ingestion of Gastropoda (49 ± 13 ind) was observed in juveniles during the late rainy season in the lower estuary (Fig. 3). Gastropoda was an important prey in number and weight for *C. spixii* juveniles (late rainy season) in the middle and lower estuary, for sub-adults (late dry season) in all areas, and for adults during the rainy seasons in the upper estuary (Tables 2 & 3). The highest ingestion of Bivalvia (16 ± 6 ind) was observed in sub-adults during the late dry season in the upper estuary (Fig. 3, Table 1). This item was important in number and weight for *C. spixii* sub-adults (late dry season) in the upper estuary, and for adults in weight (rainy season) in the lower estuary (Tables 2 & 3). The highest ingestion of Ostracoda (369 ± 106 ind and 42 ± 15 mg) was observed in sub-adults during the early dry season in the middle estuary (Figs. 3 & 4, Table 1). Ostracoda was an important prey in number and weight for *C. spixii* juveniles (rainy season) and sub-adults (all seasons) in all areas of the estuary, and for adults (dry season) in the upper and middle estuary (Tables 2 & 3). The highest ingestion of Calanoida in number (343 ± 141 ind) was observed in adults during the late rainy season in the upper estuary, and in weight (4 ± 1 mg) in sub-adults during the same period in the middle estuary (Figs. 3 & 4, Table 1). Calanoida was an important item in number and weight for *C. spixii* juveniles (rainy season) and sub-adults (late dry and rainy season), and for adults in number (rainy season) in all areas of the estuary (Tables 2 & 3). The highest ingestion of Eucarida in number (1 ± 0.8 ind) was observed in sub-adults during the early rainy season in the middle estuary, and in weight (5 ± 5 mg) in adults during the early rainy season in the upper estuary (Figs. 3 & 4). Eucarida was an important prey in weight during the early rainy season for *C. spixii* juveniles in the upper estuary, for sub-adults in the middle estuary, and for adults in the upper and middle estuary (Tables 2 & 3).

For *C. agassizii* the highest ingestion of Polychaeta (2 ± 1 ind and 9 ± 8 mg) was observed in adults during the early rainy season in the upper estuary (Figs. 5 & 6, Table 1). This item was important in weight for *C. agassizii* juveniles (late dry season), and for sub-adults and for adults (early dry, late dry and early rainy season) in the upper estuary (Tables 4 & 5). The highest ingestion of Gastropoda was observed in adults (104 ± 34 ind and 113 ± 36 mg) during the early rainy season in the upper estuary (Figs. 5 & 6, Table 1). Gastropoda was an important item in number and weight for *C. agassizii* juveniles (late dry and late rainy season) and for sub-adults (late rainy season) in the middle estuary, and for adults (all seasons) in the upper estuary (Tables 4 & 5). The highest ingestion of Bivalvia (13 ± 4 ind) was observed in sub-adults during the late rainy season in the upper estuary (Fig. 5, Table 1). Bivalvia was an important prey in number and weight for *C. agassizii* adults (late dry season) in the lower estuary (Tables 4 & 5). The highest ingestion of Ostracoda (407 ± 110 ind and 30 ± 10 mg) was observed in sub-adults during the early rainy season in the upper estuary (Figs. 5 & 6, Table 1). This item was important in number and weight for *C. agassizii* juveniles (late dry and early rainy season) in the upper and middle estuary, for sub-adults (rainy season) in all areas of the estuary, and in number for adults (all seasons) in the upper and middle estuary (Tables 4 & 5). The highest ingestion of Calanoida (118 ± 50 ind and 5 ± 3 mg) was observed in adults during the late rainy season in the upper estuary

(Figs. 5 & 6, Table 1). Calanoida was an important prey in number and weight for *C. agassizii* juveniles and sub-adults (rainy season) in all areas of the estuary, and for adults in number (late rainy season) in the upper estuary (Tables 4 & 5). The highest ingestion in number of Eucarida (22 ± 13 ind) was observed in sub-adults during the late dry season in the upper estuary (Figs. 5 & 6). This item was important in number and weight for *C. agasiizii* juveniles (late dry season), and in weight for sub-adults (late rainy season) and adults (early rainy season) in the upper estuary (Tables 4 & 5). The highest ingestion in number of Actinopterygii (0.8 ± 0.6 ind) was observed in adults during the early dry season in the upper estuary, and in weight (69 ± 29 mg) in the adults during the late rainy season in the lower estuary (Figs. 5 & 6). This prey was important in number and weight for *C. agassizii* adults (late rainy season) in the lower estuary (Tables 4 & 5).

Influence of environmental variables on the diet of ontogenetic phases

The canonical correspondence analysis (CCA) was performed to determine the influence of environmental gradients on the diet of the different ontogenetic phases of *C. spixii* and *C. agassizii* in the main channel of Goiana Estuary. For *C. spixii* the first axis explained 35.2% and the second axis explained 29.7% of the variance of the species-environmental relation (Fig. 7a). The first axis showed a negative correlation with salinity and dissolved oxygen ($p < 0.01$), and a positive correlation with rainfall ($p < 0.01$) (Fig. 7a, Table 6). Ostracoda and Cirripedia showed correlation with sub-adults and adults during the early dry season in the middle estuary, and during the late dry in the upper (Fig. 7a). Cumacea and Polychaeta were correlated with sub-adults and adults during the early dry season in the upper estuary (Fig. 7a). Isopoda, Corophiidea, Diptera (larvae), Gammaridea, Eucarida, Daphnia, Calanoida, Gastropoda and Myscidacea showed correlation with all phases during the early rainy season in the upper and middle estuary (Fig. 7a). Harpacticoida, Bivalvia and Nematoda showed correlation with all phases during the late rainy season in the lower estuary, and Insecta and Actinopterygii with sub-adults and adults during the late rainy season in the upper and middle estuary (Fig. 7a).

For *C. agassizii* the first axis explained 47.7% and showed positive correlation with salinity ($p < 0.05$), and the second axis explained 25% of the variance of the species-environmental relation (Fig. 7b). Corrophiidae showed correlation with adults during the early dry season in the upper estuary (Fig. 7b). Gastropoda, Polychaeta, Gammaridea, Cumacea, Eucarida, Ostracoda, Isopoda, Daphnia, Cirripedia and Insecta showed correlation with all phases during the early rainy season, and with juveniles and adults during the late dry season in the upper estuary (Fig. 7b). Actinopterygii, Bivalvia and Harpacticoida showed correlation with all phases during the late rainy season in the lower estuary (Fig. 7b). Calanoida was correlated with sub-adults and adults during the late rainy season and with juveniles during the early rainy season in the middle estuary (Fig. 7b).

Seasonal and spatial diet overlap between *C. spixii* and *C. agassizii*

The dietary analyses showed high values of diet overlap using the Schoener's Index (C) (Table 7). During the early dry season in the upper ($C = 0.63$) and middle ($C = 0.69$) estuary sub-adults and adults of *C. spixii* showed a remarkable similarity in their prey utilization (Table 7). During the late dry season in the upper estuary, *C. spixii* adults showed similarity in their diet with juveniles ($C = 0.60$) and adults ($C = 0.62$) of *C.*

agassizii (Table 7). During the early rainy season, in the upper estuary, nich overlap was observed between juveniles of *C. spixii* and *C. agassizii* (C = 0.60), sub-adults of both species (C = 0.62), and between juveniles and sub-adults of *C. agassizii* (C = 0.72) (Table 7). During the late rainy season, in the middle estuary, diet overlap was observed between juveniles and sub-adults of *C. spixii* and *C. agassizii* (C = 0.62 – 0.79) (Table 7). At this time, in the lower estuary *C. spixii* and *C. agassizii* juveniles (C = 0.64) and sub-adults (C = 0.64) showed remarkable diet overlap (Table 7).

Discussion

In South America (Western South Atlantic), the Family Ariidae appears to be the most abundant in estuaries (Araújo 1988; Barletta et al. 2005, 2008; Dantas et al. 2010). At the Goiana Estuary (Northeast Brazil), the species of this family corresponds to 53% of the capture in number (~1600 individuals ha^{-1}) and 63% in weight (~19 kg ha^{-1}) (Dantas et al. 2010). The most representative ariid species were *Cathorops spixii* (1340 individuals ha^{-1} and 14 kg ha^{-1}) and *Cathorops agassizii* (250 individuals ha^{-1} and 4 kg ha^{-1}) (Dantas et al. 2010). Moreover, the distribution of the different ontogenetic phases of these species along the estuarine ecocline are defined by the seasonal fluctuations of salinity (late dry and late rainy season) and dissolved oxygen (early rainy and late dry season) values, and each ontogenetic phase respond differently to this fluctuations (Dantas et al. 2012a). During the early dry season, the middle estuary, with high salinity and dissolved oxygen values, was characterized as nursery habitat for both species with high abundance of juveniles (Dantas et al. 2012a). During the late dry season, the upper estuary played an important role in reproduction, hatchery and pre-settlement for both species. During the early rainy season, with the increase in the freshwater inflow, the middle estuary showed low values for salinity and dissolved oxygen. High densities of juveniles of both species were found in this section of the estuary, characterizing the nursery function of this area for both species (Dantas et al. 2012a). Moreover, at this time, sub-adults and adults of both species remained in the upper estuary, where the environmental conditions were highly stressful for estuarine or marine fishes, to avoid competition for food with other fish. During the late rainy season, the upper estuary becomes a feeding ground only for adults and sub-adults of *C. agassizii*. However, the middle estuary becomes a nursery for *C. agassizii* juveniles and a feeding area for adults and sub-adults of *C. spixii*, and the lower estuary become a reproduction, hatchery, pre-settlement and nursery area for *C. spixii* (Dantas et al. 2012a).

Both ariid species feed on a wide variety of organisms, consuming predominantly invertebrates associated with the substratum. They are essentially benthophagous (Barletta and Blaber 2007), but along their life-cycle and between the different habitats and seasons, this trophic guild can change for both species. They can feed predominantly on invertebrates associated with the substratum, including animals that live just above the sediment (hyperbenthos), on the sediment (epifauna) or in the sediment (infauna). Juveniles of both species showed a zoobenthivore (hyperbenthos) diet preference, feeding mainly on Polychaeta, Ostracoda, Calanoida and Gastropoda, but during the rainy season these juveniles showed a zooplanktivore preference, including in their diet Calanoida (upper, middle and lower estuary), Ostracoda (upper, middle and lower estuary) and Daphnia (upper estuary). Sub-adults of *C. spixii* showed a zoobenthivore preference during the dry season, feeding essentially on Gastropoda (upper, middle and lower estuary), Bivalvia (upper estuary) and Ostracoda (upper, middle and lower estuary). However, Ostracoda and Calanoida (upper, middle and lower estuary) were important items during the rainy season. Sub-adults of *C. agassizii* showed a zoobenthivore preference, with a high contribution of Ostracoda (upper, middle and lower estuary) during the early rainy season, and during the late rainy season a zooplanktivore preference, with the high ingestion of Calanoida (upper and middle estuary) and Harpacticoida (lower estuary). Adults of *C. spixii* could be considered an integral zoobenthivore, feeding mainly on Polychaeta and Ostracoda (upper and middle estuary) during the dry season, and Gastropoda (upper estuary), Bivalvia (upper estuary), Calanoida (upper, middle and lower estuary) and Eucarida (upper and middle estuary). Adults of *C. agassizii* were zoobenthivore, feeding on a diverse range of preys (Polychaeta, Gastropoda, Bivalvia, Ostracoda, Calanoida, Corophiidea, Eucarida and Actinopterygii). The types of food consumed by estuarine resident or estuary-associated fish species change markedly with growth (Elliot et al. 2007). In north Brazilian mangrove creeks the wingfin anchovy *Pterengraulis atherinoides* (L.) showed a marked variation in the food selection with their growth, with a predominantly zooplanktivore preference by smaller sizes and a piscivore preference by the larger predator sizes (Krumme et al. 2005). Thus, it is expected that some groups of species will move from one trophic guild to another during their life (Elliot et al. 2007), according to different time scale and prey availability.

Although they are occurring in the same habitat, a high degree of competition for resources between the two species was not observed. During the early dry season, in the upper and middle estuary, sub-adults and adults of *C. spixii* showed a diet overlap indicating a high similarity in prey utilization, mainly by the high ingestion of Polychaeta and Ostracoda. During the late dry season, in the upper estuary, adults of *C. spixii* showed diet overlap with juveniles and adults of *C. agassizii*, principally due to the high ingestion of Gastropoda, Ostracoda and Calanoida. During the early rainy season, in the upper estuary, significant diet overlap was observed between juveniles of both species, sub-adults of both species and between juveniles and sub-adults of *C.*

agassizii. This diet overlap was influenced by the high ingestion of Ostracoda and Calanoida. During the late rainy season, in the middle estuary, diet overlap was observed between juveniles and sub-adults of *C. spixii* and *C. agassizii*, with high ingestion of Gastropoda, Calanoida and Harpacticoida. At this time, in the lower estuary *C. spixii* and *C. agassizii* juveniles, and sub-adults showed a remarkable diet overlap, with high ingestion of Gastropoda, Ostracoda and Calanoida. Sympatric species will likely consume slightly different prey to minimize niche overlap (Schoener 1974). Competition for food can affect patterns of habitat selection, niche overlap and diel activity (Hilderbrand and Kershner 2004; David et al. 2007) and a number of studies tested this hypothesis for fish inhabiting coastal ecosystems (Darnaude et al. 2001; Platell et al. 2006; Russo et al. 2008). When food resources are shared, coexistence of fish species has been suggested to be related to differential use of space (Amarasekare 2003; Sandlund et al. 2010).

Plastic, especially blue nylon fragments, ingested by demersal fish was observed as an environmental problem during this study (Dantas et al. 2012b). All phases of both species presented some contamination by this pollutant (Possatto et al. 2011), but for *C. spixii* the highest ingestion of plastic fragments in number was observed in sub-adults during the late rainy season in the upper estuary and in weight in adults during the early rainy season in the middle estuary. For *C. agassizii* the highest ingestion in number was observed in juveniles during the early rainy season in the upper estuary and in weight was observed in adults during the late dry season in the upper estuary. These species are epibenthophagous (Barletta and Blaber 2007) and prey on small animals living on the surface of the sediment (Costa et al. 2004). Additionally, they are estuarine residents (Barletta and Blaber 2007), which means that they only feed inside the estuary. Their realm extends to the continental platform during the rainy season, when salinity drops even in coastal waters. This is specially known to be so for the tropical estuaries of the Brazilian coast (Barletta et al. 2005, 2008; Dantas et al. 2010). This strongly indicates that plastic marine debris contamination spreads throughout the sediments of the whole system (Costa et al. 2011; Possatto et al. 2011). The ingestion of plastic fragments threads by fish is a demonstrated form of pollution in the Goiana Estuary (Possatto et al. 2011; Dantas et al. 2012b). The physiological and toxicological consequences of the ingestion of this type of debris are unknown, as is the actual extent of the problem worldwide (Dantas et al. 2012b).

The study of the feeding habits and resource partitioning in closely related fish species can be very useful to understand the flows of energy across the food web and provides important insights into the trophic flexibility of sympatric species (Darnaude 2005, Platell et al. 2006, Russo et al. 2008). Moreover, the patterns of prey overlap and resource partitioning between species in estuarine habitats vary depending on the specific system studied (Mariani et al. 2011). In the present study it was clear that the prey selection by the two predator species vary according to each habitat, season and ontogenetic phase. The food niche separation was strongly influenced by the environmental fluctuations resulting from rainfall and river input. In all estuary-dependent fish there are ontogenetic shifts and therefore species can change guilds during their life-cycle, especially with respect to feeding (Elliot et al. 2007).

The knowledge of feeding habits and habitat utilization by different ontogenetic phases is essential to understand the ecological role of fish populations. The recognition of a habitat as a feeding ground or nursery for a species or group of species should be one of the fundamental values accounted for by state or federal environmental agencies and fishery management councils to make better regulatory decisions for fisheries management, habitat conservation, habitat restoration, and impact mitigation. The

Goiana Estuary is an important site on the Northeast Brazilian coast for commercial, artisanal and subsistence fisheries because of the high productivity and nursery role of the different habitats within and surrounding the system. However, the feeding and nursery function can be severely impacted by natural or man-made alterations to the habitats, with consequent effects on the hydrological conditions at each site. According to Barletta and Costa (2009), inappropriate land use and dredging operations in the Goiana Estuary main channel are threats to the sustainability of this ecosystem and could eliminate the nursery function of these habitats in the estuarine ecosystem. Identification of those habitats that function as nurseries for invertebrates and fishes in this estuary is an important first step in decision-making about the sustainable use of all Goiana Estuary's living and non-living resources.

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Figure Legends

Figure 1. Goiana Estuary. ⬚ = upper (1), middle (2) and lower (3) estuaries, where the samples were taken with an otter trawl net.

Figure 2. Monthly total rainfall (a) and mean (± standard deviation) salinity (b), water temperature (ºC) (c), dissolved oxygen (mg l^{-1}) (d) and Secchi depth (cm) (e) in the upper (○), middle (□) and lower (Δ) Goiana Estuary between December 2005 and November 2006.

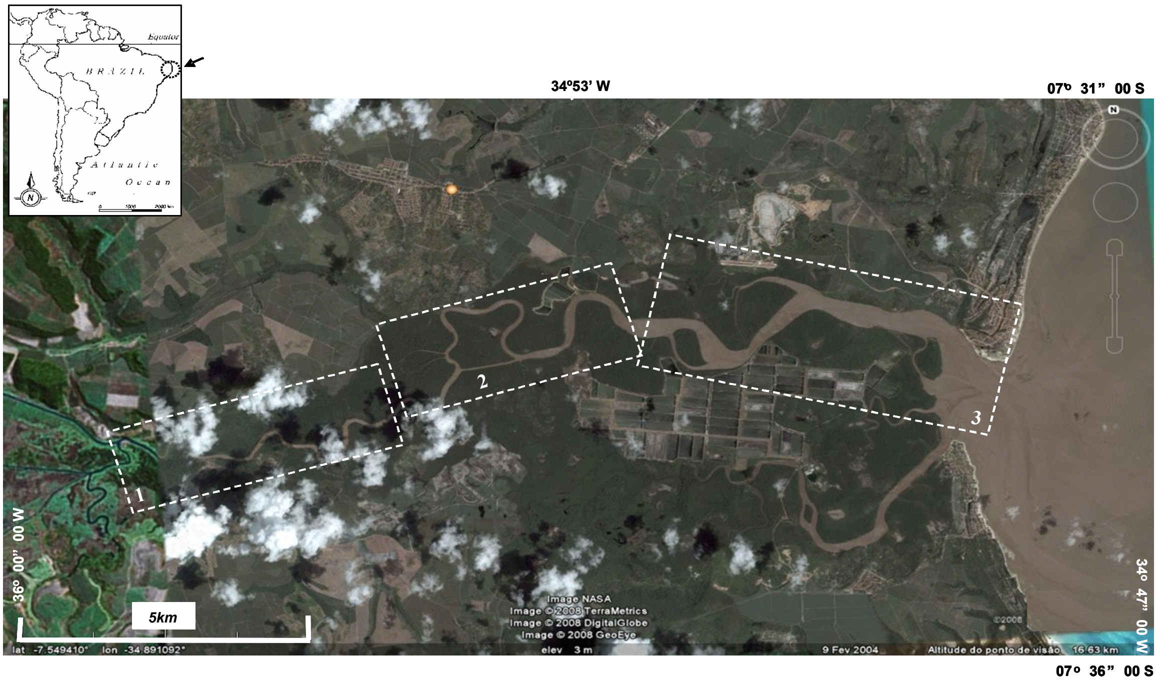
Figure 3. Mean (+ standard error) of number of prey items ingested by the different size classes of *Cathorops spixii* in each season (early dry, late dry, early rainy and late rainy) at three areas of the Goiana Estuary (upper, middle and lower estuary). Juveniles (black square); sub-adults (red square); adult (white square).

Figure 4. Mean (+ standard error) of weight (mg) of prey items ingested by the different size classes of *Cathorops spixii* in each season (early dry, late dry, early rainy and late rainy) at three areas of the Goiana Estuary (upper, middle and lower estuary). Juveniles (black square); sub-adults (red square); adult (white square).

Figure 5. Mean (+ standard error) of number of prey items ingested by the different size classes of *Cathorops agassizii* in each season (early dry, late dry, early rainy and late rainy) at three areas of the Goiana Estuary (upper, middle and lower estuary). Juveniles (black square); sub-adults (red square); adult (white square).

Figure 6. Mean (+ standard error) of weight (mg) of prey items ingested by the different size classes of *Cathorops agassizii* in each season (early dry, late dry, early rainy and late rainy) at three areas of the Goiana Estuary (upper, middle and lower estuary). Juveniles (black square); sub-adults (red square); adult (white square).

Figure 7. Canonical correspondence analysis triplots for the index of relative importance (%IRI) of prey items ingested by the different size classes of (a) *Cathorops spixii* and (b) *Cathorops agassizii* in the three areas (upper, middle and lower) of the main channel of Goiana Estuary in each season (early dry; late dry; early rainy; late rainy. (∆) Prey items (*Poly*: Polychaeta; *Ostr*: Ostracoda; *Cala*: Calanoida; *Harp*: Harpacticoida; *Isop*: Isopoda; *Dipt*: Diptera (larvae); *Daph*: Daphnia; *Cuma*: Cumacea; *Euca*: Eucarida; *Coro*: Corophiidea *Gamm*: Gammaridea; *Gast*: Gastropoda; *Biva*: Bivalvia; *Acti*: Actinopterygii; *Cirr*: Cirripedia; *Nema*: Nematoda; *Mysi*: Mysidacea; *Inse*: Insecta; *Plas*: Plastic). (○) Season (ED: early dry; LD: late dry; ER: early rainy; LR: late rainy), area (U: upper; M: middle; L: lower) and size classes (1: juvenile; 2: sub-adult; 3: adult) were represented by points and the environmental variables (rainfall, salinity, water temperature, dissolved oxygen and Secchi depth) were represented by arrows.


Equator
BRAZIL
Atlantic Ocean
34º53' W
07º 31" 00 S
1
2
3
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5km
Image NASA
Image © 2008 TerraMetrics
Image © 2008 DigitalGlobe
Image © 2008 GeoEye
lat -7.549410° lon -34.891092°
elev 3 m
9 Fev 2004
Altitude do ponto de visão 16.63 km
07º 36" 00 S

Figure 1.

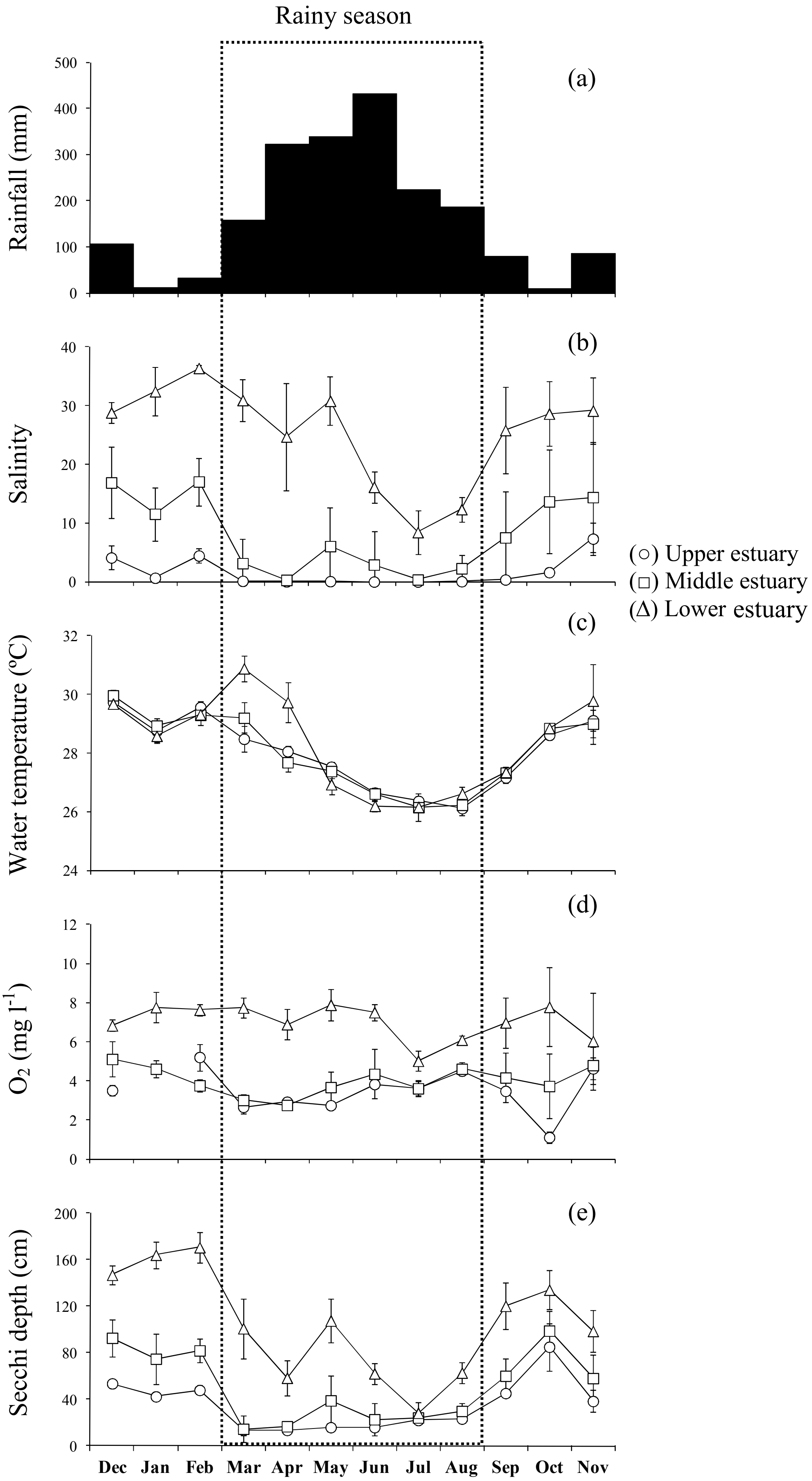
Rainy season
(a)
Rainfall (mm)
500
400
300
200
100
0
(b)
Salinity
40
30
20
10
0
(○) Upper estuary
(□) Middle estuary
(Δ) Lower estuary
(c)
Water temperature (ºC)
32
30
28
26
24
(d)
O_2 (mg l^{-1})
12
10
8
6
4
2
0
(e)
Secchi depth (cm)
200
160
120
80
40
0
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov

Figure 2.

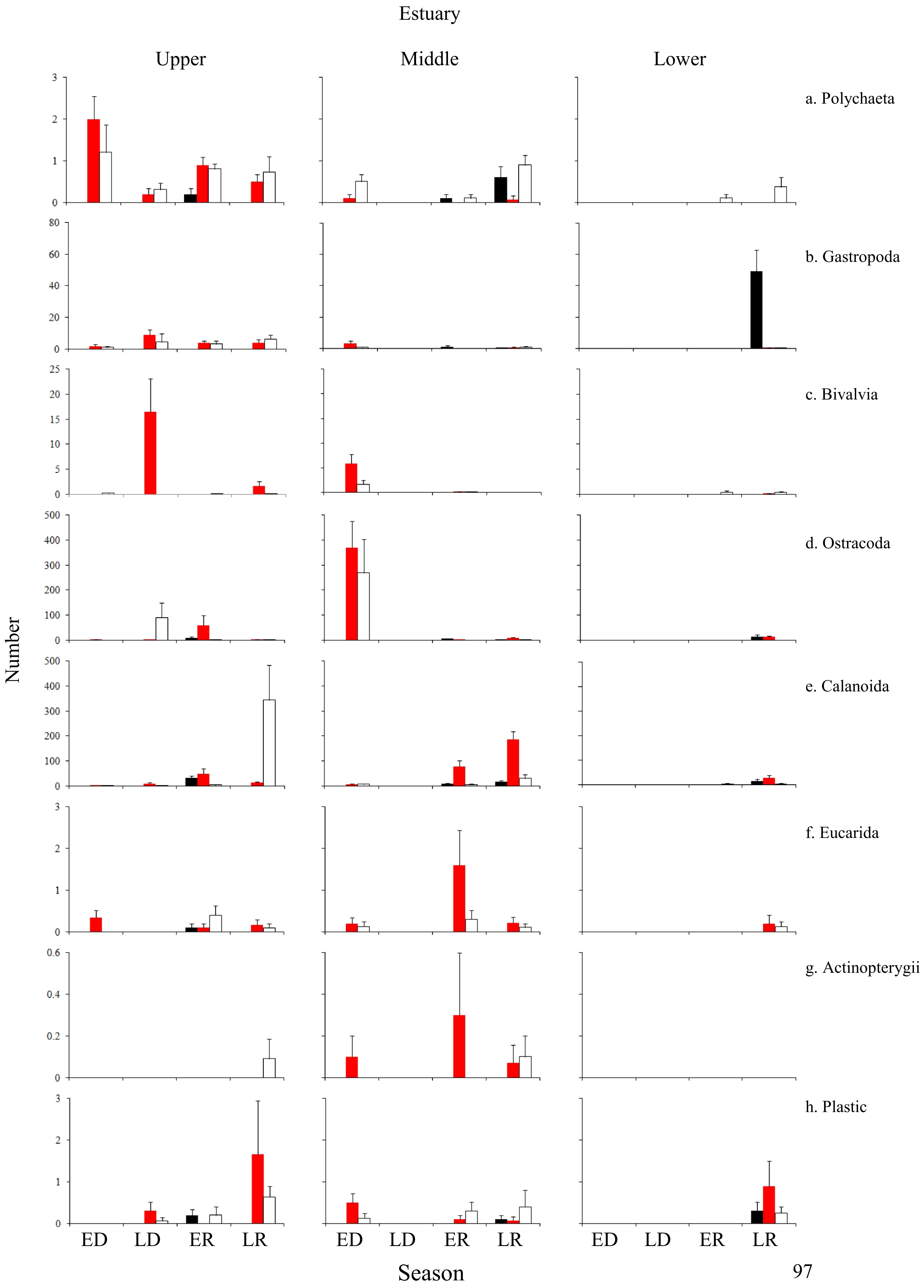
Estuary
Upper
Middle
Lower
a. Polychaeta
b. Gastropoda
c. Bivalvia
d. Ostracoda
e. Calanoida
f. Eucarida
g. Actinopterygii
h. Plastic
Number
Season
ED
LD
ER
LR
0
1
2
3
20
40
60
80
5
10
15
25
100
200
300
400
500
0.2
0.4
0.6

Figure 3.

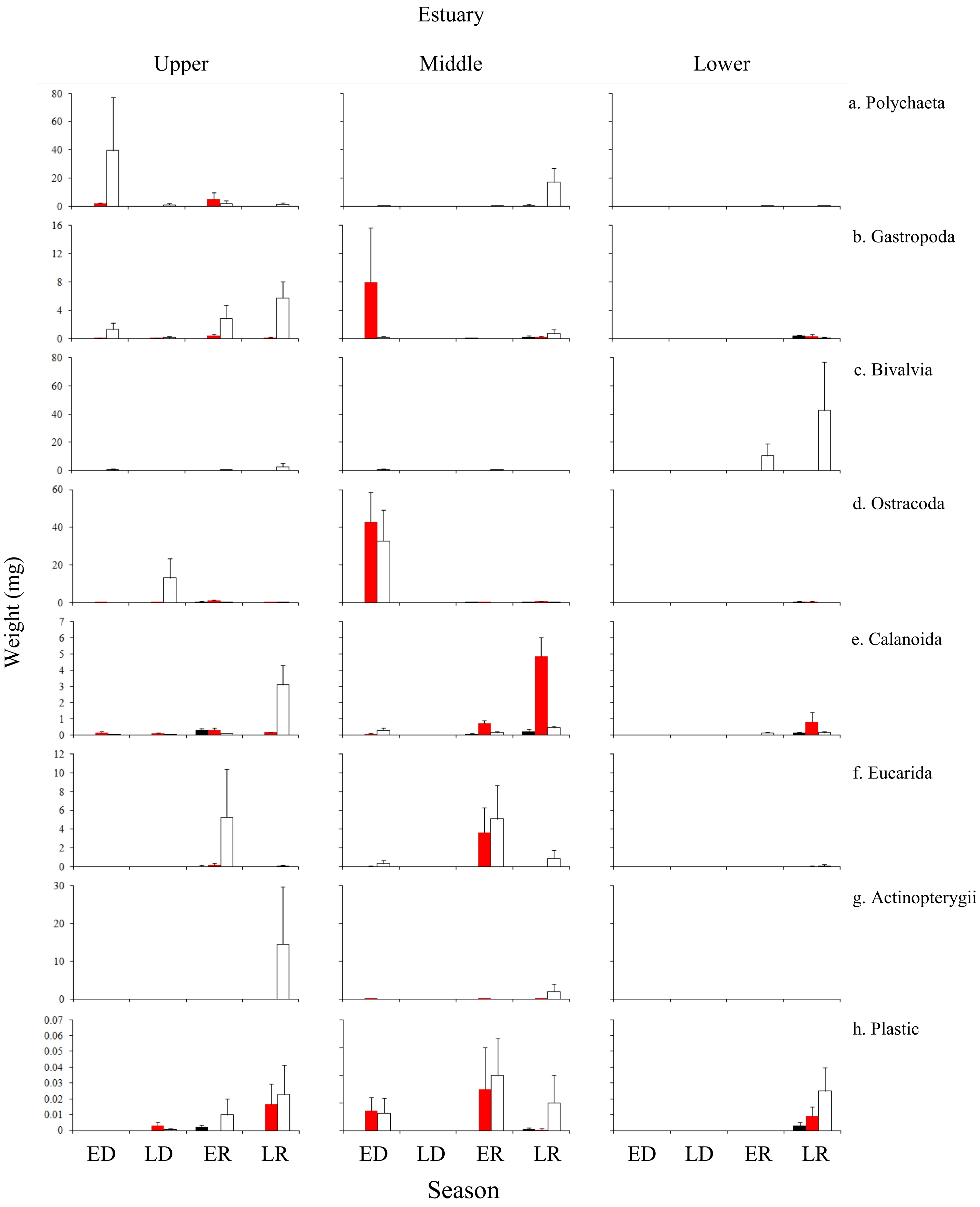
Estuary
Upper
Middle
Lower
a. Polychaeta
b. Gastropoda
c. Bivalvia
d. Ostracoda
e. Calanoida
f. Eucarida
g. Actinopterygii
h. Plastic
Weight (mg)
0
20
40
60
80
0
4
8
12
16
0
20
40
60
80
0
20
40
60
0
1
2
3
4
5
6
7
0
2
4
6
8
10
12
0
10
20
30
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
ED
LD
ER
LR
ED
LD
ER
LR
ED
LD
ER
LR
Season

Figure 4.

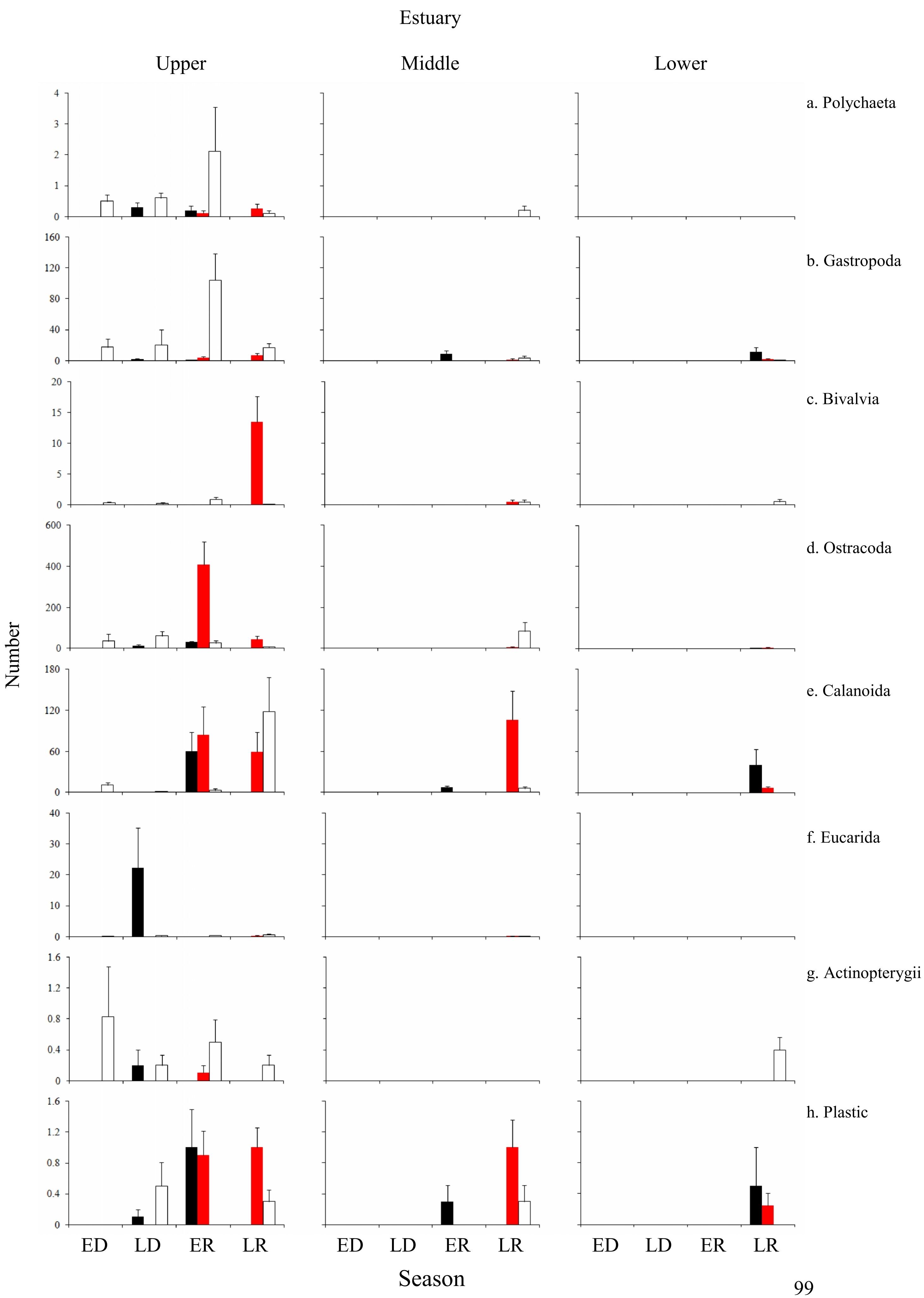
Estuary
Upper
Middle
Lower
a. Polychaeta
b. Gastropoda
c. Bivalvia
d. Ostracoda
e. Calanoida
f. Eucarida
g. Actinopterygii
h. Plastic
Number
Season
ED
LD
ER
LR
0
1
2
3
4
40
80
120
160
5
10
15
20
200
400
600
60
180
30
0.4
0.8
1.2
1.6

Figure 5.

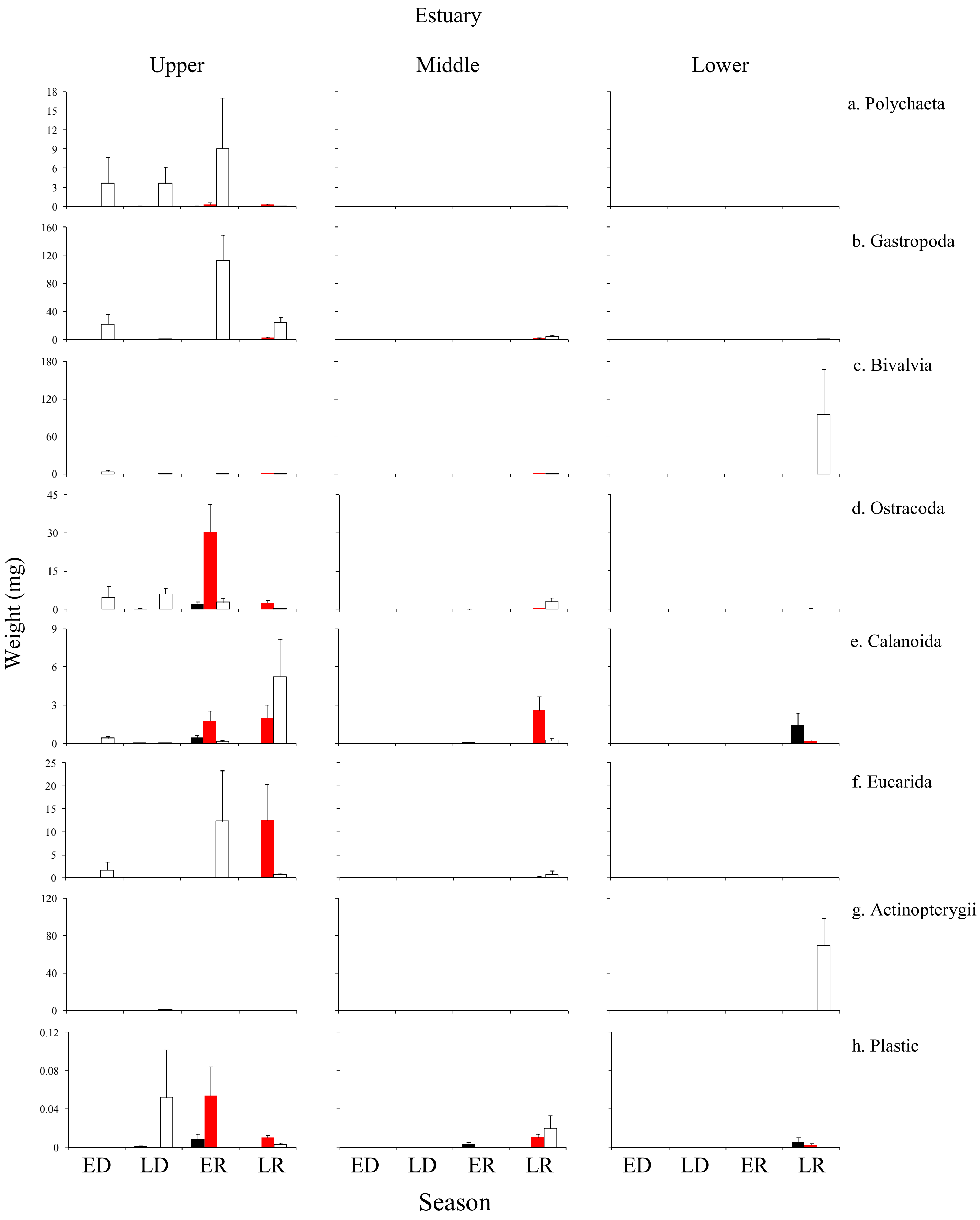
Estuary
Upper
Middle
Lower
a. Polychaeta
b. Gastropoda
c. Bivalvia
d. Ostracoda
e. Calanoida
f. Eucarida
g. Actinopterygii
h. Plastic
Weight (mg)
18
15
12
9
6
3
0
160
120
80
40
0
180
120
60
0
45
30
15
0
9
6
3
0
25
20
15
10
5
0
120
80
40
0
0.12
0.08
0.04
0
ED
LD
ER
LR
ED
LD
ER
LR
ED
LD
ER
LR
Season

Figure 6.

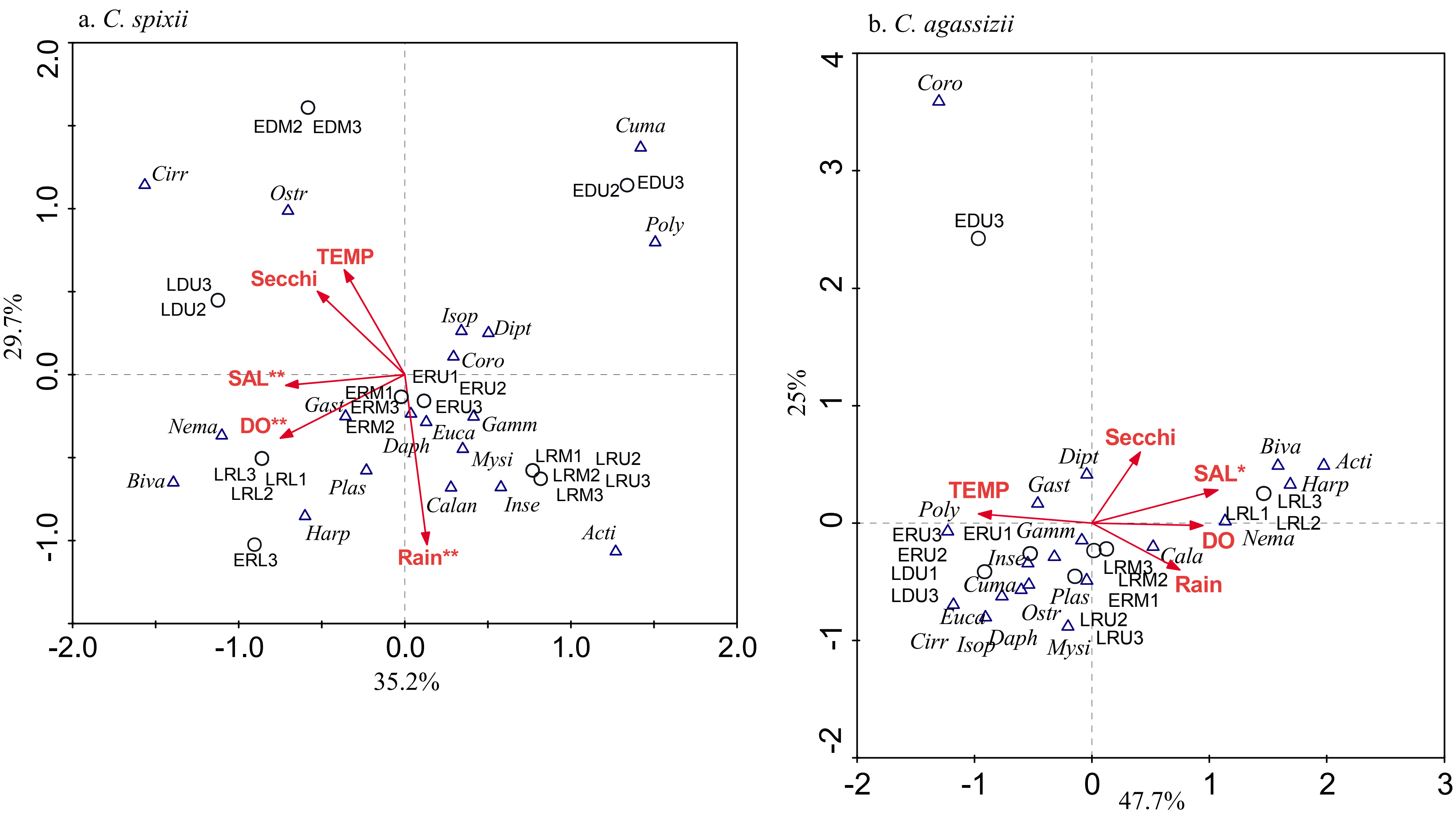
a. *C. spixii*
2.0
1.0
0.0
-1.0
-2.0
29.7%
35.2%
EDM2 EDM3
Cuma
Cirr
Ostr
EDU2
EDU3
Poly
TEMP
Secchi
LDU3
LDU2
Isop
Dipt
Coro
SAL**
ERU1
ERU2
ERM1
Gast
ERM3
ERU3
ERM2
Nema
DO**
Euca
Gamm
Daph
Mysi
LRM1
LRU2
LRM2
LRU3
LRM3
Biva
LRL3
LRL1
LRL2
Plas
Calan
Inse
Harp
Acti
ERL3
Rain**
b. *C. agassizii*
4
3
2
1
0
-1
-2
25%
47.7%
3
Coro
EDU3
Secchi
Dipt
Biva
Acti
SAL*
Gast
Harp
TEMP
LRL3
Poly
LRL1
LRL2
ERU3
ERU1
Gamm
DO
Nema
ERU2
Inse
Cala
LDU1
LRM3
LRM2
Rain
Cuma
LDU3
Plas
ERM1
Euca
Ostr
LRU2
Cirr
Isop
Daph
Mysi
LRU3

Figure 7.

Table 1. Summary of the ANOVA (*F-values*, df: degree of freedom. *p-value* and *Post-hoc* comparisons) for significant results for prey items (number and weight (mg)) for different size classes of *Cathorops spixii* and *Cathorops agassizii* for the factors season, area and phase. Differences among factors were determined by Bonferroni's Test *post hoc* comparisons (italics and bolds indicate homogeneous groups). ED: early dry season; LD: late dry season; ER: early rainy season; LR: late rainy season; Areas of the Goiana Estuary (U: upper; M: middle; L: lower); J: juveniles; S: sub-adults; A: adults. (**$p < 0.01$; *$p < 0.05$).

Variables	Factors	*F*	*df*	*p*-value	Post-hoc
Polychaeta (number)					
C. spixii	Area	13.6506	2	0.000009	** *L M* **U**
	Phase	9.5000	2	0.000218	** *J* ***S*** **A**
	Interaction (area *vs* phase)	4.0034	4	0.005472	**
C. agassizii	Area	8.1698	2	0.000634	** *L M* **U**
	Phase	5.1509	2	0.008114	** *S J* **A**
	Interaction (area *vs* phase)	4.1509	4	0.004413	**
Polychaeta (weight)					
C. agassizii	Area	3.2726	2	0.043614	* *L M* **U**
	Interaction (area *vs* phase)	2.9535	4	0.025589	*
Gastropoda (number)					
C. spixii	Season	11.9246	3	0.000002	** *ED ER LD* **LR**
	Area	6.41180	2	0.002738	** *M* ***U*** **L**
	Phase	4.30328	2	0.017165	** *A S* **J**
	Interaction (season *vs* area *vs* phase)	11.34446	12	0.000001	**
C. agassizii	Area	4.675541	2	0.012328	* *L M* **U**
	Phase	4.159528	2	0.019521	** *S* ***J*** **A**
	Interaction (season *vs* area *vs* phase)	4.951528	4	0.001391	**
Gastropoda (weight)					
C. agassizii	Area	6.612804	2	0.002309	** *L M* **U**
	Phase	6.874563	2	0.001852	** *J S* **A**
	Interaction (season *vs* area *vs* phase)	1.954655	12	0.041520	*
Bivalvia (number)					
C. spixii	Season	3.14581	3	0.030253	* *ED* ***ER*** **LD LR**
	Area	3.31077	2	0.042119	* *L* ***M*** **U**
	Phase	7.40261	2	0.001192	** *J A* **S**
	Interaction (season *vs* area *vs* phase)	4.75697	12	0.000011	**

Table 1. Continued.

C. agassizii	Season	5.211838	3	0.002589	**	*LD* ***ED*** **ER** **LR**
	Area	4.237150	2	0.018210	*	*L* ***M*** **U**
	Phase	3.325935	2	0.041538	*	*J* ***A*** **S**
	Interaction (season *vs* area *vs* phase)	3.582749	12	0.000333	**	
Ostracoda (number)						
C. spixii	Season	9.78450	3	0.000017	**	*LR ER LD* **ED**
	Area	9.96394	2	0.000151	**	*L* ***U*** **M**
	Phase	5.78557	2	0.004677	**	*J* ***A*** **S**
	Interaction (season *vs* area *vs* phase)	5.14761	12	0.000004	**	
C. agassizii	Season	7.20338	3	0.000270	**	*ED LD LR* **ER**
	Area	14.75228	2	0.000004	**	*L M* **U**
	Phase	5.56361	2	0.005665	**	*J* ***A*** **S**
	Interaction (season *vs* area *vs* phase)	8.01847	12	0.000001	**	
Ostracoda (weight)						
C. spixii	Season	6.16605	3	0.000864	**	*ER LR* ***LD*** **ED**
	Area	5.88660	2	0.004287	**	*L* ***U*** **M**
	Interaction (season *vs* area *vs* phase)	2.92090	12	0.002392	**	
C. agassizii	Season	6.38407	3	0.000675	**	*LR ED LD* **ER**
	Area	16.03497	2	0.000002	**	*L M* **U**
	Phase	4.92635	2	0.009881	**	*J* ***A*** **S**
	Interaction (season *vs* area *vs* phase)	7.21653	12	0.000001	**	
Calanoida (number)						
C. spixii	Season	8.00479	3	0.000112	**	*LD ED* ***ER*** **LR**
	Interaction (season *vs* area *vs* phase)	4.00737	12	0.000096	**	
C. agassizii	Season	5.97239	3	0.001077	**	*LD ED* ***ER*** **LR**
	Interaction (season *vs* area *vs* phase)	3.45700	12	0.000483	**	
Calanoida (weight)						
C. spixii	Season	5.303308	3	0.002328	**	*LD ED* ***ER*** **LR**
	Interaction (season *vs* area *vs* phase)	2.432966	12	0.010268	**	
C. agassizii	Season	7.16767	3	0.000281	**	*LD ED* ***ER*** **LR**
	Interaction (season *vs* area *vs* phase)	3.48416	12	0.000446	**	

Table 1. Continued.

Eucarida (number)					
C. spixii	Season	7.29293	3	0.000245	** *LD ED* ***LR*** **ER**
	Area	6.46970	2	0.002606	** *L* ***U*** **M**
	Phase	7.19697	2	0.001414	** *J* ***A*** **S**
	Interaction (season *vs* area *vs* phase)	3.33081	12	0.000703	**
C. agassizii	Season	3.648048	3	0.016499	* *ED ER* ***LR*** **LD**
	Area	4.125474	2	0.020126	* *L M* **U**
	Phase	3.428858	2	0.037808	* *S A* **J**
	Interaction (season *vs* area *vs* phase)	3.702640	12	0.000234	**
Eucarida (weight)					
C. spixii	Season	4.619267	3	0.005185	** *LD ED LR* **ER**
Actinopterygii (number)					
C. agassizii	Area	3.968085	2	0.023185	* *M* ***L*** **U**
	Phase	4.478723	2	0.014680	* *J S* **A**
Actinopterygii (weight)					
C. agassizii	Season	3.027013	3	0.034938	* *ER ED LD* **LR**
	Phase	3.224991	2	0.045565	* *J S* **A**
Plastic (number)					
C. spixii	Season	5.06076	3	0.003088	** *LD* ***ED ER*** **LR**
C. agassizii	Season	7.14327	3	0.000289	** *ED LD* ***ER*** **LR**
	Area	4.48246	2	0.014631	* *L* ***M*** **U**
	Interaction (season *vs* area *vs* phase)	3.45029	12	0.000493	**
Plastic (weight)					
C. spixii	Phase	4.17188	2	0.019306	* *J* ***S*** **A**

Table 2. Frequency of occurrence (%Fi), number (%Ni), weight (%Wi) and index of relative importance (%IRI) of preys found in the stomachs of each size class (juveniles, sub-adults and adults) of *Cathorops spixii* in the three areas of the Goiana Estuary (upper, middle and lower).

Prey Item	Predator phase	Upper				Middle				Lower			
		%Fi	%Ni	%Wi	%IRI	%Fi	%Ni	%Wi	%IRI	%Fi	%Ni	%Wi	%IRI
Polychaeta	Juv	0	0	0	0	20	2.0	44.3	6.9	0	0	0	0
	Sub	55.1	1.1	33.9	19.9	5.8	0.02	0.02	0.002	0	0	0	0
	Adu	51.0	0.5	33.9	21.9	42.8	0.5	17.8	10.1	16.6	4	0.1	0.8
Gastropoda	Juv	0	0	0	0	25	3.7	11.6	2.8	100	50.9	24.7	50.5
	Sub	58.6	9.1	3.6	7.7	35.2	0.5	9.4	2.7	20	0.4	14.1	2.1
	Adu	29.7	3.2	7.9	4.1	17.8	0.4	0.8	0.2	5.5	1	0.09	0.07
Bivalvia	Juv	0	0	0	0	0	0	0	0	0	0	0	0
	Sub	27.5	10.1	2.2	3.5	26.4	0.7	0.4	0.2	10	0.2	0.04	0.01
	Adu	8.5	0.07	2.7	0.3	21.4	0.5	0.8	0.3	33.3	7	51.8	23.2
Diptera (larvae)	Juv	0	0	0	0	0	0	0	0	0	0	0	0
	Sub	48.2	1.2	1.4	1.3	23.5	0.1	0.09	0.04	60	2.3	2.9	2.2
	Adu	17.0	0.1	0.1	0.06	10.7	0.2	0.06	0.04	11.1	5	0.04	0.6
Insecta	Juv	10	0.1	0.1	0.02	0	0	0	0	0	0	0	0
	Sub	13.7	0.2	0.1	0.05	11.7	0.05	0.03	0.008	70	1.8	2.4	2.1
	Adu	21.2	0.2	4.1	1.1	10.7	0.1	0.3	0.06	0	0	0	0
Ostracoda	Juv	60	11.5	57.1	34.2	75	21.0	28.0	27.5	50	12.8	36.1	16.3
	Sub	65.5	36.6	8.1	30.2	64.7	49.1	50.7	50.3	80	26.5	31.1	33.2
	Adu	36.1	25.7	15.8	18.7	35.7	81.3	27.2	50.1	0	0	0	0
Calanoida	Juv	90	42.2	30.0	54.0	100	68.8	13.9	62.1	90	16.1	7.8	14.4
	Sub	72.4	37.3	3.2	30.3	85.2	44.4	8.7	35.5	80	60.2	36.2	55.5
	Adu	53.1	68.1	2.6	46.9	67.8	15.0	0.8	13.9	38.8	69	0.2	31.9
Harpacticoida	Juv	10	6.7	0.9	0.6	10	3.7	0.5	0.3	90	13.1	5.4	11.2
	Sub	0	0	0	0	41.1	3.6	0.3	1.2	40	2.7	0.5	0.9
	Adu	0	0	0	0	0	0	0	0	0	0	0	0
Cumacea	Juv	0	0	0	0	0	0	0	0	20	1.0	13.3	1.9
	Sub	17.2	0.7	0.5	0.2	23.5	0.1	0.09	0.05	10	1.0	1.3	0.1
	Adu	12.7	0.4	0.1	0.08	14.2	0.4	0.05	0.1	11.1	2	0.002	0.2
Corophiidea	Juv	0	0	0	0	0	0	0	0	10	0.1	1.2	0.09
	Sub	17.2	0.6	1.4	0.3	8.8	0.03	0.1	0.01	20	0.8	0.9	0.2
	Adu	29.7	0.6	1.8	0.9	10.7	0.1	0.2	0.05	27.7	6	0.2	2.0
Gammaridea	Juv	0	0	0	0	0	0	0	0	0	0	0	0
	Sub	10.3	0.1	0.4	0.06	5.8	0.02	0.8	0.03	0	0	0	0
	Adu	19.1	0.3	1.8	0.5	21.4	0.3	1.4	0.5	5.5	1	0.03	0.06
Isopoda	Juv	0	0	0	0	5	0.2	0.4	0.02	60	1.9	4	2.38
	Sub	10.3	0.2	38.0	4.0	5.8	0.02	0.3	0.01	30	0.8	4.6	1.1
	Adu	12.7	0.1	0.1	0.04	3.5	0.03	0.1	0.006	5.5	2	0.03	0.1
Daphnia	Juv	30	38.7	2.0	10.1	0	0	0	0	20	0.3	1.1	0.19
	Sub	3.4	0.1	0.006	0.006	0	0	0	0	10	0.6	0.4	0.07
	Adu	0	0	0	0	0	0	0	0	0	0	0	0
Cirripedia	Juv	0	0	0	0	0	0	0	0	10	0.2	0.5	0.05
	Sub	0	0	0	0	2.9	0.01	0.02	0.0008	0	0	0	0
	Adu	6.3	0.05	0.8	0.07	10.7	0.1	0.2	0.05	0	0	0	0
Mysidacea	Juv	0	0	0	0	0	0	0	0	0	0	0	0
	Sub	0	0	0	0	8.8	0.05	0.03	0.005	0	0	0	0
	Adu	2.1	0.01	0.1	0.004	0	0	0	0	0	0	0	0
Eucarida	Juv	10	0.1	9.5	0.8	0	0	0	0	0	0	0	0
	Sub	10.3	0.1	1.5	0.1	29.4	0.2	4.2	1.0	10	0.4	2.2	0.1
	Adu	8.5	0.08	4.0	0.4	14.2	0.1	6.5	1.2	5.5	1	0.1	0.07

Table 2. Continued.

Actinopterygii	Juv	0	0	0	0	0	0	0	0	0	0	0	0
	Sub	0	0	0	0	8.8	0.06	0.1	0.01	0	0	0	0
	Adu	2.1	0.01	11.9	0.3	3.5	0.03	2.0	0.09	0	0	0	0
Nematoda	Juv	0	0	0	0	0	0	0	0	40	2.9	1.2	1.13
	Sub	3.4	1.1	0.5	0.06	17.6	0.4	0.05	0.07	0	0	0	0
	Adu	0	0	0	0	0	0	0	0	0	0	0	0
Plant material	Juv	0	-	0	0	10	-	0.9	0.07	60	-	4	1.6
	Sub	37.9	-	4.4	1.7	44.1	-	24.1	8.3	70	-	2.4	1.2
	Adu	29.7	-	11.5	4.2	42.8	-	41.1	22.7	72.2	-	47	40.3
Plastic	Juv	20	0.2	0.2	0.08	5	0.2	0.04	0.01	20	0.3	0.1	0.06
	Sub	13	0.7	0.08	0.1	17.6	0.09	0.05	0.01	30	1.8	0.4	0.4
	Adu	14.8	0.1	0.02	0.03	14.2	0.3	0.07	0.06	11.1	2	0.02	0.2

Table 3. Frequency of occurrence (%Fi), number (%Ni), weight (%Wi) and index of relative importance (%IRI) of preys found in the stomachs of each size class (juveniles, sub-adults and adults) of *Cathorops spixii* during the different seasons (early dry, late dry, early rainy and late rainy) in the Goiana Estuary. (-) no capture.

Prey items	**Predator phase**	**Early dry**				**Late dry**				**Early rainy**				**Late rainy**			
		%Fi	**%Ni**	**%Wi**	**%IRI**	**%Fi**	**%Ni**	**%Wi**	**%IRI**	**%Fi**	**%Ni**	**%Wi**	**%IRI**	**%Fi**	**%Ni**	**%Wi**	**%IRI**
Polychaeta	Juv	-	-	-	-	-	-	-	-	15	0.3	0.6	0.1	20	0.5	27.9	5.1
	Sub	30.7	0.1	0.8	0.1	20	0.5	0.01	0.09	40	0.4	25.8	10.8	13.3	0.1	0.08	0.01
	Adu	55.5	0.6	50.2	33.1	25	0.3	7.1	1.3	33.3	4.2	2.9	3.4	48.2	0.4	13.6	6.6
Gastropoda	Juv	-	-	-	-	-	-	-	-	15	1.2	2.0	0.3	60	42.2	18.6	32.9
	Sub	53.8	0.9	10.8	3.9	60	24.7	12.2	20.0	30	1.9	2.2	1.2	40	0.9	5.2	1.4
	Adu	27.7	0.6	1.8	0.7	6.2	4.4	0.7	0.2	16.6	13.3	3.9	4.1	31.0	1.8	5.1	2.1
Bivalvia	Juv	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
	Sub	61.5	1.4	0.4	0.7	60	44.9	48.9	50.9	5	0.05	0.4	0.02	10	0.3	0.7	0.06
	Adu	38.8	0.6	1.6	1.0	0	0	0	0	16.6	2.5	15.1	4.2	13.7	0.09	26.7	3.6
Diptera (larvae)	Juv	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
	Sub	46.1	0.1	0.1	0.09	40	1.0	2.2	1.2	30	0.4	0.6	0.3	40	0.6	1.0	0.4
	Adu	16.6	0.3	0.07	0.07	6.2	0.06	0.03	0.004	16.6	3.4	0.1	0.8	13.7	0.1	0.09	0.02
Insecta	Juv	-	-	-	-	-	-	-	-	5	0.1	0.07	0.007	0	0	0	0
	Sub	7.6	0.02	0.001	0.001	10	0.2	0.01	0.02	5	0.05	0.05	0.002	40	0.3	0.8	0.3
	Adu	11.1	0.1	1.9	0.2	0	0	0	0	13.3	2.1	0.6	0.5	24.1	0.2	2.7	0.7
Ostracoda	Juv	-	-	-	-	-	-	-	-	75	15.5	60.6	43.9	55	12.4	26.8	19.5
	Sub	84.6	93.3	58.3	80.3	40	2.4	8.8	4.0	50	30.4	6.0	18.8	80	6.8	14.9	10.5
	Adu	38.8	93.7	33.0	57.8	75	91.0	78.6	95.4	6.6	2.5	0.02	0.2	20.6	0.5	0.07	0.1
Calanoida	Juv	-	-	-	-	-	-	-	-	95	44.1	25.3	50.7	95	27.1	10.8	32.5
	Sub	61.5	1.2	0.1	0.5	60	23.9	15.6	21.4	80	63.8	5.3	57.0	93.3	81.8	63.8	82.5
	Adu	44.4	2.6	0.3	1.5	43.7	0.9	0.05	0.3	46.6	52.7	0.4	35.6	75.8	95.6	2.8	73.1
Harpaticoida	Juv	-	-	-	-	-	-	-	-	10	5.7	0.7	0.5	50	11.9	2.9	6.7
	Sub	30.7	0.7	0.02	0.1	0	0	0	0	0	0	0	0	46.6	7.3	2.1	2.6
	Adu	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cumacea	Juv	-	-	-	-	-	-	-	-	0	0	0	0	10	0.8	6.5	0.6
	Sub	53.8	0.5	0.1	0.2	0	0	0	0	10	0.1	0.1	0.02	16.6	0.2	0.6	0.09
	Adu	11.1	0.4	0.05	0.06	31.2	1.4	0.5	0.4	13.3	2.1	0.01	0.4	3.4	0.02	0.01	0.001
Corophiidea	Juv	-	-	-	-	-	-	-	-	0	0	0	0	5	0.08	0.6	0.03
	Sub	15.3	0.1	0.04	0.01	0	0	0	0	15	0.2	1.0	0.2	16.6	0.1	1.1	0.1
	Adu	27.7	0.3	1.3	0.5	18.7	1.4	4.5	0.8	40	6.0	0.8	3.9	6.8	0.09	0.08	0.01

Table 3. Continued.

Gammaridea	Juv	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
	Sub	15.3	0.05	0.9	0.09	10	0.2	3.7	0.3	10	0.1	0.2	0.03	0	0	0	0
	Adu	22.2	0.2	0.3	0.1	6.2	0.06	0.03	0.004	20	3.8	0.6	1.3	17.2	0.3	2.2	0.4
Isopoda	Juv	-	-	-	-	-	-	-	-	5	0.1	0.6	0.03	35	1.6	1.9	1.1
	Sub	15.3	0.07	0.05	0.01	0	0	0	0	10	0.1	32.4	3.3	13.3	0.1	3.3	0.2
	Adu	0	0	0	0	6.2	0.06	0.03	0.004	10	1.7	0.2	0.2	13.7	0.1	0.1	0.03
Daphinia	Juv	-	-	-	-	-	-	-	-	15	32.4	1.4	3.9	10	0.2	0.5	0.07
	Sub	0	0	0	0	10	0.8	0.1	0.09	0	0	0	0	3.3	0.08	0.07	0.003
	Adu	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cirripedia	Juv	-	-	-	-	-	-	-	-	0	0	0	0	5	0.1	0.2	0.02
	Sub	0	0	0	0	0	0	0	0	0	0	0	0	3.3	0.02	0.1	0.003
	Adu	16.6	0.1	0.3	0.08	6.2	0.1	4.4	0.2	0	0	0	0	0	0	0	0
Mysidacea	Juv	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
	Sub	7.6	0.02	0.01	0.001	0	0	0	0	10	0.1	0.1	0.02	0	0	0	0
	Adu	0	0	0	0	0	0	0	0	0	0	0	0	3.4	0.02	0.1	0.005
Eucarida	Juv	-	-	-	-	-	-	-	-	5	1.1	6.6	0.2	0	0	0	0
	Sub	23.0	0.07	0.09	0.02	0	0	0	0	30	0.8	20.6	6.6	16.6	0.1	0.9	0.1
	Adu	5.5	0.04	0.3	0.02	0	0	0	0	16.6	3.0	14.5	4.1	10.3	0.06	0.7	0.08
Actinopterygii	Juv	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
	Sub	7.6	0.02	0.001	0.001	0	0	0	0	5	0.1	0.3	0.02	3.3	0.02	0.1	0.003
	Adu	0	0	0	0	0	0	0	0	0	0	0	0	6.8	0.04	12.9	0.8
Nematoda	Juv	-	-	-	-	-	-	-	-	0	0	0	0	20	2.4	0.6	0.5
	Sub	30.7	0.8	0.03	0.1	0	0	0	0	5	1.0	0.4	0.07	6.6	0.1	0.1	0.01
	Adu	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plant material	Juv	-	-	-	-	-	-	-	-	10	-	1.4	0.1	30	-	1.9	0.5
	Sub	76.9	-	27.8	13.4	20	-	7.5	1.3	35	-	3.5	1.2	46.6	-	4.1	1.1
	Adu	44.4	-	8.4	4.4	37.5	-	3.7	1.0	46.6	-	60.2	40.3	37.9	-	32.2	11.9
Plastic	Juv	-	-	-	-	-	-	-	-	10	0.2	0.1	0.02	15	0.3	0.1	0.06
	Sub	30.7	0.1	0.01	0.02	20	0.8	0.5	0.2	5	0.05	0.1	0.01	16.6	0.5	0.1	0.07
	Adu	0	0	0	0	6.2	0.06	0.003	0.003	10	2.1	0.07	0.3	27.5	0.3	0.04	0.09

Table 4. Frequency of occurrence (%Fi), number (%Ni), weight (%Wi) and index of relative importance (%IRI) of preys found in the stomachs of each size class (juveniles, sub-adults and adults) of *Cathorops agassizii* in the three areas of the Goiana Estuary (upper, middle and lower).

Prey Item	Predator phase	Upper				Middle				Lower			
		%Fi	%Ni	%Wi	%IRI	%Fi	%Ni	%Wi	%IRI	%Fi	%Ni	%Wi	%IRI
Polychaeta	Juv	25	0.1	2.4	0.5	0	0	0	0	0	0	0	0
	Sub	14.2	0.03	0.7	0.06	0	0	0	0	0	0	0	0
	Adu	38.4	0.5	4.9	1.6	18.1	0.1	0.01	0.03	0	0	0	0
Gastropoda	Juv	45	0.7	6.2	2.6	60	42.8	21.7	30.1	70	20.3	6.1	10.2
	Sub	71.4	1.2	2.8	1.6	33.3	0.9	25.4	6.1	25	2.0	1.2	1.2
	Adu	76.9	27.5	45.9	43.0	18.1	3.3	3.5	1.1	10	10	0.004	1.7
Bivalvia	Juv	0	0	0	0	0	0	0	0	0	0	0	0
	Sub	21.4	0.9	0.2	0.1	20	0.3	1.1	0.2	0	0	0	0
	Adu	25.6	0.2	1.6	0.3	9.0	0.3	0.05	0.03	20	50	47.6	35.0
Diptera (larvae)	Juv	10	0.06	0.2	0.02	20	1.0	0.4	0.2	0	0	0	0
	Sub	64.2	0.8	0.4	0.4	26.6	0.4	0.9	0.2	25	1.4	7.0	3.2
	Adu	61.5	2.9	0.6	1.6	27.2	3.3	0.2	0.8	0	0	0	0
Insecta	Juv	5	0.03	0.7	0.03	10	0.5	0.2	0.05	0	0	0	0
	Sub	14.2	0.07	0.07	0.01	6.6	0.04	3.5	0.1	0	0	0	0
	Adu	20.5	0.1	0.2	0.07	0	0	0	0	0	0	0	0
Ostracoda	Juv	85	14.6	59.6	53.4	40	10.7	29.3	12.4	20	0.8	2.8	0.4
	Sub	100	75.2	60.1	77.8	66.6	4.3	7.7	5.6	50	5.6	16.9	17.0
	Adu	56.4	25.1	4.5	12.7	36.3	81.7	2.9	27.4	0	0	0	0
Calanoida	Juv	70	21.2	12.1	19.8	100	36.7	16.8	41.6	100	70.7	83.4	85.1
	Sub	92.8	19.0	4.8	12.7	93.3	74.1	46.2	78.1	75	8.6	12.5	23.9
	Adu	69.2	26.1	1.8	14.7	63.6	5.6	0.2	3.3	0	0	0	0
Harpacticoida	Juv	25	8.8	2.9	2.5	30	6.6	3.1	2.2	70	5.3	1.4	2.6
	Sub	14.2	0.07	0.01	0.006	46.6	13.3	1.4	4.7	25	80.11	56.5	51.5
	Adu	7.6	0.1	0.001	0.006	0	0	0	0	0	0	0	0
Cumacea	Juv	0	0	0	0	0	0	0	0	10	0.1	0.5	0.03
	Sub	7.1	0.01	0.001	0.0008	6.6	0.09	0.3	0.02	25	0.8	1.4	0.8
	Adu	17.9	1.0	0.09	0.1	0	0	0	0	0	0	0	0
Corophiidea	Juv	5	0.03	2.4	0.1	0	0	0	0	0	0	0	0
	Sub	7.1	0.4	1.9	0.09	13.3	0.09	0.2	0.02	0	0	0	0
	Adu	48.7	13.9	6.3	7.5	0	0	0	0	0	0	0	0
Gammaridea	Juv	0	0	0	0	0	0	0	0	0	0	0	0
	Sub	28.5	0.07	0.3	0.06	6.6	0.04	0.1	0.007	25	0.2	1.2	0.5
	Adu	30.7	0.9	1.4	0.5	18.1	0.5	0.7	0.2	0	0	0	0
Isopoda	Juv	5	0.03	0.4	0.02	0	0	0	0	10	0.1	0.5	0.03
	Sub	7.1	0.03	0.03	0.003	0	0	0	0	0	0	0	0
	Adu	10.2	0.1	0.2	0.02	9.0	0.09	0.01	0.009	0	0	0	0
Daphnia	Juv	40	45.8	4.1	16.9	0	0	0	0	0	0	0	0
	Sub	28.5	1.6	0.2	0.3	33.3	5.3	1.4	1.5	0	0	0	0
	Adu	5.1	0.03	0.001	0.001	0	0	0	0	0	0	0	0
Cirripedia	Juv	0	0	0	0	0	0	0	0	0	0	0	0
	Sub	14.2	0.03	0.2	0.02	0	0	0	0	0	0	0	0
	Adu	20.5	0.1	1.6	0.2	0	0	0	0	0	0	0	0
Mysidacea	Juv	0	0	0	0	0	0	0	0	0	0	0	0
	Sub	0	0	0	0	0	0	0	0	0	0	0	0
	Adu	5.1	0.05	0.3	0.01	0	0	0	0	0	0	0	0
Eucarida	Juv	20	7.7	3.3	1.8	0	0	0	0	0	0	0	0
	Sub	7.1	0.01	9.6	0.3	13.3	0.09	3.5	0.3	0	0	0	0
	Adu	30.7	0.25	4.1	1.0	9.0	0.09	0.7	0.07	0	0	0	0

Table 4. Continued.

Actinopterygii	Juv	5	0.06	0.2	0.01	0	0	0	0	0	0	0	0
	Sub	7.1	0.01	0.01	0.001	0	0	0	0	0	0	0	0
	Adu	23.0	0.3	0.5	0.1	0	0	0	0	40	40	35.2	53.9
Nematoda	Juv	0	0	0	0	0	0	0	0	20	1.4	0.5	0.2
	Sub	7.1	0.05	0.03	0.003	13.3	0.09	0.2	0.02	25	0.5	1.2	0.7
	Adu	0	0	0	0	9.0	4.2	0.01	0.3	0	0	0	0
Plant material	Juv	45	-	4.6	1.7	60	-	27.3	12.7	50	-	4.1	1.1
	Sub	57	-	18.0	5.9	46.6	-	7.2	2.3	25	-	1.4	0.5
	Adu	82.0	-	25.2	15.7	81.8	-	91.4	66.5	30	-	17.0	9.1
Plastic	Juv	30	0.3	0.2	0.1	20	1.5	0.7	0.3	10	0.8	0.2	0.06
	Sub	64.2	0.2	0.1	0.1	60	0.7	0.1	0.3	25	0.2	0.1	0.1
	Adu	15.3	0.1	0.01	0.02	18.1	0.2	0.01	0.05	0	0	0	0

Table 5. Frequency of occurrence (%Fi), number (%Ni), weight (%Wi) and index of relative importance (%IRI) of preys found in the stomachs of each size class (juveniles, sub-adults and adults) of *Cathorops agassizii* during the different seasons (early dry, late dry, early rainy and late rainy) in the Goiana Estuary. (-) no capture.

Prey items	Predator phase	Early dry				Late dry				Early rainy				Late rainy			
		%Fi	%Ni	%Wi	%IRI	%Fi	%Ni	%Wi	%IRI	%Fi	%Ni	%Wi	%IRI	%Fi	%Ni	%Wi	%IRI
Polychaeta	Juv	-	-	-	-	30	0.7	11.2	3.5	10	0.07	0.01	0.005	0	0	0	0
	Sub	-	-	-	-	-	-	-	-	10	0.01	0.6	0.03	4.3	0.03	0.5	0.02
	Adu	41.6	0.4	6.3	2.4	60	0.6	9.4	4.9	37.5	1.3	5.2	1.4	10	0.1	0.01	0.01
Gastropoda	Juv	-	-	-	-	50	4.2	23.9	13.7	50	3.3	3.6	2.7	70	20.3	6.1	10.2
	Sub	-	-	-	-	-	-	-	-	70	0.7	1.2	0.7	39.1	1.7	17.3	6.4
	Adu	75	14.2	37.7	32.9	40	21.5	3	8	100	64.9	65.1	74.5	40	8.2	7.7	7.7
Bivalvia	Juv	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0
	Sub	-	-	-	-	-	-	-	-	0	0	0	0	26	1.9	1.1	0.7
	Adu	33.3	0.2	6.4	1.8	10	0.2	1	0.1	50	0.5	0.2	0.2	13.3	0.4	25.9	4.2
Diptera (larvae)	Juv	-	-	-	-	10	0.2	1.1	0.1	15	0.1	0.08	0.02	0	0	0	0
	Sub	-	-	-	-	-	-	-	-	70	0.1	0.2	0.1	30.4	1.6	1.4	0.8
	Adu	66.6	3.7	0.7	2.5	30	0.6	0.8	0.3	87.5	5.8	0.7	3.3	30	1.8	0.1	0.7
Insecta	Juv	-	-	-	-	0	0	0	0	10	0.07	0.8	0.07	0	0	0	0
	Sub	-	-	-	-	-	-	-	-	0	0	0	0	13	0.1	1.9	0.2
	Adu	25	0.2	0.3	0.1	10	0.1	0.2	0.03	0	0	0	0	13.3	0.2	0.1	0.05
Ostracoda	Juv	-	-	-	-	70	32.8	38.4	48.6	70	11.8	61.3	40.9	20	0.8	2.8	0.4
	Sub	-	-	-	-	-	-	-	-	100	81.4	70.1	80.9	69.5	9.2	9.4	11.2
	Adu	50	29.3	8.1	15.8	60	64.2	15.9	39.4	62.5	15.8	1.5	6.2	30	35.7	0.9	13.3
Calanoida	Juv	-	-	-	-	40	1.8	1.8	1.4	100	25	15.2	32.2	100	70.7	83.4	85.1
	Sub	-	-	-	-	-	-	-	-	100	16.7	4	11	86.9	59.2	26.8	64.6
	Adu	58.3	8.6	0.7	4.6	70	1.3	0.05	0.8	37.5	1.7	0.07	0.4	56.6	49.8	1.5	35.2
Harpaticoida	Juv	-	-	-	-	10	0.2	0.2	0.04	35	9.9	3.6	3.7	70	5.3	1.4	2.6
	Sub	-	-	-	-	-	-	-	-	0	0	0	0	43.4	17.8	2.9	7.8
	Adu	0	0	0	0	20	0.5	0.01	0.08	0	0	0	0	33.3	0.04	0.0001	0.001
Cumacea	Juv	-	-	-	-	0	0	0	0	0	0	0	0	10	0.1	0.5	0.03
	Sub	-	-	-	-	-	-	-	-	0	0	0	0	13	0.1	0.2	0.04
	Adu	0	0	0	0	50	5.1	0.7	2.3	0	0	0	0	6.66	0.1	0.005	0.01
Corophiidea	Juv	-	-	-	-	0	0	0	0	5	0.03	2.8	0.1	0	0	0	0
	Sub	-	-	-	-	-	-	-	-	10	0.4	2.3	0.1	8.6	0.06	0.1	0.01
	Adu	58.3	41.6	24.7	32.7	60	3.5	3	3.2	75	6.2	0.8	3	0	0	0	0

Table 5. Continued.

	Juv	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0
Gammaridea	Sub	-	-	-	-	-	-	-	-	30	0.05	0.2	0.04	13	0.09	0.6	0.07
	Adu	16.6	0.2	1.8	0.3	10	0.1	0.1	0.02	75	2.6	1.9	1.9	16.6	0.6	0.3	0.2
	Juv	-	-	-	-	0	0	0	0	5	0.03	0.5	0.02	10	0.1	0.5	0.03
Isopoda	Sub	-	-	-	-	-	-	-	-	10	0.03	0.04	0.004	0	0	0	0
	Adu	0	0	0	0	20	0.5	0.5	0.1	12.5	0.1	0.2	0.03	6.6	0.08	0.02	0.008
	Juv	-	-	-	-	0	0	0	0	40	48.9	4.6	17.1	0	0	0	0
Daphnia	Sub	-	-	-	-	-	-	-	-	20	0.05	0.004	0.006	30.4	6.5	1.2	2
	Adu	8.3	0.06	0.001	0.004	0	0	0	0	12.5	0.07	0.0001	0.005	0	0	0	0
	Juv	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0
Cirripedia	Sub	-	-	-	-	-	-	-	-	0	0	0	0	8.6	0.06	0.7	0.06
	Adu	16.6	0.2	0.8	0.1	30	0.3	12	3	0	0	0	0	3.3	0.04	0.01	0.002
	Juv	-	-	-	-	0	0	0	0	0	0	0	0	0	0	0	0
Mysidacea	Sub	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
	Adu	0	0	0	0	0	0	0	0	0	0	0	0	6.6	0.1	0.2	0.03
	Juv	-	-	-	-	40	58.9	15.2	28.9	0	0	0	0	0	0	0	0
Eucarida	Sub	-	-	-	-	-	-	-	-	0	0	0	0	13	0.09	29.5	3.3
	Adu	8.3	0.06	2.8	0.2	30	0.3	0.4	0.1	37.5	0.2	7.1	1.5	20	0.2	0.4	0.1
	Juv	-	-	-	-	10	0.5	1	0.1	0	0	0	0	0	0	0	0
Actinopterygii	Sub	-	-	-	-	-	-	-	-	10	0.01	0.02	0.002	0	0	0	0
	Adu	25	0.6	0.9	0.3	20	0.2	2.6	0.4	25	0.3	0.02	0.04	20	0.2	19.2	4.7
	Juv	-	-	-	-	0	0	0	0	0	0	0	0	20	1.4	0.5	0.2
Nematoda	Sub	-	-	-	-	-	-	-	-	0	0	0	0	17.3	0.2	0.2	0.07
	Adu	0	0	0	0	0	0	0	0	0	0	0	0	3.3	1.7	0.005	0.07
	Juv	-	-	-	-	50	-	6.7	3.3	50	-	6.7	2.7	50	-	4.1	1.1
Plant material	Sub	-	-	-	-	-	-	-	-	60	-	20.8	6.6	43.4	-	5.4	2
	Adu	83.3	-	8.2	5.7	90	-	49.5	36.4	75	-	16.7	7.1	63.3	-	43.3	33.2
	Juv	-	-	-	-	10	0.2	0.1	0.03	35	0.4	0.3	0.2	10	0.8	0.2	0.06
Plastic	Sub	-	-	-	-	-	-	-	-	60	0.1	0.1	0.09	56.5	0.6	0.1	0.3
	Adu	0	0	0	0	30	0.5	0.1	0.1	0	0	0	0	16.6	0.2	0.006	0.05

Table 6. Summary of canonical correspondence analysis using five environmental parameters (rainfall, salinity, water temperature, dissolved oxygen and Sechhi depth) and the index of relative importance (%IRI) of prey items ingested by the different size classes of *Cathorops spixii* and *Cathorops agassizii* different size classes (juvenile, sub-adult and adult) in the Goiana Estuary main channel. Correlations with environmental variables are presented. (** $p < 0.01$; * $p < 0.05$).

a. *Cathorops spixii*	Axis 1	Axis 2	
Eigenvalue	0.382	0.322	
Species-environmental correlation	0.873	0.793	
Cumulative % variance			
of species data	16.1	29.6	
of species environmetal relation	35.2	64.9	
Correlation with environmental variables			*p*-value
Rainfall (mm)	0.0974	-0.7095**	0.0060
Salinity	-0.5227**	-0.0443	0.0020
Water temperature (ºC)	-0.2656	0.4370	0.1560
Dissolved oxygen (mg l^{-1})	-0.5470**	-0.2653	0.0080
Secchi depth (cm)	-0.3839	0.3478	0.7160

b. *Cathorops agassizii*	Axis 1	Axis 2	
Eigenvalue	0.503	0.263	
Species-environmental correlation	0.888	0.886	
Cumulative % variance			
of species data	17.7	27.0	
of species environmental relation	47.7	72.7	
Correlation with environmental variables			*p*-value
Rainfall (mm)	0.5266	-0.3285	0.1760
Salinity	0.7515*	0.2322	0.0220
Water temperature (ºC)	-0.6780	0.0652	0.9020
Dissolved oxygen (mg l^{-1})	0.6640	-0.0161	0.6940
Secchi depth (cm)	0.2905	-0.3285	0.5900

Table 7. Diet overlap (Schoener's index "*C*") among different ontogenetic phases of *Cathorops spixii* (*Cs*) and *Cathorops agassizii* (*Ca*) between the different areas and seasons. The ontogenetic phases of each species are given in parentheses: (1) Juvenile; (2) Sub-adult; (3) Adult. Only biologically significant results are shown ($C > 0.6$).

Season (Area)	**Species(Phase) *x***	**Species(Phase) *i***	**Schoener's Index (*C*)**
Early dry			
Upper	*Cs*(2)	*Cs*(3)	0.63
Middle	*Cs*(2)	*Cs*(3)	0.69
Late dry			
Upper	*Cs*(3)	*Ca*(1)	0.60
	Cs(3)	*Ca*(3)	0.62
Early rainy			
Upper	*Cs*(1)	*Ca*(1)	0.60
	Cs(2)	*Ca*(2)	0.62
	Ca(1)	*Ca*(2)	0.72
Late rainy			
Middle	*Cs*(1)	*Cs*(2)	0.62
	Cs(1)	*Ca*(2)	0.67
	Cs(2)	*Ca*(2)	0.79
Lower	*Cs*(1)	*Ca*(1)	0.64
	Cs(2)	*Ca*(2)	0.64

Capitulo 4

Spatial and seasonal patterns of resources partitioning between sympatric fish species that use nursery habitats along an estuarine ecocline

Spatial and seasonal patterns of resources partitioning between sympatric fish species that use nursery habitats along an estuarine ecocline

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RUNNING HEAD: Diet overlap between sympatric drums.

ABSTRACT: Habitats utilization is related to diet shifts during the life-cycles, and diet analysis of different ontogenetic phases from different habitats provides information about movement patterns between nursery and adult habitats. This study described the seasonal habitat utilization and feeding habits of different ontogenetic phases of *Stellifer brasiliensis* (*Sb*) and *S. stellifer* (*Ss*) along an estuarine ecocline in the Goiana Estuary main channel, and the food overlap when different ontogenetic phases of both species occur together. Seasonal freshwater discharge was important to define the habitat utilization of different ontogenetic phases of these species along the estuarine ecocline. The middle estuary was important as nursery and feeding ground for juveniles, and feeding ground for sub-adults and adults of both species. These species are expected to be zoobenthivorous, but along their life-cycle and between different habitats and seasons, their trophic guild can change to opportunist and/or zooplanktivore. During the late rainy season in the lower estuary all phases of both species, except juveniles of *Sb* and adults of *Ss*, showed a diet overlap indicating similarity in prey utilization. This overlap was influenced by the partition of Calanoida, Polychaeta and Eucarida by all phases of both species. The ingestion of nylon fragments was observed as an environmental problem. Information on feeding habits and habitat utilization by different ontogenetic phases is essential to understand the ecological role of fish populations, critical in the development of conservation and management plans.

KEY WORDS: Diet; Coexistence; Food niche; Ontogenetic phases; Spatial-temporal variability; Fish movement; Nursery role; Water quality.

INTRODUCTION

Estuaries and adjacent coastal waters have high ecological and socio-economic importance to many regions around the tropical and subtropical world (Nagelkerken & van der Velde 2002, Barletta & Blaber 2007, Barletta et al. 2008). Because of their importance to coastal fisheries, studies have addressed many of its functions, *e.g.,* nursery, protection or feeding grounds (Barletta et al. 2010), by approaching the role of various habitats, *e.g.* main channel, mangrove, tidal creeks and seagrass habitats (Faunce & Serafy 2007, Mariani et al. 2011, Ramos et al. 2011, Dantas et al. 2012a) of these ecosystems for fish species (Barletta et al. 2008, Cocheret de la Morinière et al. 2003).

An important ecological function which has been discussed at large is the nursery role of these coastal ecosystems for coral reef fish species, *e.g.* in Curaçao, Caribbean Sea (Nagelkerken et al. 2002, Cocheret de la Morinière et al. 2003), New Caledonia, Southwest Pacific (Mellin et al. 2007), and for estuarine resident fish species in a tropical estuary in Northeast Brazil (Dantas et al. 2012a). The nursery concept is based on the success of the settlement of post-larvae in the nursery habitat where they grow to juvenile and posterior migration of sub-adults from the juvenile nursery to adult habitats (Beck et al. 2003). These life-cycle patterns and movements of fish species in estuaries and adjacent coastal waters are subject to a variety of biotic (*e.g.* predation, larval supply, food availability) and abiotic (*e.g.* salinity, water temperature) factors (Barletta et al. 2005, 2008, Dantas et al. 2010). These patterns and movements can be inferred from the spatial and temporal habitat utilization by the different ontogenetic phases of fish species (Cocheret de la Morinière et al. 2003, Mellin et al. 2007, Dantas et al. 2012a). These habitats utilization could be related to diet shifts during the life-cycle, and the stomach content analysis of the different ontogenetic phases in the different habitats can, therefore, provide information about the movement patterns between the nursery and adult habitats (Cocheret de la Morinière et al. 2003).

On top of habitat and diet shift, another important ecological challenge faced by fish species is to be able to share/compete for resources in a densely populated and frequently variable environment (Mariani et al. 2011). Sympatric species will likely consume slightly different prey to minimize niche overlap (Schoener 1974), and a number of studies tested this hypothesis for fish that inhabiting coastal ecosystems, *e.g.* in a Mediterranean coastal shallow sandy area (Darnaude et al. 2001), in Wilson Inlet, a seasonally open estuary in Western Australia (Platell et al. 2006), and in a tidal inshore habitat (Dublin Bay) in the Irish Sea (Russo et al. 2008). Moreover, competition for food can affect patters of habitat selection, niche overlap and distribution (David et al. 2007, Hilderbrand & Kershner 2004). When food resources are shared, coexistence of fish species has been suggested to be related to selection for different activity patterns or differential use of space (Hesthagen et al. 2004, Sandlund et al. 2010). Moreover, knowledge of feeding habits and habitat utilization by different ontogenetic phases is essential to understand the ecological role of these to fish population and a critical requirement to develop conservation and management plans (Mellin et al. 2007, Teixeira & Cortes 2006).

The sympatric Sciaenidae species *Stellifer brasiliensis* (*Sb*) (Schultz) and *Stellifer stellifer* (*Ss*) (Bloch) are most abundant in warm and shallow inshore waters and over sand or muddy bottoms (Carpenter 2002). These species could be classified as zoobenthivore or zooplanktivore, feeding on small crustaceans, fishes or other invertebrates associated to the substrate or living just above the sediment (Carpenter 2002, Barletta & Blaber 2007). *Stellifer* have high abundance in tropical and subtropical estuaries from the South America Atlantic coast (Barletta et al. 2005, Barletta et al. 2008). Studies in Caeté Estuary, in the tropical-humid region of the eastern Amazon in northern Brazil, showed that species of *Stellifer*, especially *S. rastrifer* (Jordan) and *S. microps* (Steindachner), were the most abundant Scieanidae fishes in terms of density and biomass (Barletta et al. 2005). In the Paranaguá Estuary, in the subtropical–tropical transition region of southern Brazil, Barletta *et al*. (2008) describing the structure of the demersal fish community in relation to seasonal variations of abiotic variables also found that *Stellifer* spp. have a great abundance in terms of density and biomass. Because of their high abundance in tropical estuarine ecosystems, especially as juveniles, *Stellifer* serve as food resources for important ecological and commercial fish that visit the estuary in search for food, *e.g. Trichiurus lepturus* L. (Bittar & Di

Beneditto 2009), *Hexanematichthys proops* (Valenciennes, 1840), *Trachurus symmetricus* (Ayres, 1855) *Merluccius gayi gayi* (Guichenot, 1848), *Carcharhinus porosus* (Ranzani, 1839) and *Pterengraulis atherinoides* (Linnaeus, 1766) (Froese & Pauly 2011).

The objective of this study was to describe the seasonal habitat utilization and feeding habits of different ontogenetic phases of sympatric drum species (*Sb* and *Ss*) along an estuarine ecocline. Moreover, this article investigated how their food niches are shared when the different ontogenetic phases of this two species occur together in the same estuarine habitats.

MATERIALS AND METHODS

Study area. The Goiana Estuary, Northeast Brazil, has a total area of 4700 ha (Fig. 1). The climate is tropical and semi-arid (mean air temperature ~ 25 ºC), with a dry season from September to February (< 50 mm monthly total) and a rainy season from March to August (> 400 mm monthly total). These two seasons can be further divided into early dry (September to November), late dry (December to February), early rainy (March to May) and late rainy (June to August) (Barletta & Costa 2009). This study considered three habitats of the estuary main channel (upper, middle and lower estuary), divided according to the salinity gradient and geomorphology (Fig. 1). The main channel of Goiana Estuary presents a sharp salinity gradient between the upper reaches of the estuary, which have more freshwater input, and the mouth of the estuary (lower estuary), at the coastal marine environment. This change occurs along 20km of river channel, and is largely affected by seasonal rainfall that controls river discharge. This seasonal variation also determines the fluctuation of other abiotic factors in the estuary main channel such as water temperature and dissolved oxygen (Dantas et al. 2010, Dantas et al. 2012a). The characteristics of the estuarine habitats and uses are described in detail by Barletta & Costa (2009).

Sampling methods. Between December 2005 and November 2006, salinity, water temperature (ºC), dissolved oxygen (mg l^{-1}) and Secchi depth (cm) were recorded before trawling for fish sampling. For the fish samples, six replicate trawls were made per month in each estuarine habitat (upper, middle and lower) with an otter trawl net. The net was 8.72 m long with a mesh size of 35 mm in the body and 22 mm in the cod-end. The length of the ground-rope was 8.5 m, and the head-rope was 7.1 m long. To guarantee a representative sample of all the fish sizes, a cover with a smaller mesh-size (5 mm) was used over the cod-end (Barletta et al. 2005, 2008, Dantas et al. 2010).

The position was recorded by GPS before and after net deployment and was used to calculate the swept area. The swept area (A) was calculated from:

$$A = D \text{ x } h \text{ x } X_2 \qquad (1)$$

Where D is the length of the path, h is the length of the head-rope and X_2 is the fraction of the head-rope (h x X_2) that is equal to the width of the path swept by the trawl (Sparre & Venema 1997). Estimations of the density (D) and biomass (B) were made using CPUA (catch per unit area), which was calculated by dividing the catch by the swept area (m^2):

$$D = C_N A^{-1} \text{ (Individuals m}^{-2}\text{)} \qquad (2)$$

$$B = C_M A^{-1} \text{ (g m}^{-2}\text{)} \qquad (3)$$

Where C_N is the catch in number and C_M is the catch in fish mass (Sparre & Venema 1997).

Fish analysis. In the laboratory, each fish was identified (Carpenter 2002), weighed and measured (standard length - cm). Each of the Sciaenidae species (*Sb* and *Ss*) was grouped in different size classes corresponding different ontogenetic stages. Three different size classes were attributed to the captured individuals of the target species. The *Sb* and *Ss* individuals in the samples were divided into juveniles (< 4 cm in standard length), sub-adults (4 – 5 cm in standard length) and adults (> 5 cm in standard length).

Diet analysis. For the diet analysis stomach contents were examined from individuals of each size classes of both species (*Sb* and *Ss*) for each area of the estuary (upper, middle and lower) and for each season (early and late dry; early and late rainy). For this analysis stomachs contents of juveniles (n(*Sb*) = 81; n(*Ss*) = 59), sub-adults (n(*Sb*) = 75; n(*Ss*) = 96) and adults (n(*Sb*) = 174; n(*Ss*) = 84), The items were analysed using a stereomicroscope (Zeiss 50x), and all dietary and non-dietary items, *e.g.* plastics, nylon fragments, were separated. Prey were sorted and identified to the lowest possible taxonomic level. The items found in the stomachs were washed with distilled water, dried with tissue paper and weighed with a precision scale (0.001 g). The quantification of food items ingestion followed three criteria (Hynes 1950, Hyslop 1980):

1. The frequency of occurrence (%F) is expressed the percentage of each prey according to the equation:

$$\%F_i = (F_i / F_t) \times 100 \qquad (4)$$

Where F_i is the number of stomachs containing the food item i and F_t is the total number of stomachs examined. The advantages of the frequency of occurrence method are that, provided food items are readily identitifiable, it is quick and requires the minimum apparatus (Hyslop 1980);

2. The percent of prey abundance in numbers (%N) according to the equation:

$$\%N_i = (N_i / N_t) \times 100 \qquad (5)$$

Where N_i is the numbers of food item i and N_t is the total number of food item in the stomachs examined. The numerical method is relatively fast and simple to operate providing identification of prey items is feasible (Hyslop 1980);

3. The percent of prey abundance in weight (%W) according to the equation:

$$\%W_i = (W_i / W_t) \times 100 \qquad (6)$$

Where W_i is the weights of food item i and W_t is the total weight of food item in the stomachs examined. The volumetric techniques (weight) probably give the most representative measure of bulk and may be applied to all food items (Hyslop 1980).

It seems realistic to base assessment of dietary importance upon these unrelated methods, and indices combining values from different sources are more representative (Hyslop 1980). Such a measure is the Index of Relative Importance (IRI) (Pinkas et al. 1971, Prince 1975) which incorporates frequency of occurrence ($\%F_i$), percentage by number ($\%N_i$) and percentage by weight ($\%W_i$) expressed by the equation:

$$IRI_i = \%F_i \times (\%N_i + \%W_i) \qquad (7)$$

This index was expressed in percentage of each prey according to the following equation proposed by Pinkas et al. (1971) and Prince (1975):

$$\%\mathrm{IRI} = 100 \times \mathrm{IRI} \,/ \sum_{i=1}^{n} \mathrm{IRI} \tag{8}$$

Where n is the total number of categories of food items (Cortés 1997). The tables with the results of the frequency of occurrence (%F), percent abundance (%N), percent weight (%W) and the percentage of the index of relative importance (%IRI) were presented in the Appendix 1, 2, 3 and 4.

In addition, Schoener's index (C) was used to evaluate food niche overlap between the different size classes of *Stellifer* spp. (Schoener 1970). The index was calculated following the equation:

$$C = 1 - 0.5 \left(\sum | W_{xi} - W_{yi} |\right) \tag{9}$$

Where W_{xi} is the mean proportion of the biomass of food item i used by the specific size classes of *Stellifer* sp. x and W_{yi} is the mean proportion of biomass of food item i used by the specific size classes of *Stellifer* sp. y (Wallace 1981). Zero values indicate no overlap, while 1 indicates complete overlap. The index value is generally considered biologically significant when it exceeds 0.6 (Wallace 1981).

Statistical analysis. Factorial ANOVA (STATISTICA 8® software) was used to test differences in distribution (density and biomass) of the *Sb* and *Ss* size classes in relation to the factors "area" (upper, middle and lower estuary) and "season" (early and late dry, early and late rainy). Moreover, ANOVA was used to test differences in the number and weight of each category of food item for each species in relation to the same factors. To perform the analyses, some food items were grouped in a major group due to their low occurrence in the diet. Crabs and shrimps were grouped in the Superorder Eucarida, Bivalves, Gastropods and Cephalopods were grouped in the Phylum Mollusca and Gammaridea and Corophiidea were grouped under Order Amphipoda. Box-Cox transformation was performed to increase the normality of the data (Box-Cox 1964). Levene's test was used to check the homogeneity of the variances. Whenever significant differences were detected, the Bonferroni test was used *a posteriori* (Quinn & Keough 2003). Canonical Correspondence Analysis (CCA) (CANOCO for Windows 4.5) was performed (ter Braak & Smilauer 2002) to observe ecological correlations between the size classes (dependent variables) and environmental conditions (independent variables). To perform the CCA, a multiple least-squares regression was computed with the site scores (derived from weighted averages of both species and of the groups) as the dependent variables and the environmental parameters as the independent variables (ter Braak 1986, Palmer 1993). The densities of the different size classes of *Sb* and *Ss* were analysed to extract patterns of variation in relation to environmental variables (direct gradient analysis). Moreover, CCA was performed with the index of relative importance (%IRI) of the ingested prey items of each Sciaenidae species for each area and season to extract patterns of diet variation in relation to environmental data. These analyses focused on symmetric and biplot scaling. A Monte Carlo Permutation Test was used to determine which environmental variables were significant to the variability of the dependent variable. An ordination diagram was computed (Triplots: with environmental variables). The positions of the density values, and %IRI of the ingested food items, of groups of both species and sites in each season were represented by different geometric shapes.

Environmental variables (rainfall, salinity, water temperature, dissolved oxygen and Secchi depth) were represented by vectors.

RESULTS

Environmental variables

The upper estuary was characterized principally by low salinity values (0 – 8) all year, but especially during the rainy season (March to August) (Fig. 2a, b). During the dry season the salinity values in the middle estuary ranged from 8 to 17, and during the rainy season 0 to 6 (Fig. 2b). Despite seasonality, the lower estuary always showed the highest salinities values throughout the year (8 – 36).

Water temperature showed a seasonal trend, with the highest values (27 – 31 ºC) during the dry season and lowest (26 – 27 ºC) during the late rainy season (Fig. 2c). Dissolved oxygen showed the highest values in the lower estuary (5.0 – 7.9 mg l^{-1}), whereas the upper and middle estuaries presented the lowest values (3.0 – 5.1 mg l^{-1} and 1.1 – 5.2 mg l^{-1}, respectively) (Fig. 2d). The highest values of Secchi depth was observed during the dry season in all areas (39 – 171 cm) and the lowest values during the rainy season (14 – 108 cm) (Fig. 2e).

Spatial-temporal patterns of ontogenetic phases and its diet shifts

The total mean density and biomass in the main channel was 0.004 ind m^{-2} and 0.044 g m^{-2} for *Sb*, and 0.013 ind m^{-2} and 0.024 g m^{-2} for *Ss*, respectively (Table 1). Moreover, significant interactions (season *vs.* area) were observed for the total mean density ($p < 0.05$) and biomass ($p < 0.01$) for *Sb*, with the highest density (0.06 ind m^{-2}, $p < 0.01$) in the middle, and biomass (0.39 g m^{-2}, $p < 0.01$) in the upper estuary, during the late rainy season (Fig. 3a, Table 2). For *Ss* the total mean density ($p < 0.01$) and biomass ($p < 0.05$) differed significantly for the factors area and season, with the highest abundance (0.51 ind m^{-2} and 0.48 g m^{-2}) observed during the late rainy season in the middle estuary (Fig. 4a, Tables 2).

The density and biomass of juveniles differed significantly ($p < 0.01$) for the factors area and season for *Sb*, with the highest values (0.02 ind m^{-2} and 0.008 g m^{-2}, respectively) observed in the middle estuary during the late rainy season (Fig. 3b, Tables 2). Moreover, significant interaction (season *vs.* area, $p < 0.05$) was observed for the biomass of *Sb* juveniles (Table 2). Significant interactions were also detected for the ingestion of the main prey items of *Sb* juveniles in the middle estuary: Calanoida in weight (season *vs.* area, $p < 0.01$), with the highest ingestion (81 ind and 1 mg, $p < 0.01$) observed during the early rainy season, and Cumacea in number and weight (season *vs.* area; season *vs.* size class, $p < 0.01$), with the highest ingestion (3.8 ind and 0.1 mg, $p < 0.01$) during the late rainy season (Figs. 5 & 6, Table 3). During the rainy season, Polychaeta in weight (middle estuary), Calanoida (all areas) and Cumacea (middle estuary) in number and weight, were important preys for *Sb* juveniles (Appendix 1 & 2). Nylon fragments were found in the stomach contents of *Sb* juveniles, especially in the lower estuary during the late rainy season (Figs. 5 & 6, Appendix 1 & 2). For *Ss* juveniles the density ($p < 0.05$) and biomass ($p < 0.01$) differed significantly among seasons, with highest values (0.37 ind m^{-2} and 0.19 g m^{-2}, respectively) observed in the middle estuary during the late rainy season (Fig. 4b, Table 2). Calanoida was the most important prey in number and weight for *Ss* juveniles (early and late rainy seasons) in the middle and lower estuary, with the highest ingestion of this item by this juveniles (16 ind and 0.5 mg) observed during the late rainy season in the lower estuary (Figs. 7 & 8, Appendix 3 & 4). Moreover, Polychaeta and Eucarida (late rainy season) in the middle and lower estuary, and Amphipoda (early rainy season) in the middle, were also important prey items in weight for *Ss* juveniles (Appendix 3 & 4). For this phase of *Ss*, was observed the ingestion of nylon fragments in the middle estuary during the rainy season (Figs. 7 & 8, Appendix 3 & 4).

Sb sub-adults showed significant interactions for the variables density and biomass (season *vs.* area, $p < 0.05$), and the highest values (0.023 ind m^{-2} and 0.037 g m^{-2}, respectively) were observed in the middle estuary during the late rainy season ($p < 0.01$) (Fig. 4c, Table 2). For this phase of *Sb*, the main prey items ingested were Polychaeta, Eucarida (early and late rainy season) and Amphipoda (early rainy season) in the middle estuary, and Calanoida (early and late rainy season) in all areas of the estuary (Figs. 5 & 6, Appendix 1 & 2). Nylon fragment were ingested by *Sb* sub-adults in the lower estuary during the late rainy season (Figs. 5 & 6, Appendix 1 & 2). For sub-adults of *Ss* significant differences were detected among seasons ($p < 0.01$), for the variables density, and among season ($p < 0.01$) and area ($p < 0.05$), for biomass, with the highest values (0.13 ind m^{-2} and 0.24 g m^{-2}) observed in the middle estuary during the late rainy season (Fig. 4c, Tables 2). *Ss* showed significant interactions (season *vs.* area) for the ingestion in number of Polychaeta ($p < 0.05$), with the highest ingestion (1.6 ind) observed in sub-adults in the middle estuary during the late dry season (Fig. 7, Table 3). For *Ss* sub-adults, Polychaeta (early and late dry seasons) and Eucarida (late rainy season) were important prey items in weight, and Calanoida was important in number and weight (early-late dry and late rainy seasons) in the middle and lower estuary (Figs. 7 & 8, Appendix 3 & 4). Moreover, Amphipoda (early and late dry seasons) and Actinopterygii (late rainy season) were important, in weight, in the middle and lower estuary, respectively (Figs. 7 & 8, Appendix 3 & 4). Nylon fragments were ingested by this phase of *Ss* in the middle and lower estuary during the dry and late rainy season (Figs. 7 & 8, Appendix 3 & 4).

The *Sb* adults showed significant interactions (season *vs.* area, $p < 0.01$) for the variable biomass (Table 2). Moreover, the highest density values (0.018 ind m^{-2}, $p < 0.01$) were observed during the late rainy season in the middle estuary, and biomass (0.37 g m^{-2}, $p < 0.01$) during early rainy season in the upper estuary (Fig. 3d, Table 2). For *Sb* significant interactions were also observed for the ingestion of Polychaeta (season *vs.* area *vs.* size class, $p < 0.01$), in number and weight, and for Amphipoda (season *vs.* area, $p < 0.05$) and Eucarida (season *vs.* area *vs.* size class, $p < 0.05$) in number (Table 3). The highest ingestion of Polychaeta (2.3 ind and 15.6 mg, $p < 0.05$) was observed in the adults during the rainy season in the upper estuary (Figs. 4 & 5, Table 3). Moreover, Amphipoda was ingested specially by *Sb* adults (3.8 ind and 5.7 mg, $p < 0.05$) during the early rainy season in the middle estuary (Figs. 4 & 5, Table 3). The highest ingestion of Eucarida was observed in adults (1 ind and 38.2 mg, $p < 0.01$) during the late dry season in the middle estuary (Figs. 4 & 5. Table 3). Polychaeta (early and late dry) was also important, in number and weight, in the middle, Amphipoda (early and late dry seasons) in the upper, and Eucarida (early and late rainy seasons) in the lower estuary (Appendix 1 & 2). Calanoida (early and late rainy season) was an important prey in number for *Sb* adults in all areas of the estuary (Appendix 1, 2). The ingestion of nylon fragments in number (size class, $p < 0.01$) and weight (season, $p < 0.05$), by *Sb* showed significant differences, with the highest ingestion observed in adults (0.27 ind and 0.01 mg) during the late rainy season in the lower estuary (Figs. 5 & 6, Table 3).

The adults of *Ss* showed significant differences among area ($p < 0.05$) for the variable biomass, with the highest values (0.09 g m^{-2}) observed in the middle estuary during the early dry season (Fig. 4d, Tables 2). Moreover, *Ss* showed significant interactions (season *vs.* area) for the ingestion in number and weight of Amphipoda ($p <$

0.01 and $p < 0.05$, respectively) and Eucarida ($p < 0.05$), and for the ingestion in weight of Calanoida ($p < 0.01$) (Table 3). Significant interactions (area *vs.* size class) were also observed for the ingestion of Actinopterygii in number ($p < 0.01$) and Amphipoda in weight ($p < 0.05$) by *Ss* (Table 2). The ingestion of Calanoida, in number and weight, showed significant differences between seasons ($p < 0.05$), with the highest values (37.7 ind and 1.7 mg) observed in adults during the late rainy season in the lower estuary (Figs. 7 & 8, Table 3). For the number of Amphipoda ingestion by *Ss*, significant differences were observed between season ($p < 0.05$) and area ($p < 0.01$), while the ingestion in weight of this item showed significant differences ($p < 0.01$) between areas (Tables 2). The highest ingestion of Amphipoda was observed in adults (0.6 ind and 0.2 mg) during the early dry season in the middle estuary (Figs. 7 & 8). Significant differences ($p < 0.01$) were observed for the ingestion of Actinopterygii in number for the factors area and size class, with the highest values observed in adults during the late rainy season in the middle estuary (1.1 ind and 24.8 mg) (Figs. 7 & 8, Table 2). Moreover, Polychaeta (late dry season) in the middle estuary, Actinopterygii (all seasons in the upper and middle, and Eucarida (all seasons) in all areas of the estuary, were important for *Ss* adults in relation to the weight of prey ingested (Fig. 8, Appendix 3 & 4). Calanoida was also important for adults in number (early-late dry and early rainy season) in all areas of the estuary (Appendix 3 & 4). The ingestion of nylon fragments by *Ss* showed significant differences in number and weight for the factor area ($p < 0.01$), with the highest ingestion observed in adults (0.4 ind and 0.04 mg) during the late rainy season in the middle estuary (Figs. 7 & 8, Table 2).

Influence of environmental variables on the distribution patterns of ontogenetic phases and its diet overlaps

The canonical correspondence analysis (CCA) was performed to determine the influence of environmental gradients on the distribution (Fig. 9) of the different ontogenetic phases of *Sb* and *Ss* in the main channel of Goiana Estuary and on its diet shifts (Fig. 10). The first axis showed a positive correlation with water temperature ($p < 0.05$), and a negative correlation with rainfall ($p < 0.01$) (Fig. 9, Table 4). The first axis explained (59.5%) the seasonality of the water temperature and rainfall and the second (32.1%) the distribution of the ontogenetic phases of *Sb* and *Ss* along the main channel of the estuary (Fig. 9). Juveniles of *Sb* and *Ss* showed a strong correlation to sites with low salinity (1.9 ± 1.4) and high temperature levels (27 ± 1.1 ºC) in the middle estuary, principally during the rainy season (Fig. 9). During this time, *Sb* juveniles showed correlations with the ingestion of Calanoida, Cumacea and nylon fragments in all areas of the estuary (Fig. 10a), while *Ss* juveniles were correlated with Calanoida in the middle and lower estuary, and Eucarida (late rainy season) in the lower estuary (Fig. 10b). For *Sb* the first axis explained (40.5 %) the seasonality of salinity and rainfall and the second (36.7%) the distribution of the species along the ecocline and its diet shifts (Fig. 10a). The first axis showed a positive correlation with salinity and secchi depth ($p < 0.05$), and a negative correlation with rainfall ($p < 0.01$) (Fig. 10a, Table 5).

Sub-adults and adults of *Sb* showed correlations with sites with very stressfull conditions in the upper estuary during the rainy season, were very low salinity (0.0 ± 0.02) and high temperature values (27 ± 0.9 ºC) prevailed. During this period, *Sb* sub-adults and adults were correlated with the ingenstion of Calanoida, Cumacea and nylon fragments in al areas of the estuary (Fig. 10a). Although, during the dry season, *Sb* adults were correlated with Eucarida in the lower, and Polychaeta, Mollusca and

Amphipoda in the upper and middle estuary (Fig. 10a). Sub-adults of *Ss* were correlated with sites with high salinity (13.4 ± 5.4) and temperature values (28 ± 2.0 ºC) in the lower estuary during the rainy season (Fig. 9). Adults of *Ss* were correlated with sites with high salinity (11.9 ± 3.7) and temperature levels (29 ± 0.8 ºC) in the middle estuary during the dry season (Fig. 9). During this time, *Ss* sub-adult and adults showed correlation with Polychaeta in the middle estuary (Fig. 10b). Moreover, sub-adults showed correlation with Calanoida (midde and lower estuary) and Eucarida (lower estuary) during the late rainy season (Fig. 10b). *Ss* adults showed correlation with Eucarida (lower estuary) during the same period, and with Actinopteyrii and nylon fragment (upper and middle estuary) durin the late dry, and with Amphipoda (middle estuary) during the early dry season (Fig. 10b).

The CCA showed correlation with the habitat use and diet preferences among some phases of both species, and these preferences were correlated to the seasonality (rainfall, water temperature and salinity). The dietary analyses showed high values of diet overlap principally during the late rainy season (Table 6). During this time, in the upper estuary, nich overlap was observed between juveniles and sub-adults (*C* = 0.80), and between sub-adults and adults (*C* = 0.71) of *Sb* (Table 6). In the middle estuary, juveniles and sub-adults (*C* = 0.69), sub-adults and adults (*C* = 0.63) of *Sb*, and juveniles and sub-adults (*C* = 0.79) of *Ss* showed remarkable similarity in their prey utilization (Table 6). Moreover, at this time, all phases of both species, except between juveniles of *Sb* and adults of *Ss*, showed high values of Schoener Index (*C* = 60 – 91) in the lower estuary (Table 6). This indicates a high similarity in the prey utilization by all phases of both species during the late rainy in the lower estuary. During the early dry season in the middle estuary sub-adults and adults of *Ss* showed a remarkable similarity in their prey utilization (*C* = 0.76) (Table 6). During the early rainy season in the middle estuary, *Sb* sub-adults and adults (*C* = 0.68), and juveniles of *Sb* and *Ss* (*C* = 0.70) showed high similarity in their prey utilization (Table 6).

Discussion

The study of the feeding habits and resource partitioning in closely related fish species can be very useful to understand the energy flows throughout the food web (Darnaude 2001). It also provides important insights into the trophic flexibility of sympatric species (Platell et al. 2006, Russo et al. 2008). Moreover, the patterns of prey overlap and resource partitioning between species in estuarine habitats vary depending on the specific system studied (Mariani et al. 2011). In the present study it was clear that the prey selection by the two predator species vary according to each habitat, season and ontogenetic phase. The food niche partitioning was strongly influenced by the environmental fluctuations resulting from rainfall. Seasonality, principally during the rainy season, influenced the distribution of both species along the estuarine ecocline and consequently their habitat utilization for each ontogenetic phase. Seasonal variations on environmental conditions play a significant role in the specialised use of a habitat, *e.g.* as nursery and feeding grounds for fish species (Beck et al. 2003; Mellin et al. 2007). Moreover, salinity appears to have the strongest effect on site-specific variation in the nursery function of an estuarine habitat (Beck et al. 2003, Dantas et al. 2012a). In the Goiana Estuary the nursery function of habitats shifts according to the seasonal fluctuation of environmental conditions (salinity and dissolved oxygen) for demersal catfishes, and each species responds differently to this change (Dantas et al. 2012a). The distribution of *Sb* and *Ss* in the main channel of this estuary showed significant correlation with the variables rainfall and water temperature. This indicates that the seasonal freshwater discharge was important to define habitat utilization by the different ontogenetic phases of these species along the estuarine ecocline (Barletta et al. 2005, 2008, Barletta & Blaber 2007). During the early dry seasons adults of both species utilized the middle estuary for feeding. In the late dry season, only adults of *Sb* were observed in the upper estuary, while adults of *Ss* remained in the middle estuary. During the late rainy season, adults of both species were observed in the middle and lower estuary. Juveniles and sub-adults of *Sb* were observed from the rainy season, especially in the middle estuary. These phases of *Ss* were observed in the middle estuary during the late rainy season. These results indicates that the middle estuary had great importance as nursery and feeding ground for juveniles, and feeding ground for sub-adults and adults of both drum species.

Both species were classified as hyperbenthophagous, feeding predominantly on invertebrates associated with the substratum (Barletta & Blaber 2007). However, along the ontogenetic phases and between the different habitats and seasons, this trophic guild have changed for both species, and according Elliot et al. (2007) they can be classified as opportunists or even zooplanktivores. The types of food consumed by estuarine resident or estuary-associated fish species change markedly with growth (Elliot et al. 2007). In north Brazilian mangrove creeks the wingfin anchovy *Pterengraulis atherinoides* (L.) showed a marked variation in food selection with growth, with a predominantly zooplanktivore preference by smaller sizes and a piscivore preference by the larger predator sizes (Krumme et al. 2005). Thus, it is expected that some groups of species will move from one trophic guild to another during their life (Elliot et al. 2007). In the present study, juveniles of both species showed a zooplanktivore diet preference, feeding mainly Calanoida in all habitats. During the late rainy season the trophic guild of these juveniles changes from essentially zooplanktivore to zoobenthivore, including small invertebrates in their diet (Polychaeta and Eucarida in the middle and lower estuary, respectively) that live just above the sediment (hyperbenthos). The *Sb* sub-adults showed a zooplanktivore preference, feeding essentially on Calanoida during the rainy season in all areas of the estuary. However, Polychaeta (upper and middle estuary) and Gammaridea (middle estuary) were important items in weight during the rainy season. Sub-adults of *Ss* showed a zoobenthivore preference, with a high contribution in weight of the food items Polychaeta and Eucarida in the middle estuary during the dry season, and Actinopterygii in the lower estuary during the late rainy season. Adults of *Sb* could be considered an integral zoobenthivore, feeding mainly on Polychaeta (upper and middle) and Eucarida (middle and lower). Adults of *Ss* were more opportunists, feeding on a diverse range of preys (Eucarida, Actinopterygii, Amphipoda and Calanoida).

Moreover, the ingestion of blue nylon fragments by *Sb* and *Ss* was observed as an environmental problem during this study. All phases of both species presented some contamination by this pollutant. For *Ss* the highest ingestion of nylon fragments was observed in adults in the middle estuary during the late rainy season and for *Sb* in adults and juveniles during the same period in the upper estuary. The ingestion of fragments of nylon threads by fish is a demonstrated form of pollution in the Goiana Estuary (Possatto et al. 2011, Dantas et al. 2012b). The physiological and toxicological consequences of the ingestion of this type of debris are unknown, as is the actual extent of the problem worldwide (Dantas et al. 2012b).

Another important ecological event observed was that, although they are occurring in the same habitat, a high degree of competition for resources between the two species was not observed, except during the late rainy season in the lower estuary. During this time, all phases of both species, except juveniles of *Sb* and adults of *Ss*, showed a large diet overlap indicating a high similarity in prey utilization. This overlap was characterized by the high consumption of Calanoida, Polychaeta, and Eucarida by all phases of both species. Calanoida was important in relation to the number of consumed prey for all phases of both species. But in relation to the weight of prey ingested, this item was important only for juveniles and sub-adults of both species during the rainy season. During the early dry season *Ss* sub-adults and adults showed a diet overlap when utilizing resources from the middle estuary, as shown by the ingestion of Eucarida, Polychaeta and Corrophiidea. During the early rainy season in the middle estuary sub-adults and adults of *Sb* fed mainly on Calanoida, Polychaeta and Gammaridea, showing a remarkable diet overlap. During this time, also in the middle estuary, juveniles of both species showed overlap in their diet by feeding mainly on Calanoida and Polychaeta.

Sympatric species consume slightly different prey to minimize niche overlap (Schoener 1974), and a number of studies tested this hypothesis for fish that inhabiting coastal ecosystems (Darnaude et al. 2001, Platell et al. 2006, Russo et al. 2008). In the present study, the different ontogenetic phases of *Sb* and *Ss* were observed consuming different prey during the dry season and early rainy season in all areas of the estuary, minimizing the niche overlap and increasing the efficiency in obtaining food. In all estuary-dependent fish there are ontogenetic shifts and therefore species might change guilds during their life-cycle, especially with respect to feeding. The knowledge of feeding habits and habitat utilization by different ontogenetic phases is essential to understand the ecological role of fish populations and to provide means to identify key habitats to be considered as priority sites in the development of conservation and management plans.

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Figures and Tables Captions

Fig. 1. Goiana Estuary. ⬚= upper (1), middle (2) and lower (3) estuaries, where the samples were taken with an otter trawl net.

Fig. 2. Monthly total rainfall (a) and mean (± standard deviation) salinity (b), water temperature (c), dissolved oxygen (d), and Secchi depth (e) in the upper (○), middle (□) and lower (Δ) Goiana Estuary between December 2005 and November 2006.

Fig. 3. Mean (+ standard error) density (ind m^{-2}) and biomass (g m^{-2}) of the different size classes of *S. brasiliensis* in each season (early dry, late dry, early rainy and late rainy) at three areas of the Goiana Estuary (upper, middle and lower estuary). (a) juvenile; (b) sub-adult; (c) adult and (d) total. Total = total density and biomass of all size classes.

Fig. 4. Mean (+ standard error) density (ind m^{-2}) and biomass (g m^{-2}) of the different size classes of *S. stellifer* in each season (early dry, late dry, early rainy and late rainy) at three areas of the Goiana Estuary (upper, middle and lower estuary). (a) juvenile; (b) sub-adult; (c) adult and (d) total. Total = total density and biomass of all size classes.

Fig. 5. Mean (+ standard error) of number of prey items ingested by the different size classes of *S. brasiliensis* in each season (early dry, late dry, early rainy and late rainy) at three areas of the Goiana Estuary (upper, middle and lower estuary). Juveniles (black square); sub-adults (red square); adult (white square).

Fig. 6. Mean (+ standard error) of weight (mg) of prey items ingested by the different size classes of *S. brasiliensis* in each season (early dry, late dry, early rainy and late rainy) at three areas of the Goiana Estuary (upper, middle and lower estuary). Juveniles (black square); sub-adults (red square); adult (white square).

Fig. 7. Mean (+ standard error) of number of prey items ingested by the different size classes of *S. stellifer* in each season (early dry, late dry, early rainy and late rainy) at three areas of the Goiana Estuary (upper, middle and lower estuary). Juveniles (black square); sub-adults (red square); adult (white square).

Fig. 8. Mean (+ standard error) of weight (mg) of prey items ingested by the different size classes of *S. stellifer* in each season (early dry, late dry, early rainy and late rainy) at three areas of the Goiana Estuary (upper, middle and lower estuary). Juveniles (black square); sub-adults (red square); adult (white square).

Fig. 9. Canonical correspondence analysis triplots for the density (ind m^{-2}) of different size classes of *S. brasiliensis* and *S. stellifer* in the three areas (upper, middle and lower) of the main channel of Goiana Estuary in each season: (early dry; late dry; early rainy; late rainy. (Δ) Species *S. brasiliensis* (*Sb*) and *S. stellifer* (*Ss*), and size classes (Juv: juveniles; Sub: sub-adults; Ad: adults). (○) Season (ED: early dry; LD: late dry; ER: early rainy; LR: late rainy) and area (U: upper; M: middle; L: lower) were represented by points and the environmental variables (rainfall, salinity, water temperature, dissolved oxygen and Secchi depth) were represented by arrows.

Fig. 10. Canonical correspondence analysis triplots for the index of relative importance (%IRI) of prey items ingested by the different size classes of (a) *S. brasiliensis* and (b) *S. stellifer* in the three areas (upper, middle and lower) of the main channel of Goiana Estuary in each season (early dry; late dry; early rainy; late rainy. (Δ) Prey items (*Poly*: Polychaeta; *Calan*: Calanoida; *Cumac*: Cumacea; *Eucar*: Eucarida; *Amphip*: Amphipoda; *Mollus*: Mollusca; *Actino*: Actinopterygii; *Nylon*: Nylon). (○) Season (ED: early dry; LD: late dry; ER: early rainy; LR: late rainy), area (U: upper; M: middle; L: lower) and size classes (1: juvenile; 2: sub-adult; 3: adult) were represented by points and the environmental variables (rainfall, salinity, water temperature, dissolved oxygen and Secchi depth) were represented by arrows.

Table 1. Total density (ind m^{-2}) and biomass (g m^{-2}); density (ind m^{-2}) and biomass (g m^{-2}) for each area (upper, middle and lower) and size classes of *S. brasiliensis* and *S. stellifer* in the Goiana Estuary.

Table 2. Summary of the ANOVA (*F-values*; df: degree of freedom; *p-value* and *Post-hoc* comparisons) for significant results for total (and components) density (ind m^{-2}) and biomass (g m^{-2}) for different size classes of *S. brasiliensis* and *S. stellifer* for the factors season and area. Differences among factors were determined by Bonferroni's Test *post hoc* comparisons (italics and bolds indicate homogeneous groups). ED: early dry season; LD: late dry season; ER: early rainy season; LR: late rainy season; Areas of the Goiana Estuary (U: upper; M: middle; L: lower). (**$p < 0.01$; *$p < 0.05$).

Table 3. Summary of the ANOVA (*F-values*, df: degree of freedom. *p-value* and *Post-hoc* comparisons) for significant results for prey items (number and weight (mg)) for different

size classes of *S. brasiliensis* and *S. stellifer* for the factors season, area and size class. Differences among factors were determined by Bonferroni's Test *post hoc* comparisons (italics and bolds indicate homogeneous groups). ED: early dry season; LD: late dry season; ER: early rainy season; LR: late rainy season; Areas of the Goiana Estuary (U: upper; M: middle; L: lower); J: juveniles; S: sub-adults; A: adults. (**$p < 0.01$; *$p < 0.05$).

Table 4. Summary of canonical correspondence analysis using five environmental parameters (rainfall, salinity, water temperature, dissolved oxygen and Sechhi depth) and density (ind m^{-2}) of *S. brasiliensis* and *S. stellifer* different size classes (juvenile, sub-adult and adult) in the Goiana Estuary main channel. Correlations with environmental variables are presented. (** $p < 0.01$; * $p < 0.05$).

Table 5. Summary of canonical correspondence analysis using five environmental parameters (rainfall, salinity, water temperature, dissolved oxygen and Sechhi depth) and the index of relative importance (%IRI) of prey items ingested by the different size classes of *S. brasiliensis* and *S. stellifer* different size classes (juvenile, sub-adult and adult) in the Goiana Estuary main channel. Correlations with environmental variables are presented. (** $p < 0.01$; * $p < 0.05$).

Table 6. Diet overlap (Schoener's index "*C*") among different size classes of *S. brasiliensis* (Sb) and *S. stellifer* (Ss) between the different areas and seasons. The ontogenetic phases of each species are given in parentheses: (1) Juvenile; (2) Sub-adult; (3) Adult. Only biologically significant results are shown ($C > 0.6$).

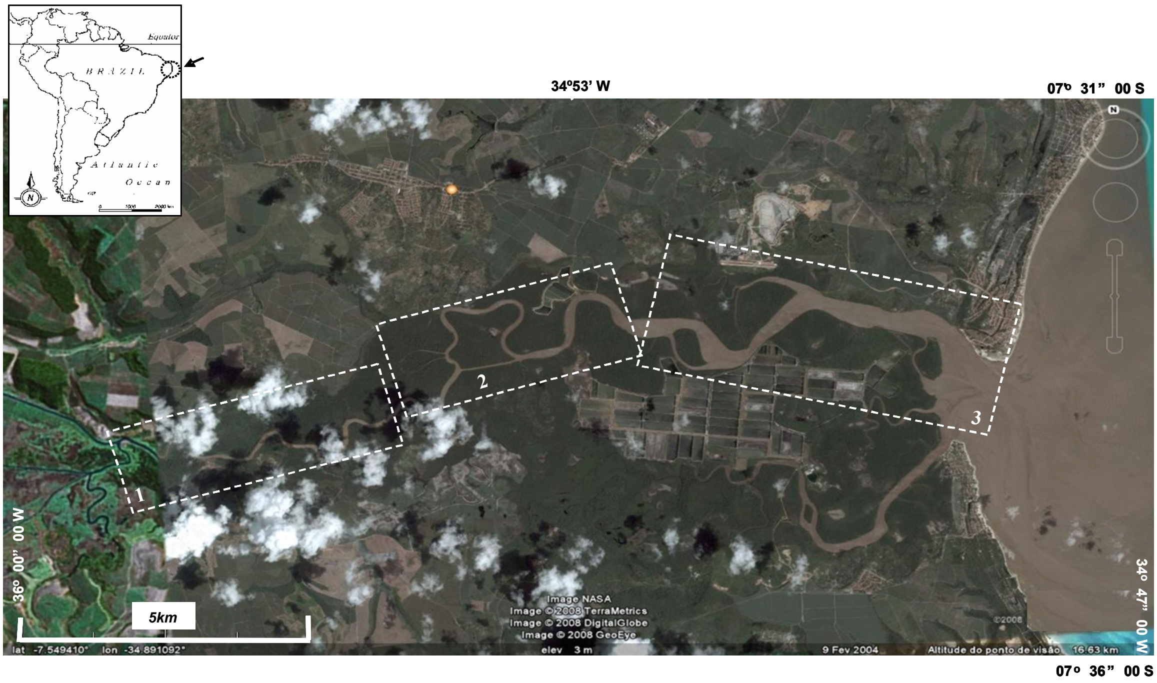

Equator
BRAZIL
Atlantic Ocean
34º53' W
07º 31" 00 S
1
2
3
36º 00" 00 W
34º 47" 00 W
5km
Image NASA
Image © 2008 TerraMetrics
Image © 2008 DigitalGlobe
Image © 2008 GeoEye
9 Fev 2004
07º 36" 00 S

Figure 1.

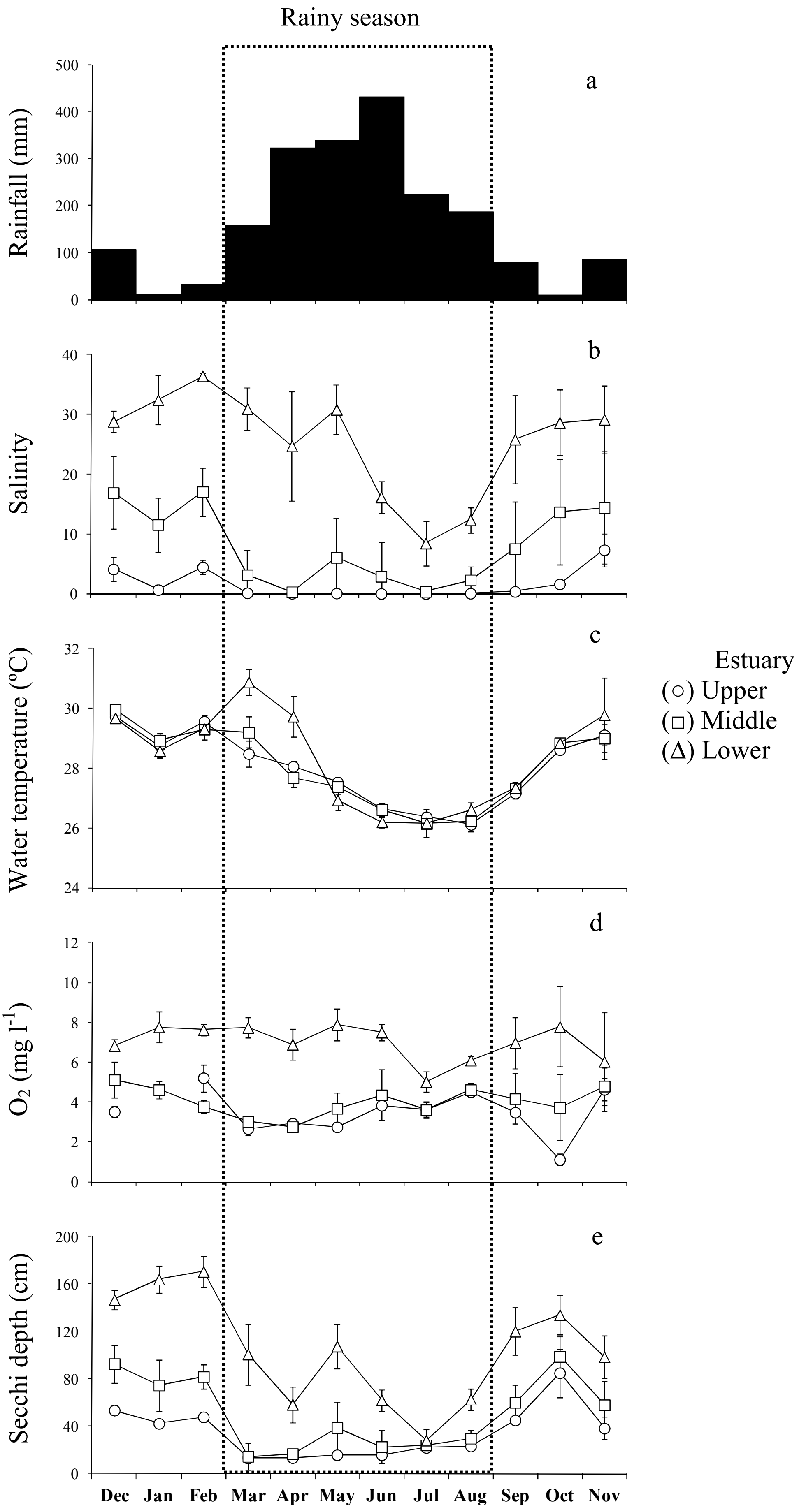

Rainy season
a
Rainfall (mm)
0
100
200
300
400
500
b
Salinity
0
10
20
30
40
c
Water temperature (ºC)
24
26
28
30
32
Estuary
(○) Upper
(□) Middle
(Δ) Lower
d
O$_2$ (mg l^{-1})
0
2
4
6
8
10
12
e
Secchi depth (cm)
0
40
80
120
160
200
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov

Figure 2.

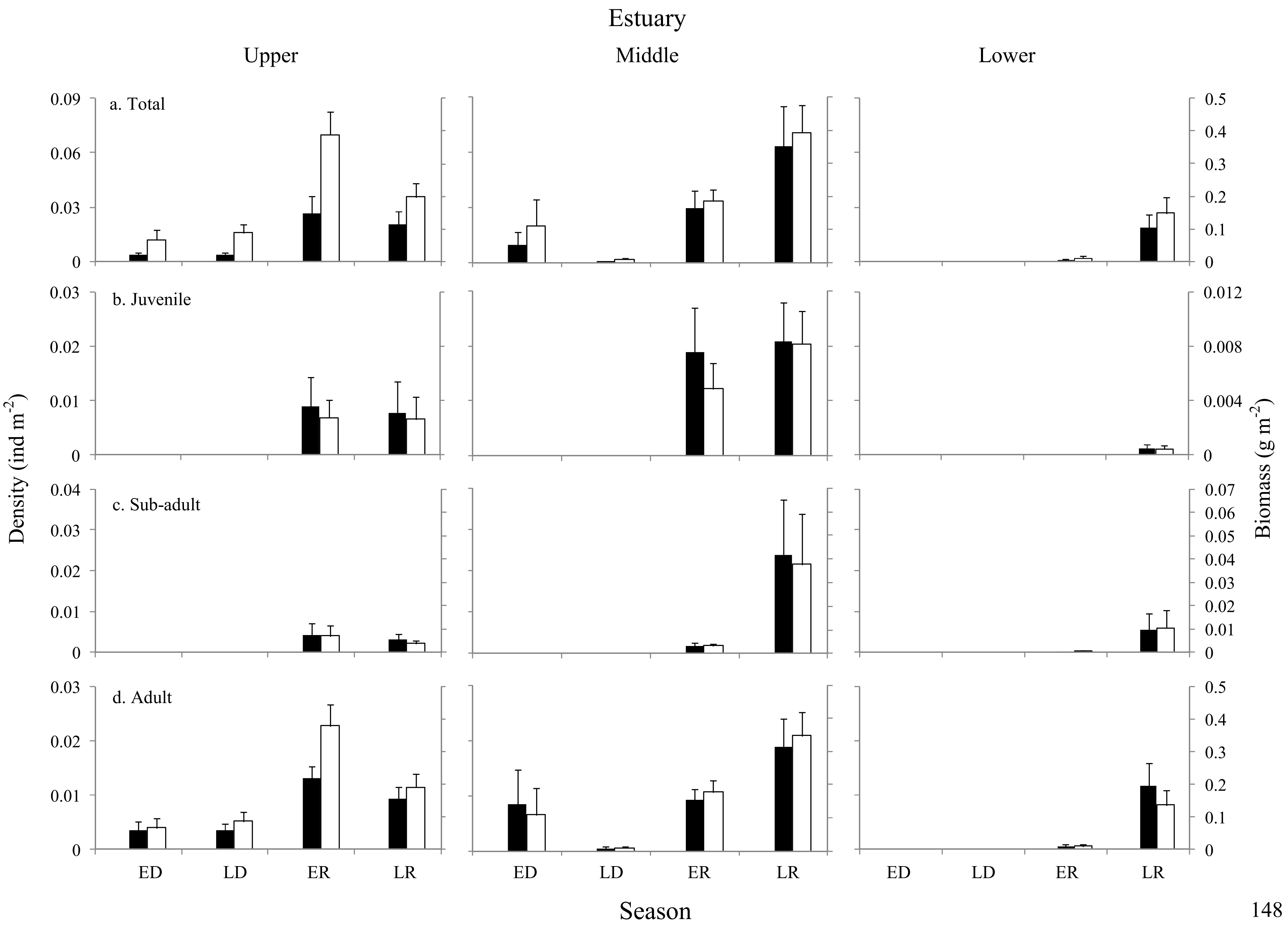

Estuary
Upper
Middle
Lower
a. Total
b. Juvenile
c. Sub-adult
d. Adult
Density (ind m-2)
Biomass (g m-2)
0.09
0.06
0.03
0
0.03
0.02
0.01
0
0.04
0.03
0.02
0.01
0
0.03
0.02
0.01
0
0.5
0.4
0.3
0.2
0.1
0
0.012
0.008
0.004
0
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0.5
0.4
0.3
0.2
0.1
0
ED
LD
ER
LR
Season

Figure 3.

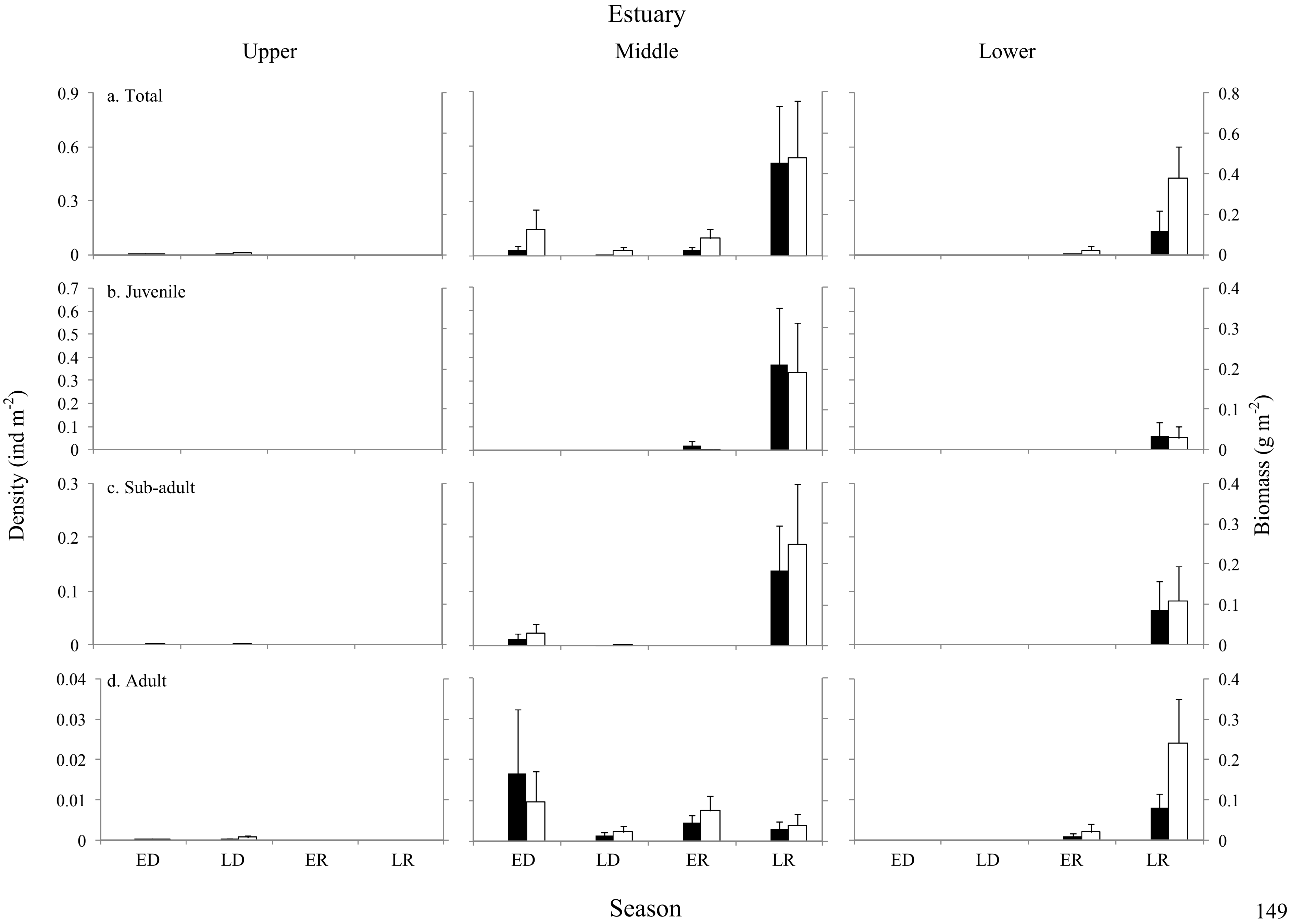

Estuary
Upper
Middle
Lower
a. Total
b. Juvenile
c. Sub-adult
d. Adult
Density (ind m^{-2})
Biomass (g m^{-2})
0.9
0.6
0.3
0
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.3
0.2
0.1
0
0.04
0.03
0.02
0.01
0
0.8
0.6
0.4
0.2
0
0.4
0.3
0.2
0.1
0
0.4
0.3
0.2
0.1
0
0.4
0.3
0.2
0.1
0
ED
LD
ER
LR
ED
LD
ER
LR
ED
LD
ER
LR
Season

Figure 4.

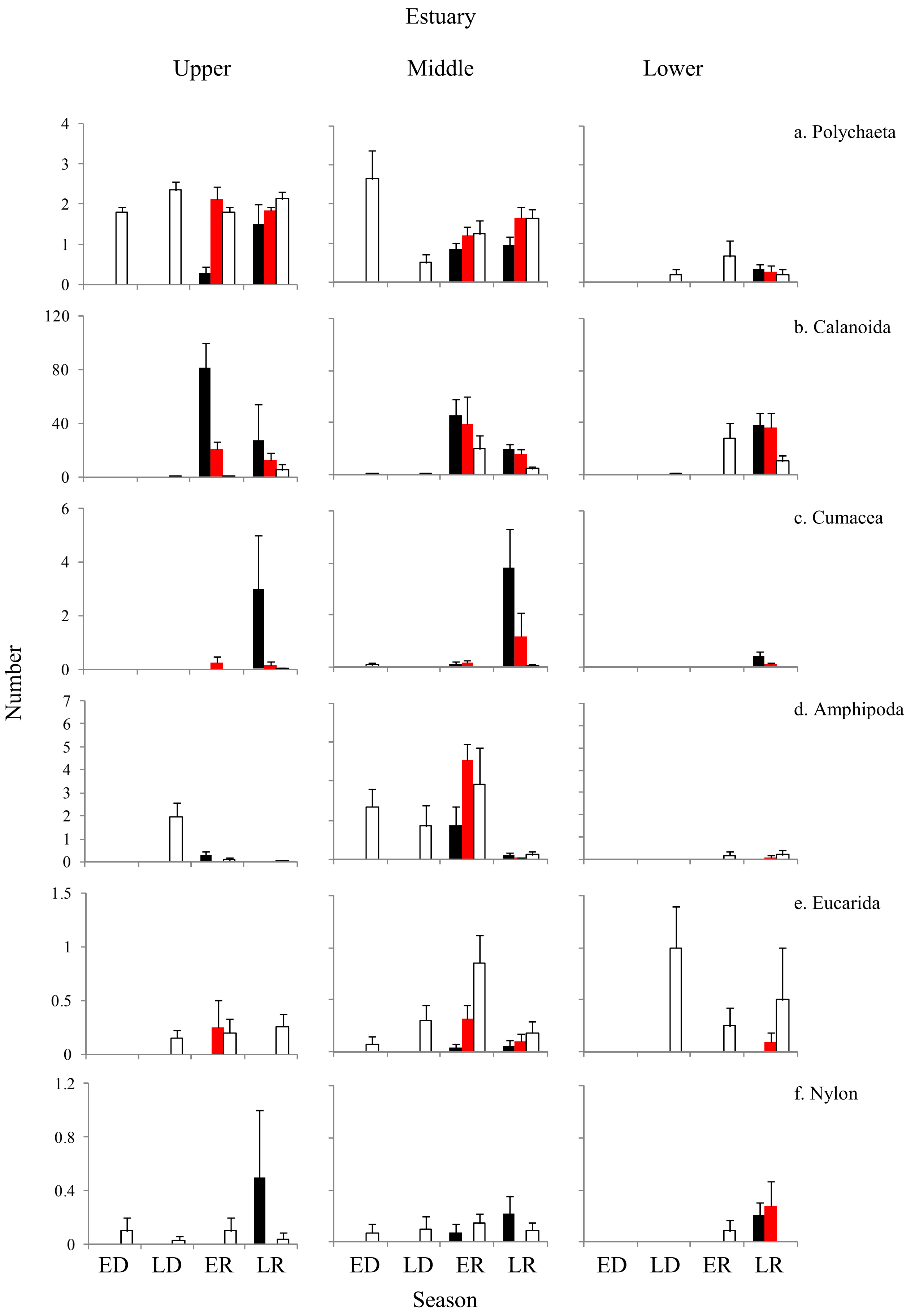
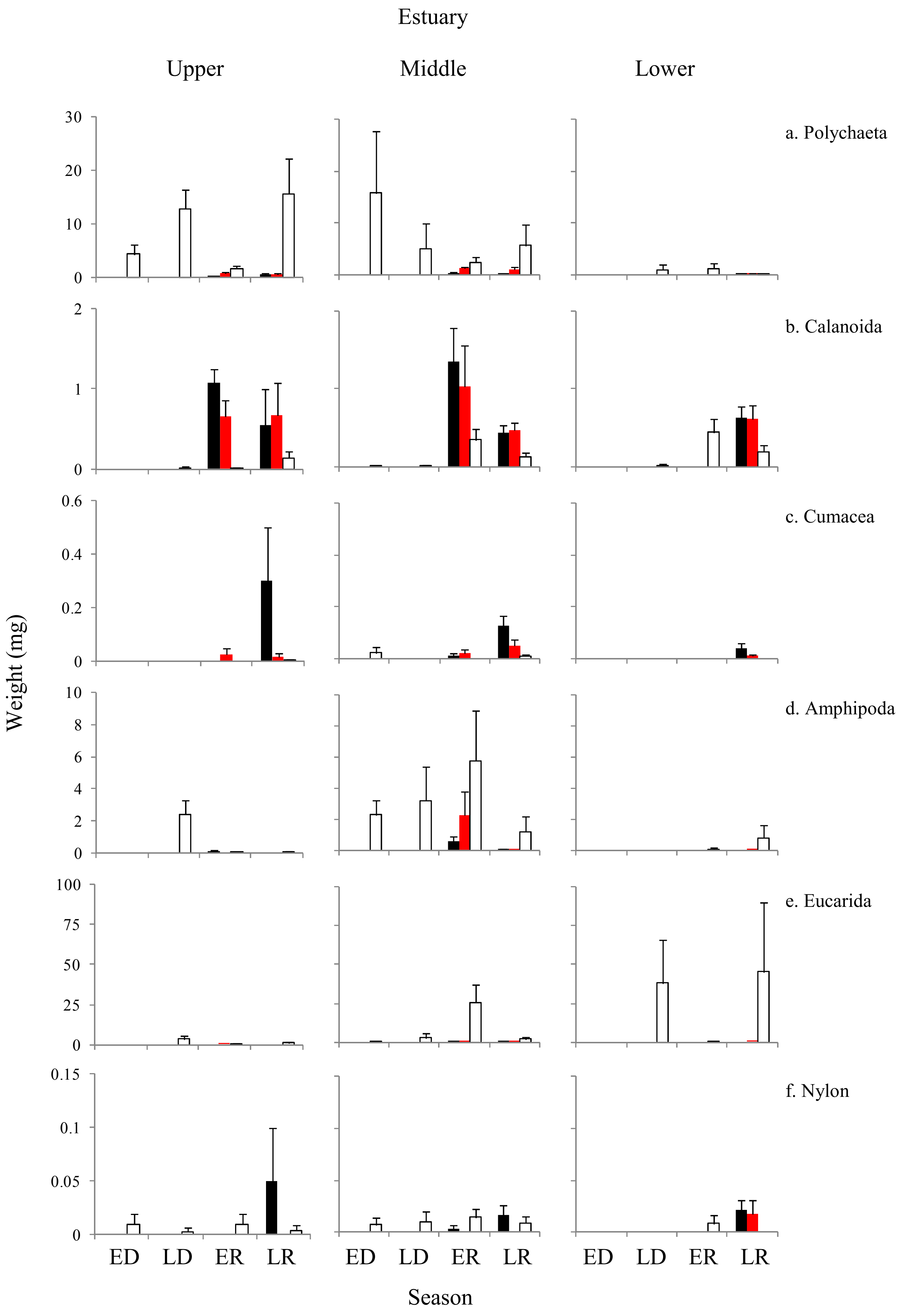

Estuary
Upper
Middle
Lower
a. Polychaeta
b. Calanoida
c. Cumacea
d. Amphipoda
e. Eucarida
f. Nylon
Number
Season
ED
LD
ER
LR
0
1
2
3
4
0
40
80
120
0
2
4
6
0
1
2
3
4
5
6
7
0
0.5
1
1.5
0
0.4
0.8
1.2

Figure 5.



Estuary
Upper
Middle
Lower
a. Polychaeta
b. Calanoida
c. Cumacea
d. Amphipoda
e. Eucarida
f. Nylon
Weight (mg)
30
20
10
0
2
1
0
0.6
0.4
0.2
0
10
8
6
4
2
0
100
75
50
25
0
0.15
0.1
0.05
0
ED
LD
ER
LR
ED
LD
ER
LR
ED
LD
ER
LR
Season

Figure 6.

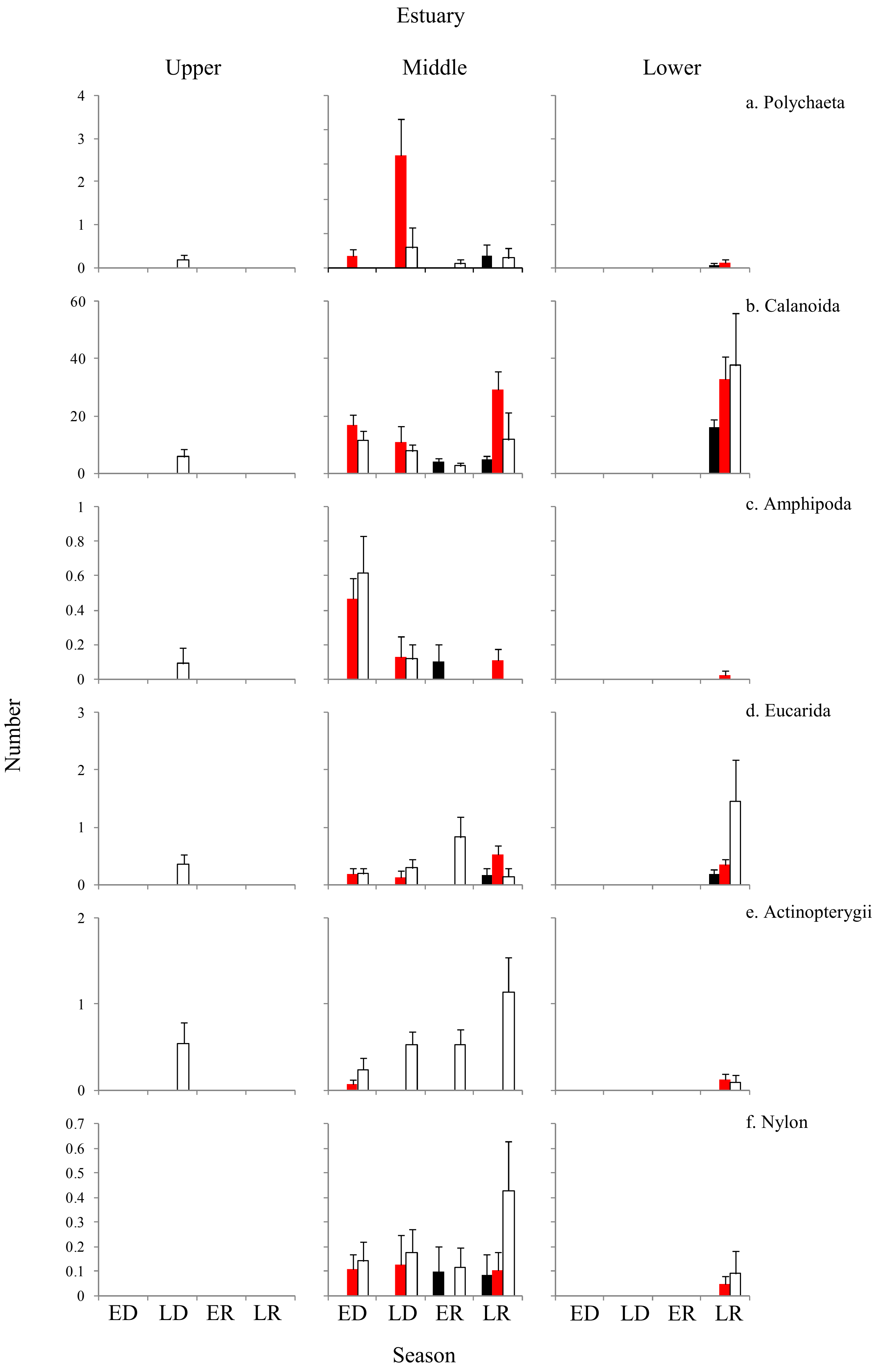

Estuary
Upper
Middle
Lower
a. Polychaeta
4
3
2
1
0
b. Calanoida
60
40
20
0
c. Amphipoda
1
0.8
0.6
0.4
0.2
0
d. Eucarida
3
2
1
0
e. Actinopterygii
2
1
0
f. Nylon
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Number
ED
LD
ER
LR
Season

Figure 7.

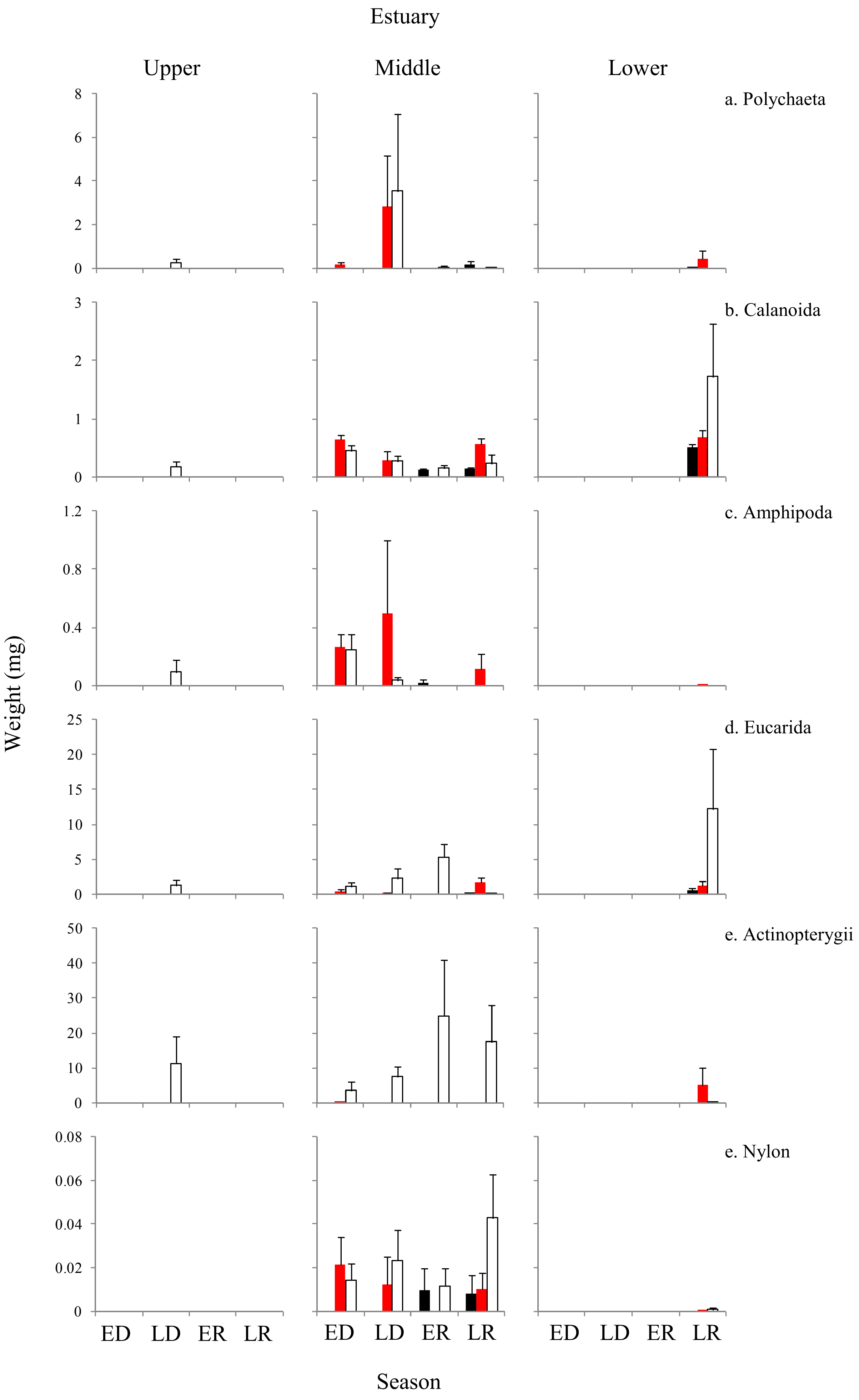
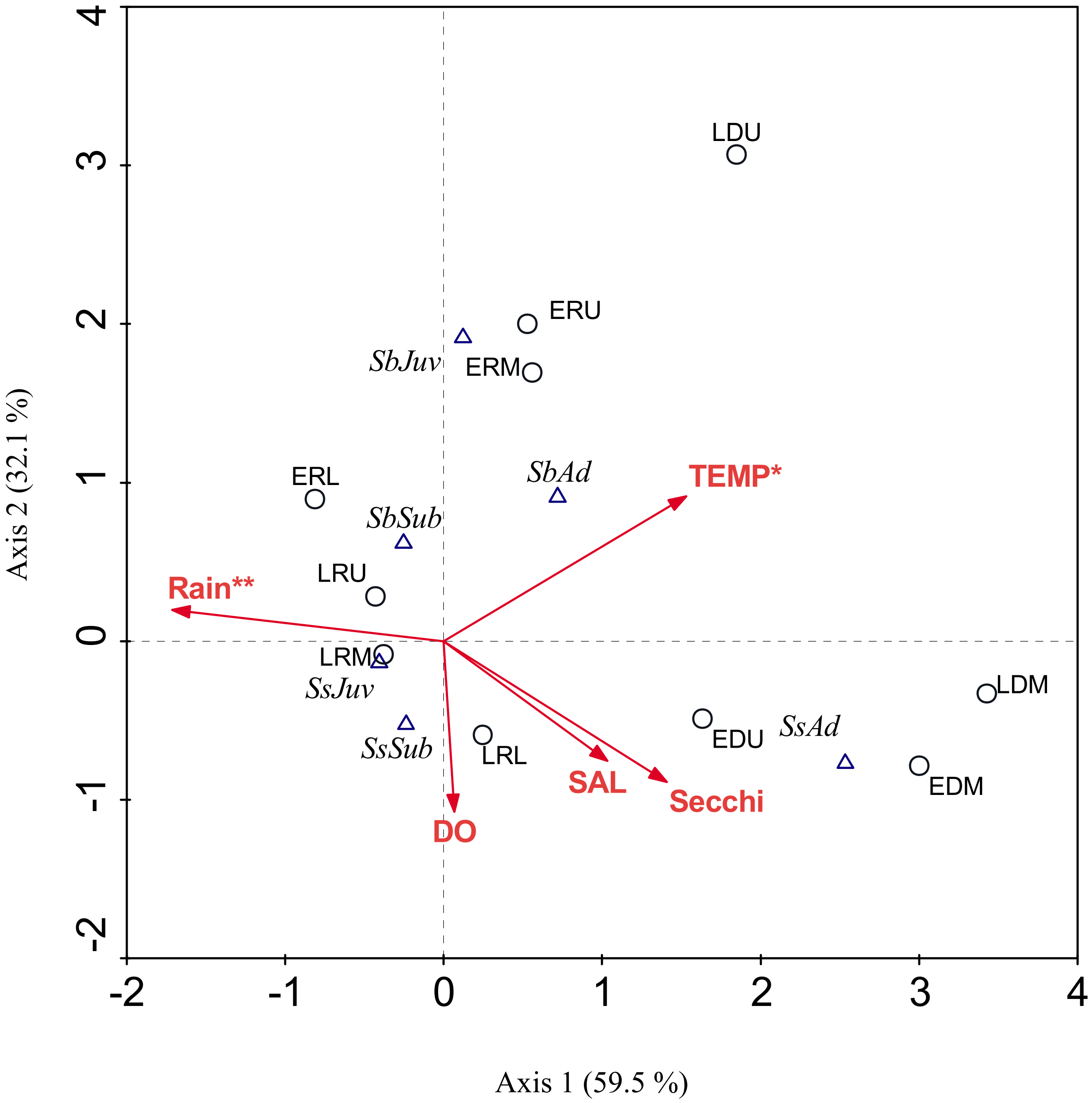
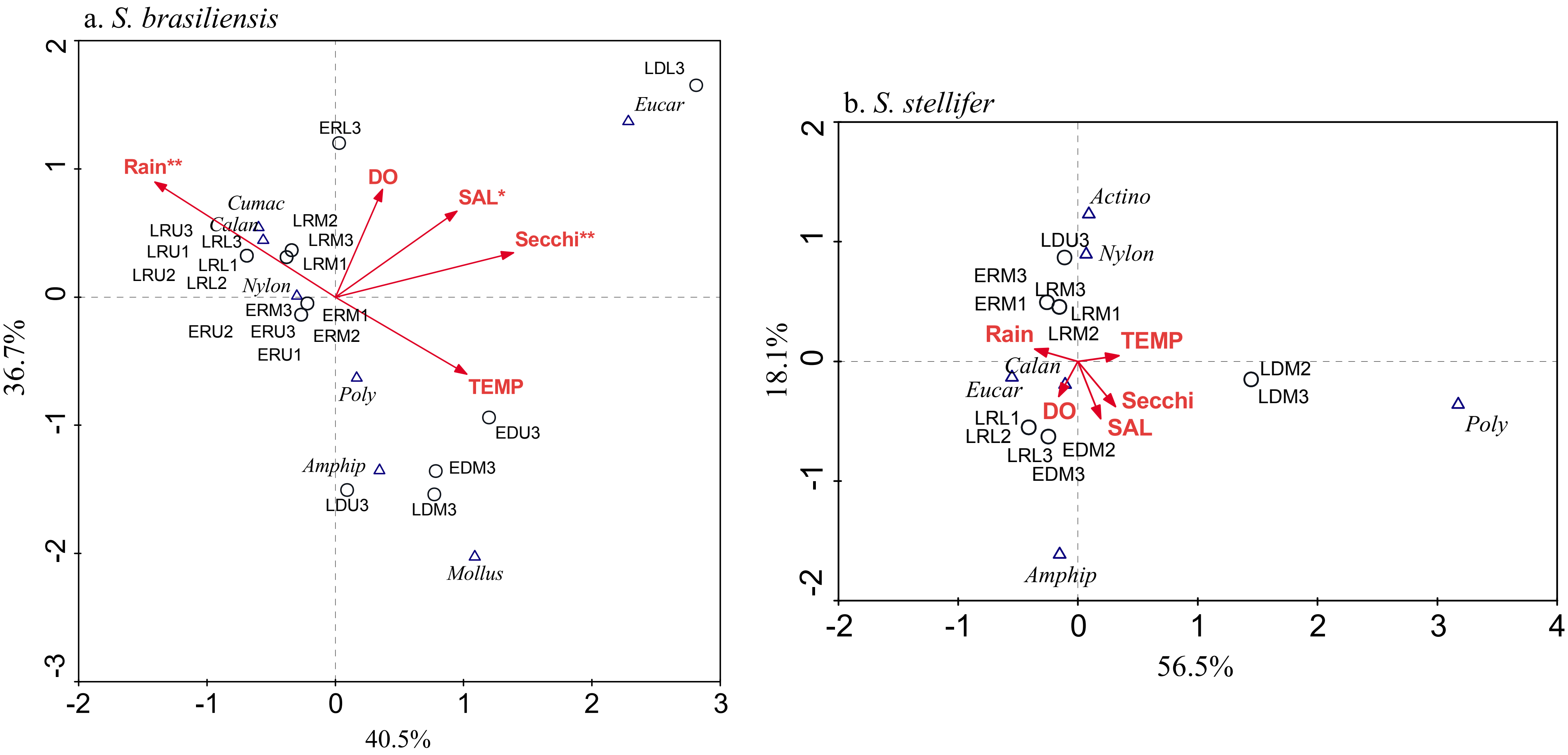

Estuary
Upper
Middle
Lower
a. Polychaeta
b. Calanoida
c. Amphipoda
d. Eucarida
e. Actinopterygii
e. Nylon
Weight (mg)
0
2
4
6
8
0
1
2
3
0
0.4
0.8
1.2
0
5
10
15
20
25
0
10
20
30
40
50
0
0.02
0.04
0.06
0.08
ED
LD
ER
LR
Season

Figure 8.



LDU
ERU
SbJuv
ERM
ERL
SbAd
TEMP*
SbSub
LRU
Rain**
LRM
SsJuv
SsSub
LRL
EDU
SsAd
LDM
EDM
SAL
Secchi
DO
4
3
2
1
0
-1
-2
-2
-1
0
1
2
3
4
Axis 2 (32.1 %)
Axis 1 (59.5 %)

Figure 9.



a. *S. brasiliensis*

b. *S. stellifer*

Figure 10.

Table 1.

Parameters	Size classes	Total density	Total biomass	Density (ind m^{-2})			Biomass (g m^{-2})		
	S_L(cm)	Ind m^{-2}	g m^{-2}	Upper	Middle	Lower	Upper	Middle	Lower
A. *S. brasiliensis*									
Total		0.004	0.044	0.003	0.008	0.001	0.059	0.058	0.014
I. Juvenile	2.4 ⊢ 4	0.003	0.001	0.001	0.009	0.0003	0.0007	0.003	0.0001
II. Sub-adult	4 ⊢ 5	0.002	0.004	0.001	0.006	0.001	0.001	0.009	0.003
III. Adult	5 ⊢ 13.6	0.006	0.125	0.006	0.008	0.003	0.176	0.163	0.039
B. *S. stellifer*									
Total		0.013	0.024	0.00003	0.031	0.010	0.0007	0.042	0.033
I. Juvenile	2.2 ⊢ 4	0.025	0.011	0	0.065	0.013	0	0.029	0.006
II. Sub-adult	4 ⊢ 5	0.011	0.022	0.00004	0.022	0.014	0.0002	0.043	0.025
III. Adult	5 ⊢ 12.9	0.002	0.041	0.00006	0.006	0.002	0.001	0.054	0.068

S_L = Standard lenght.

Table 2.

Variables	Factors	*F*	*df*	*p*-value	Post-hoc
S.brasiliensis (density)					
Total	Season	13.71398	3	0.000001	** *LD ED* ***ER*** **LR**
	Area	8.45715	2	0.000414	** *L* ***U*** **M**
	Iteraction (season *vs* area)	2.65929	6	0.01978	*
Juvenile	Season	4.88976	3	0.003311	** *LD ED* ***ER*** **LR**
	Area	5.0288	2	0.008376	** *L* ***U*** **M**
Sub-adult	Season	6.3797	3	0.000547	** *LD ED* ***ER*** **LR**
	Iteraction (season *vs* area)	2.35141	6	0.036659	*
Adult	Season	11.38413	3	0.000002	** *LD ED* ***ER*** **LR**
	Area	5.60562	2	0.004983	** *L* ***U*** **M**
S.brasiliensis (biomass)					
Total	Season	29.6993	3	0.000001	** *LD ED* **ER LR**
	Area	25.164	2	0.000001	** *L* **M U**
	Iteraction (season *vs* area)	5.4266	6	0.000072	**
Juvenile	Season	6.51008	3	0.000468	** *LD ED* ***ER*** **LR**
	Area	6.38334	2	0.002496	** *L* ***U*** **M**
	Iteraction (season *vs* area)	2.3324	6	0.03807	*
Sub-adult	Season	6.60572	3	0.000418	** *LD ED* ***ER*** **LR**
	Iteraction (season *vs* area)	2.33396	6	0.037952	*
Adult	Season	27.4018	3	0.000001	** *LD ED* **ER LR**
	Area	24.6796	2	0.000001	** *L* **M U**
	Iteraction (season *vs* area)	5.1386	6	0.000128	**
S.stellifer (density)					
Total	Season	4.27402	3	0.007059	** *LD* ***ED ER*** **LR**
	Area	4.97203	2	0.008817	** *U* **L M**
Juvenile	Season	3.823526	3	0.01233	* *ED LD* ***ER*** **LR**
Sub-adult	Season	5.308661	3	0.001986	** *ER LD* ***ED*** **LR**

Table 2. Continued.

S.stellifer (biomass)					
Total	Season	3.83665	3	0.012130	* *LD* ***ED ER*** **LR**
	Area	6.38803	2	0.002486	** *U* ***L*** **M**
Juvenile	Season	4.581124	3	0.004835	** *ED LD ER* **LR**
Sub-adult	Season	5.370804	3	0.001842	** *ER* ***LD ED*** **LR**
	Area	3.48232	2	0.034673	* *U* ***L*** **M**
Adult	Area	4.32322	2	0.015931	* *U* ***L*** **M**

Table 3.

Variables	Factors	*F*	*df*	*p*-value	Post-hoc
S.brasiliensis (number)					
Polychaeta	Season	7.9273	3	0.000122	** *ED* *LD* ***ER*** **LR**
	Area	25.7803	2	0.000001	** *L* **M** **U**
	Size class	29.7833	2	0.000001	** *J* *S* **A**
	Iteraction (season *vs* area *vs* phase)	4.4195	12	0.000029	**
Calanoida	Season	6.51267	3	0.000584	** *ED* *LD* ***LR*** **ER**
Cumacea	Season	7.627415	3	0.000169	** *LD* *ED* *ER* **LR**
	Area	4.840321	2	0.010658	** *L* *U* **M**
	Size class	3.55857	2	0.033591	** *A* ***S*** **J**
	Iteraction (season *vs* area)	4.010892	6	0.001607	**
	Iteraction (season *vs* phase)	3.446774	6	0.00476	**
Amphipoda	Season	4.21774	3	0.008345	** *LR* *ED* ***LD*** **ER**
	Area	7.33383	2	0.001262	** *L* ***U*** **M**
	Iteraction (season *vs* area)	5.4093	6	0.000116	**
Eucarida	Season	6.37681	3	0.000681	** *ED* ***LD*** ***LR*** **ER**
	Area	5.24348	2	0.007483	** *L* **U** **M**
	Size class	14.7913	2	0.000004	** *J* *S* **A**
	Iteraction (season *vs* area *vs* phase)	1.9029	12	0.048104	*
Nylon	Size class	5.323	2	0.00698	** *S* ***J*** **A**
S.brasiliensis (weight)					
Polychaeta	Area	4.51169	2	0.014256	* *L* **M** **U**
	Size class	13.61049	2	0.00001	** *J* *S* **A**
	Iteraction (season *vs* area *vs* phase)	1.95564	12	0.041404	*
Calanoida	Season	10.28308	3	0.00001	** *ED* *LD* ***LR*** **ER**
	Area	4.23788	2	0.018198	* *L* ***U*** **M**
	Iteraction (season *vs* area)	3.90716	6	0.00196	**
Cumacea	Season	14.375	3	0.000001	** *LD* *ED* *ER* **LR**
	Area	5.94271	2	0.004086	** *L* ***U*** **M**

Table 3. Continued.

	Size class	5.50521	2	0.005959	** *A* ***S*** **J**
	Iteraction (season *vs* area)	2.56771	6	0.026071	*
	Iteraction (season *vs* phase)	6.04687	6	0.000037	**
Amphipoda	Size class	4.097027	2	0.020647	* *J* ***S*** **A**
Eucarida	Size class	4.190151	2	0.018993	* *J* *S* **A**
Nylon	Season	2.99074	3	0.03651	* *ED LD* ***ER*** **LR**
S.stellifer (number)					
Polychaeta	Area	4.26829	2	0.01771	* *U* **L** **M**
	Iteraction (season *vs* area)	2.42547	6	0.034263	*
Calanoida	Season	3.042969	3	0.034269	* *ER LD ED* **LR**
Amphipoda	Season	4.203562	3	0.008487	** *ER LR LD* **ED**
	Area	7.335878	2	0.00126	** *L* *U* **M**
	Iteraction (season *vs* area)	4.547074	6	0.00058	**
Eucarida	Iteraction (season *vs* area)	2.43296	6	0.033775	*
Actinopterygii	Area	6.86813	2	0.001862	** *L* *U* **M**
	Size class	12.01099	2	0.000032	** *J* *S* **A**
	Iteraction (area *vs* phase)	7.90659	4	0.000024	**
Nylon	Area	10.09677	2	0.000136	** *U* *L* **M**
S.stellifer (weight)					
Calanoida	Season	3.5081	3	0.019527	* *ER LD ED* **LR**
	Iteraction (season *vs* area)	3.43379	6	0.004881	**
Amphipoda	Area	7.969963	2	0.000747	** *L* *U* **M**
	Iteraction (season *vs* area)	2.634291	6	0.022932	*
	Iteraction (area *vs* phase)	3.003289	6	0.023778	*
Eucarida	Iteraction (season *vs* area)	2.417431	6	0.034795	*
Nylon	Area	9.38	2	0.00024	** *U* *L* **M**

Table 4.

Goiana Estuary	Axis 1	Axis 2	
Eigenvalue	0.375	0.202	
Species-environmental correlation	0.973	0.822	
Cumulative % variance			
Of species data	47.2	72.6	
Of species-environmental relation	59.5	91.6	
Correlation with environmental variables			*p*-value
Rainfall (mm)	-0.8807**	0.1004	0.004**
Salinity	0.5314	-0.3824	0.1400
Water temperature (ºC)	0.7863*	0.4628	0.0180*
Dissolved oxygen (mg l^{-1})	0.0337	-0.5461	0.1800
Secchi depth (cm)	0.7231	-0.4497	0.6460

Table 5.

a. *Stellifer brasiliensis*	Axis 1	Axis 2	
Eigenvalue	0.395	0.357	
Species-environmental correlation	0.832	0.803	
Cumulative % variance			
of species data	21.0	40.0	
of species environmetal relation	40.7	77.5	
Correlation with environmental variables			*p*-value
Rainfall (mm)	-0.6697**	0.4220	0.004
Salinity	0.4507*	0.3158	0.018
Water temperature (ºC)	0.4880	-0.2823	0.3880
Dissolved oxygen (mg l^{-1})	0.1749	0.3953	0.3020
Secchi depth (cm)	0.6606*	0.1629	0.016

b. *Stellifer stellifer*	Axis 1	Axis 2	
Eigenvalue	0.145	0.077	
Species-environmental correlation	0.708	0.476	
Cumulative % variance			
of species data	18.6	28.4	
of species environmental relation	55.8	85.4	
Correlation with environmental variables			*p*-value
Rainfall (mm)	-0.4134	0.0925	0.4360
Salinity	0.2161	-0.4328	0.9980
Water temperature (ºC)	0.3920	0.0428	0.2980
Dissolved oxygen (mg l^{-1})	-0.1849	-0.2634	0.8480
Secchi depth (cm)	0.3596	-0.3406	0.3040

Table 6.

Season (Area)	**Species(Phase)** ***x***	**Species(Phase)** ***i***	**Schoener's Index (*C*)**
Early dry			
Middle	*Ss*(2)	*Ss*(3)	0.76
Early rainy			
Middle	*Sb*(2)	*Sb*(3)	0.68
	Sb(1)	*Ss*(1)	0.70
Late rainy			
Upper	*Sb*(1)	*Sb*(2)	0.80
	Sb(2)	*Sb*(3)	0.71
Middle	*Sb*(1)	*Sb*(2)	0.69
	Sb(2)	*Sb*(3)	0.63
	Ss(1)	*Ss*(2)	0.79
Lower	*Sb*(1)	*Sb*(2)	0.84
	Sb(1)	*Sb*(3)	0.85
	Sb(1)	*Ss*(1)	0.79
	Sb(1)	*Ss*(2)	0.70
	Sb(2)	*Sb*(3)	0.86
	Sb(2)	*Ss*(1)	0.80
	Sb(2)	*Ss*(2)	0.78
	Sb(2)	*Ss*(3)	0.60
	Sb(3)	*Ss*(1)	0.91
	Sb(3)	*Ss*(2)	0.82
	Sb(3)	*Ss*(3)	0.67
	Ss(1)	*Ss*(2)	0.76
	Ss(1)	*Ss*(3)	0.64
	Ss(2)	*Ss*(3)	0.82

Appendix captions

Appendix 1. Frequency of occurrence (%Fi), number (%Ni), weight (%Wi) and index of relative importance (%IRI) of preys found in the stomachs of each size classes (juveniles, sub-adults and adults) of *Stellifer brasiliensis* in the three areas of the Goiana Estuary (upper, middle and lower).

Appendix 2. Frequency of occurrence (%Fi), number (%Ni), weight (%Wi) and index of relative importance (%IRI) of preys found in the stomachs of each size classes (juveniles, sub-adults and adults) of *Stellifer brasiliensis* during the different seasons (early dry, late dry, early rainy and late rainy) in the Goiana Estuary. (-) no capture.

Appendix 3. Frequency of occurrence (%Fi), number (%Ni), weight (%Wi) and index of relative importance (%IRI) of preys found in the stomachs of each size classes (juveniles, sub-adults and adults) of *Stellifer stellifer* in the three areas of the Goiana Estuary (upper, middle and lower). (-) no capture.

Appendix 4. Frequency of occurrence (%Fi), number (%Ni), weight (%Wi) and index of relative importance (%IRI) of preys found in the stomachs of each size classes (juveniles, sub-adults and adults) of *Stellifer stellifer* during the different seasons (early dry, late dry, early rainy and late rainy) in the Goiana Estuary. (-) no capture.

Appendix 1.

Prey item	Predator	Upper				Middle				Lower			
	Phase	%Fi	%Ni	%Wi	%IRI	%Fi	%Ni	%Wi	%IRI	%Fi	%Ni	%Wi	%IRI
Polychaeta	Juv	46.66	0.62	7.81	2.14	54.34	2.25	17.64	6.96	26.31	0.81	6.75	1.14
	Sub	100	10.74	43.83	32.54	76.92	4.37	33.11	22.77	18.18	0.74	13.26	1.64
	Adu	97.33	40.60	77.92	90.97	71.64	12.39	30.03	42.62	21.87	2.30	2.80	1.34
Eucarida	Juv	0	0	0	0	4.34	0.11	1.10	0.03	0	0	0	0
	Sub	5	0.55	6.5	0.21	17.94	0.62	9.11	1.38	9.09	0.24	4.08	0.25
	Adu	16	3.29	13.96	2.17	23.88	3.09	41.84	15.04	28.12	3.46	92.88	32.58
Ostracoda	Juv	0	0	0	0	10.86	0.44	0.77	0.08	0	0	0	0
	Sub	0	0	0	0	10.25	0.86	0.44	0.10	0	0	0	0
	Adu	2.66	0.5	0.02	0.01	7.46	0.83	0.06	0.09	3.12	0.19	0.01	0.007
Calanoidea	Juv	100	98.4	79.16	96.74	100	88.83	50.38	89.66	94.73	97	81.75	97.08
	Sub	85	86.22	45.54	66.78	79.48	83.42	21.4	65.82	90.9	97.27	68.36	97
	Adu	14.66	35.78	0.37	4.18	34.32	60.9	0.7	29.66	62.5	85.96	0.82	65.21
Cumacea	Juv	13.33	0.53	3.12	0.26	23.91	3.96	2.86	1.05	31.57	1.08	5.4	1.17
	Sub	15	1.1	1.36	0.22	15.38	2.03	1.03	0.37	9.09	0.24	1.02	0.07
	Adu	16	0.25	0.009	0.03	2.98	0.23	0.03	0.01	0	0	0	0
Cirripedia	Juv	0	0	0	0	0	0	0	0	10.52	0.27	2.7	0.17
	Sub	0	0	0	0	0	0	0	0	9.09	0.24	1.02	0.07
	Adu	0	0	0	0	4.47	0.47	1.21	0.1	0	0	0	0
Isopoda	Juv	0	0	0	0	13.04	0.38	3.63	0.33	5.26	0.27	0.67	0.02
	Sub	0	0	0	0	0	0	0	0	0	0	0	0
	Adu	0	0	0	0	5.97	0.59	3.97	0.38	3.12	0.19	0.01	0.007
Gammaridae	Juv	20	0.26	6.25	0.71	8.69	1.04	13	0.78	0	0	0	0
	Sub	0	0	0	0	30.76	4.45	26.14	7.43	9.09	0.24	1.02	0.07
	Adu	14.66	12.69	4.97	2.04	25.37	10.6	10.93	7.66	0	0	0	0
Corrophiidae	Juv	6.66	0.08	3.12	0.11	10.86	1.92	6.06	0.55	0	0	0	0
	Sub	0	0	0	0	20.51	3.20	5.62	1.43	0	0	0	0
	Adu	8	3.8	2.34	0.38	16.41	6.19	3.38	2.2	6.25	0.76	0.99	0.13
Bivalvia	Juv	0	0	0	0	0	0	0	0	0	0	0	0
	Sub	0	0	0	0	0	0	0	0	0	0	0	0
	Adu	0	0	0	0	11.94	1.31	7.24	1.43	6.25	0.76	2.34	0.23
Diptera (larvae)	Juv	0	0	0	0	15.21	0.71	4.07	0.46	0	0	0	0
	Sub	10	1.37	2.73	0.24	20.51	1.01	3.11	0.66	9.09	0.24	9.18	0.55
	Adu	8	2.03	0.33	0.14	14.92	2.5	0.52	0.63	6.25	6.15	0.11	0.47
Nylon	Juv	6.66	0.08	0.52	0.02	8.69	0.33	0.44	0.04	21.05	0.54	2.70	0.39
	Sub	0	0	0	0	0	0	0	0	18.18	0.74	2.04	0.32
	Adu	5.33	1.01	0.03	0.04	10.44	0.83	0.04	0.12	3.12	0.19	0.01	0.007

Appendix 2.

Prey item	Predator Phase	Early dry				Late dry				Early rainy				Late rainy			
		%Fi	%Ni	%Wi	%IRI	%Fi	%Ni	%Wi	%IRI	%Fi	%Ni	%Wi	%IRI	%Fi	%Ni	%Wi	%IRI
Polychaeta	Juv	-	-	-	-	-	-	-	-	51.21	1.15	13.56	4.58	41.02	2.05	17.83	5.12
	Sub	-	-	-	-	-	-	-	-	85.18	3.75	26.85	19.63	69.76	5.91	44.74	24.43
	Adu	100	52.38	86.96	89.19	71.15	37.1	38.1	68.21	58.13	5.38	10.4	11.87	76.36	18.83	43.5	55.68
Eucarida	Juv	-	-	-	-	-	-	-	-	2.43	0.04	1.02	0.01	2.56	0.07	0.27	0.005
	Sub	-	-	-	-	-	-	-	-	22.22	0.75	7.69	1.41	6.97	0.3	9.48	0.47
	Adu	4.16	0.95	1.32	0.06	26.92	8.14	42.15	17.26	30.23	2.38	69.5	28.09	16.36	3.24	47.28	9.67
Ostracoda	Juv	-	-	-	-	-	-	-	-	2.43	0.08	0.34	0.006	10.25	0.47	1.08	0.1
	Sub	-	-	-	-	-	-	-	-	0	0	0	0	9.3	1.12	0.88	0.12
	Adu	4.16	0.95	0.09	0.02	5.76	2.26	0.04	0.16	9.3	0.41	0.06	0.05	0	0	0	0
Calanoidea	Juv	-	-	-	-	-	-	-	-	100	95.94	59.17	94.21	97.43	88.52	57.02	89.12
	Sub	-	-	-	-	-	-	-	-	77.77	85.36	23.38	63.68	86.04	88.06	35.55	73.54
	Adu	8.33	1.9	0.06	0.1	15.38	9.04	0.08	1.79	53.48	77.92	1.59	54.99	40	70.34	0.71	33.25
Cumacea	Juv	-	-	-	-	-	-	-	-	4.87	0.12	0.34	0.01	43.58	6.56	10	4.53
	Sub	-	-	-	-	-	-	-	-	11.11	0.46	0.56	0.08	16.27	2.65	1.92	0.51
	Adu	4.16	0.95	0.09	0.02	0	0	0	0	0	0	0	0	3.63	0.43	0.02	0.01
Cirripedia	Juv	-	-	-	-	-	-	-	-	0	0	0	0	5.12	0.15	1.08	0.03
	Sub	-	-	-	-	-	-	-	-	0	0	0	0	2.32	0.1	0.14	0.004
	Adu	8.33	1.9	0.66	0.13	0	0	0	0	0	0	0	0	1.81	0.43	1.43	0.03
Isopoda	Juv	-	-	-	-	-	-	-	-	9.75	0.2	2.62	0.16	7.69	0.31	2.97	0.15
	Sub	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
	Adu	0	0	0	0	3.84	0.9	2.09	0.14	2.32	0.1	0.01	0.003	3.63	0.64	2.96	0.15
Gammaridae	Juv	-	-	-	-	-	-	-	-	9.75	0.78	13.79	0.86	5.12	0.23	2.43	0.08
	Sub	-	-	-	-	-	-	-	-	44.44	5.34	33.14	12.88	2.32	0.1	0.14	0.004
	Adu	37.5	27.61	8.61	8.69	19.23	22.17	4.2	6.46	13.95	5.69	13.73	3.5	5.45	1.29	2.51	0.24
Corrophiidae	Juv	-	-	-	-	-	-	-	-	1.21	1.44	6.72	0.06	2.56	0.07	0.54	0.009
	Sub	-	-	-	-	-	-	-	-	25.92	3.75	6.85	2.07	2.32	0.1	0.44	0.008
	Adu	20.83	8.57	1.94	1.4	15.38	14.02	4.58	3.65	11.62	3	1.69	0.7	1.81	0.43	0.71	0.02
Bivalvia	Juv	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
	Sub	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
	Adu	0	0	0	0	13.46	4.07	8.62	2.17	6.97	0.62	2.7	0.29	0	0	0	0

Appendix 2. Continued.

	Juv	-	-	-	-	-	-	-	-	4.87	0.12	2.28	0.07	12.82	0.79	4.59	0.43
Diptera (larvae)	Sub	-	-	-	-	-	-	-	-	14.81	0.56	1.5	0.23	16.27	1.32	6.37	0.86
	Adu	12.5	2.85	0.16	0.24	3.84	1.35	0.09	0.07	6.97	3.93	0.21	0.37	16.36	3.67	0.8	0.85
	Juv	-	-	-	-	-	-	-	-	2.43	0.08	0.11	0.002	20.51	0.71	2.16	0.37
Nylon	Sub	-	-	-	-	-	-	-	-	0	0	0	0	4.65	0.3	0.29	0.01
	Adu	8.33	1.9	0.06	0.1	3.84	0.9	0.01	0.04	11.62	0.51	0.06	0.08	5.45	0.64	0.02	0.04

Appendix 3.

Prey item	Predator	Upper				Middle				Lower			
	Phase	%Fi	%Ni	%Wi	%IRI	%Fi	%Ni	%Wi	%IRI	%Fi	%Ni	%Wi	%IRI
Polychaeta	Juv	-	-	-	-	18.51	6.21	40.15	6.98	6.25	0.38	3.47	0.16
	Sub	-	-	-	-	16.36	1.51	22.13	2.99	12.5	0.36	5.66	0.71
	Adu	18.18	2.5	1.89	0.76	4.83	1.17	6.11	0.39	0	0	0	0
Eucarida	Juv	-	-	-	-	11.11	1.55	15.9	1.57	15.62	1.14	49.56	5.48
	Sub	-	-	-	-	21.81	1.34	35.31	6.18	34.37	1.01	16.77	5.82
	Adu	36.36	5	8.45	4.65	25.8	4.03	15.25	5.59	45.45	3.69	86.95	31.74
Calanoidea	Juv	-	-	-	-	85.18	90.67	40.9	91.21	93.75	98.47	46.95	94.35
	Sub	-	-	-	-	96.36	93.87	25.63	89.06	85.36	97.96	9.02	87.04
	Adu	81.81	78.75	1.26	62.28	62.9	84.53	1.81	61.1	81.81	95.84	12.32	68.17
Cumacea	Juv	-	-	-	-	0	0	0	0	0	0	0	0
	Sub	-	-	-	-	7.27	0.58	0.4	0.05	0	0	0	0
	Adu	0	0	0	0	0	0	0	0	0	0	0	0
Isopoda	Juv	-	-	-	-	0	0	0	0	0	0	0	0
	Sub	-	-	-	-	9.09	0.5	3.58	0.28	2.43	0.07	0.03	0.002
	Adu	18.18	3.75	8.2	2.06	1.61	0.33	1.1	0.02	0	0	0	0
Gammaridae	Juv	-	-	-	-	0	0	0	0	0	0	0	0
	Sub	-	-	-	-	7.27	0.41	5.12	0.31	2.43	0.07	0.03	0.002
	Adu	0	0	0	0	0	0	0	0	0	0	0	0
Corrophiidae	Juv	-	-	-	-	3.7	0.51	1.51	0.06	0	0	0	0
	Sub	-	-	-	-	18.18	0.92	5.93	0.96	0	0	0	0
	Adu	9.09	1.25	0.63	0.16	16.12	2.52	0.58	0.56	0	0	0	0
Bivalvia	Juv	-	-	-	-	0	0	0	0	0	0	0	0
	Sub	-	-	-	-	1.81	0.08	0.16	0.003	0	0	0	0
	Adu	0	0	0	0	1.61	0.16	0.2	0.006	0	0	0	0
Gastropode	Juv	-	-	-	-	0	0	0	0	0	0	0	0
	Sub	-	-	-	-	1.81	0.08	0.16	0.003	0	0	0	0
	Adu	0	0	0	0	0	0	0	0	0	0	0	0
Cephalopode	Juv	-	-	-	-	0	0	0	0	0	0	0	0
	Sub	-	-	-	-	0	0	0	0	0	0	0	0
	Adu	0	0	0	0	1.61	0.16	0.1	0.004	0	0	0	0
Diptera (larvae)	Juv	-	-	-	-	0	0	0	0	0	0	0	0
	Sub	-	-	-	-	0	0	0	0	0	0	0	0
	Adu	9.09	1.25	0.63	0.16	0	0	0	0	0	0	0	0
Actinopterygii	Juv	-	-	-	-	0	0	0	0	0	0	0	0
	Sub	-	-	-	-	3.63	0.16	0.81	0.02	9.75	0.36	68.4	6.39
	Adu	36.36	7.5	78.91	29.89	35.48	5.21	74.71	31.9	9.09	0.23	0.64	0.06
Nylon	Juv	-	-	-	-	7.4	1.03	1.51	0.15	0	0	0	0
	Sub	-	-	-	-	10.9	0.5	0.73	0.1	4.87	0.14	0.06	0.009
	Adu	0	0	0	0	17.74	1.84	0.12	0.39	9.09	0.23	0.06	0.02

Appendix 4.

Prey item	Predator	Early dry				Late dry				Early rainy				Late rainy			
	Phase	%Fi	%Ni	%Wi	%IRI	%Fi	%Ni	%Wi	%IRI	%Fi	%Ni	%Wi	%IRI	%Fi	%Ni	%Wi	%IRI
Polychaeta	Juv	-	-	-	-	-	-	-	-	0	0	0	0	6.81	0.67	8.12	0.44
	Sub	14.28	0.97	10.32	1.09	62.5	12.14	66.66	36.68	-	-	-	-	6.66	0.11	0.13	0.01
	Adu	0	0	0	0	10.71	2.92	15.63	1.87	5.88	1.38	0.19	0.1	5.55	0.18	0.03	0.01
Eucarida	Juv	-	-	-	-	-	-	-	-	0	0	0	0	15.9	1.35	46.19	5.59
	Sub	10.71	0.97	23.47	1.77	12.5	0.93	2.92	0.35	-	-	-	-	31.66	1.16	19.81	6.23
	Adu	19.04	1.49	20.35	4.99	28.57	3.76	13	5.52	41.17	19.44	17.45	17.92	33.33	3.21	48.18	17.07
Calanoidea	Juv	-	-	-	-	-	-	-	-	100	95.55	81.25	98.7	88.63	97.79	45.43	93.95
	Sub	100	92.8	42.95	91.89	87.5	81.3	6.72	57.35	-	-	-	-	88.33	97.96	9.68	89.31
	Adu	66.66	90.29	8.28	78.82	82.14	81.58	1.63	64.57	47.05	63.88	0.48	35.74	66.66	94.13	7.4	67.45
Cumacea	Juv	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
	Sub	14.28	1.36	1.17	0.24	0	0	0	0	-	-	-	-	0	0	0	0
	Adu	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Isopoda	Juv	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
	Sub	0	0	0	0	37.5	3.73	11.69	4.3	-	-	-	-	5	0.17	0.16	0.01
	Adu	0	0	0	0	10.71	2.09	5.95	0.81	0	0	0	0	0	0	0	0
Gammaridae	Juv	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
	Sub	7.14	0.38	0.23	0.03	12.5	0.93	11.69	1.17	-	-	-	-	5	0.17	0.77	0.04
	Adu	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Corrophiidae	Juv	-	-	-	-	-	-	-	-	10	2.22	12.5	0.82	0	0	0	0
	Sub	35.71	2.14	17.13	4.65	0	0	0	0	-	-	-	-	0	0	0	0
	Adu	38.09	4.85	4.58	4.3	10.71	1.25	0.39	0.16	0	0	0	0	0	0	0	0
Bivalvia	Juv	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
	Sub	3.57	0.19	0.46	0.01	0	0	0	0	-	-	-	-	0	0	0	0
	Adu	0	0	0	0	3.57	0.41	0.49	0.03	0	0	0	0	0	0	0	0
Gastropode	Juv	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
	Sub	3.57	0.19	0.46	0.01	0	0	0	0	-	-	-	-	0	0	0	0
	Adu	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cephalopode	Juv	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
	Sub	0	0	0	0	0	0	0	0	-	-	-	-	0	0	0	0
	Adu	4.76	0.37	0.88	0.07	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 4. Continued.

Diptera (larvae)	Juv	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
	Sub	0	0	0	0	0	0	0	0	-	-	-	-	0	0	0	0
	Adu	0	0	0	0	3.57	0.41	0.24	0.02	0	0	0	0	0	0	0	0
Actinopterygii	Juv	-	-	-	-	-	-	-	-	0	0	0	0	0	0	0	0
	Sub	7.12	0.38	2.34	0.13	0	0	0	0	-	-	-	-	6.66	0.17	69.29	4.34
	Adu	14.28	1.86	65.63	11.56	42.85	6.27	62.53	27.85	41.17	12.5	81.83	45.83	33.33	1.70	44.23	15.25
Nylon	Juv	-	-	-	-	-	-	-	-	10	2.22	6.25	0.47	2.27	0.16	0.25	0.007
	Sub	10.71	0.58	1.4	0.14	12.5	0.93	0.29	0.11	-	-	-	-	6.66	0.23	0.13	0.02
	Adu	14.28	1.11	0.26	0.23	10.71	1.25	0.09	0.13	11.76	2.77	0.03	0.39	22.22	0.75	0.14	0.19

Capitulo 5

The seasonal and spatial patterns of ingestion of polyfilament nylon fragments by estuarine drums (Sciaenidae)

The seasonal and spatial patterns of ingestion of polyfilament nylon fragments by estuarine drums (Sciaenidae)

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Abstract

Introduction

Artisanal fisheries in tropical estuaries are an important economic activity worldwide. However, gear (*e.g.,* ropes, nets, buoys, crates) and vessels are often in use under dangerous conditions. Polyfilament nylon ropes are used until they are well beyond human and environmental safety limits. Severe wear and tear results in the contamination of the environment with micro-fragments. The spread of these fragments in the marine environment and their ingestion by the biota are documented in the scientific literature and are increasing concerns. The aim of this study was to evaluate the ingestion of plastic fragments by two fish (drum) species in relation to seasonal, habitat and fish size–class variation.

Materials and methods

The stomach contents of 569 individuals of *Stellifer brasiliensis* and *Stellifer stellifer* from the main channel of the Goiana Estuary were examined to identify variation in the number and the weight of plastic fragments and relate this variation to differences among the seasons (early dry, late dry, early rainy and late rainy), the habitats within the estuary (upper, middle and lower) and the size classes of the fish (juveniles, sub-adults and adults).

Results

Plastic fragments were found in 7.9% of the individuals of these two drum species captured from December 2005 to August 2008. Nylon fragments occurred in 9.2% of *S. stellifer* and 6.9% of *S. brasiliensis* stomachs. The highest number of nylon fragments ingested was observed in adults during the late rainy season in the middle estuary.

Discussion

Blue polyfilament nylon ropes are used extensively in fisheries and can be lost, inappropriately discarded or damaged during use in the estuary. These fragments were the only type of plastic detected during this study. The ingestion of nylon fragments by fish probably occurred during the animals' normal feeding activities. During the rainy season, the discharge of freshwater transports nylon fragments to the main channel and makes the fragments more available to fish. Fishery activities are responsible for a significant amount of the marine debris found in the estuary.

Conclusions

The ingestion of fragments of nylon threads by fish is a demonstrated form of pollution in the Goiana Estuary. The physiological and toxicological consequences of the ingestion of this type of debris are unknown, as is the actual extent of the problem worldwide. The solutions to the problem are in the hands of authorities and communities alike because the good care and timely replacement of gear requires education, investment and effective policies.

Keywords: South America; Goiana Estuary; Seasonal changes; Marine debris; Ontogenetic phases; Polyamide; Small-scale fisheries

1 Introduction

The accumulation of plastic debris in marine and coastal environments can significantly affect wildlife through entanglement and ingestion. The ingestion of plastic marine debris by seabirds, turtles and mammals has been widely reported and reviewed (Gregory 2009; Moore 2008). Fish are also affected by plastic marine debris, and the ingestion of this form of debris is known to occur in teleost fishes (Hoss and Settle 1990; Laist 1997), such as bathypelagic longnose lancetfish (Kubota 1990), planktivorous fish (Boerger et al. 2010) and epibenthophagous catfish species (Possatto et al. 2011).

Plastic debris has a range of sizes, from micrometers (< 1 mm) to larger items (> 1 mm) (Browne et al. 2010). Previous studies have reported that plastic fragments of very small sizes (< 2 mm) are available to fish, are mixed with food items and could be ingested by the fish (Hoss and Settle 1990; Possatto et al. 2011). Fishery activities produce some significant sources of plastic debris, such as polystyrene buoys, nylon ropes and fragments of lines or gill nets (Costa et al. 2011; Guebert-Bartholo et al. 2011a; Possatto et al. 2011). These items and their fragments occur in greater abundance than other types of plastics because they are manufactured in large quantities, are used widely and are frequently discarded or lost (Browne et al. 2010). Reports on the ingestion of plastic marine debris by fishes usually consist of casual observations and are not based on systematic research (i.e., temporal or spatial sampling designs). Coastal and estuarine resident species are known to have ingested whole plastic items and/or plastic fragments (Carpenter et al. 1972; Kartar et al. 1976; Possatto et al. 2011), but no data on the seasonal and spatial variation in this form of impact exist for fish.

The drums *Stellifer brasiliensis* (Schultz, 1945) and *Stellifer stellifer* (Bloch, 1790) (Sciaenidae) are found over shallow muddy or sand-mud bottoms of estuaries and adjacent coastal waters (Carpenter 2002). Moreover, these species are hyperbenthophagous and estuarine residents (Barletta and Blaber 2007). They only feed inside the estuary and in adjacent coastal waters. In South America, these species occur primarily in the middle and lower portions of estuaries (Barletta et al. 2005, 2008) and occasionally in mangrove tidal creeks (Ramos et al. 2011). Based on this information, this study investigated the ingestion of non-dietary items (*e.g.,* plastics, nylon threads) by different size classes of two estuarine fish species in different seasons (early and late dry, early and late rainy) along an estuarine ecocline.

2 Materials and methods

2.1 Study area

The Goiana Estuary in Northeast Brazil has 17 km of main channel. The total estuarine area of 4700 ha, including the flood plain, is dominated by mangrove forest (Fig. 1). Three municipalities border the estuary (Goiana in Pernambuco, Caaporã and Pitimbú in Paraíba State). Small fishing harbours (Barreirinhas, Congaçari, Acaú and Carne de Vaca) are located along the main channel (Fig. 1). The climate is tropical semi-arid (mean air temperature approximately 25 ºC). The area’s rainfall patterns define four seasons: early dry (September to November), late dry (December to February), early rainy (March to May) and late rainy (June to August) (Barletta & Costa 2009). According to these authors, the estuary supports a rich fauna of fish, crustaceans, and molluscs that play an important role in subsistence, artisanal and commercial fisheries. However, raw sewage and solid wastes are discharged into the estuary and pose a threat to the living resources that use this ecosystem. Small commercial, artisanal and subsistence fisheries account for approximately half of all finfish landings in Brazil, especially in the Northeast (Diegues 2008). These fisheries therefore represent an important economic activity that has so far received little official attention in terms of capacity building, access to financial credit and new technologies. In the present study, the estuary was divided into three areas (the upper, middle and lower estuary) according to the salinity gradient and geomorphology of the main channel (Fig. 1).

2.2 Fish samples

Fish samples were taken from the main channel of the Goiana Estuary using an otter trawl (Dantas et al. 2010) from December 2005 to August 2008. During the first year (December 2005 to November 2006), six replicate trawls per month were made in each habitat of the estuary (upper, middle and lower). A total of 216 samples were collected (54 for each season or 72 for each area). Subsequently (December 2006 to August 2008), the fish samples were collected over a period of three months during the late dry and late rainy seasons using the same method. A total of 108 samples were collected during each year (54 for each season or 36 for each area). Three different size classes were defined for the captured individuals of the target species. The *S. brasiliensis* (Sb) and *S. stellifer* (Ss) individuals in the samples were divided into juveniles (< 3 cm in standard length; n(Sb) = 81; n(Ss) = 59), sub-adults (4-5 cm in standard length; n(Sb) = 75; n(Ss) = 96) and adults (> 5 cm in standard length; n(Sb) = 174; n(Ss) = 84). The stomach contents were analysed using a stereomicroscope (Zeiss 50x), and all non-dietary items (*e.g.,* plastics, nylon) were separated from the ordinary organic food. The plastics found in the stomachs were washed with distilled water, dried with tissue paper and weighed with a precision scale (0.001 g). The quantification of plastic debris ingestion followed three criteria: the number of individuals in which some debris was found; the number of debris items in the stomach contents of each animal; and the weight (mass) of the debris in the stomach contents of each animal. The type of debris (nylon, hard and soft plastics) was also verified.

2.3 Statistical analysis

The original data describing the number and weight of the ingested debris were transformed (Box and Cox 1964) to increase the normality of the distribution. Levene's test was used to check the homogeneity of the variances. Analysis of variance (ANOVA) was used to test differences in debris ingestion (number and weight) for each size class of both species for each area and season. If significant differences among season, area, species and/or size factors were detected, a *post hoc* Bonferroni test was applied to identify the sources of the variation (Quinn and Keough 2002).

3 Results

The stomach contents of 569 (330 *S. brasiliensis* and 239 *S. stellifer*) individuals were analysed. Polyfilament blue nylon fragments (polyamide) were the only form of plastic found in the stomachs. These plastic fragments were found in 45 (7.9%) of the individuals examined. The fragments weighed 0.03 ± 0.1 mg on average. The blue nylon fragments were found in 22 (9.2%) of the *S. stellifer* stomachs examined (2 juveniles, 8 sub-adults and 12 adults) and in 23 (6.9%) of the *S. brasiliensis* stomachs examined (9 juveniles, 2 sub-adults and 12 adults). Only 2 juveniles and 1 adult of *S. brasiliensis* had more than 1 nylon fragment in their stomach.

The results of ANOVA showed that the total amount of plastic ingestion differed significantly among seasons, areas and size classes (Tab. 1). The highest amount of plastic in the stomach contents was observed in adults during the late rainy season in the middle estuary (mean 0.83 ± 0.16) (Fig. 2a). Moreover, the total weight of plastic ingested showed a significant interaction of sampling area and species (Tab. 1). This finding suggests that the weight of the plastic fragments ingested by each species was influenced by the location of the fish within the estuary. The greatest weight of plastic ingested was found in the middle estuary (mean 0.047 ± 0.010 mg) (Fig. 3a).

If the ingestion of plastic debris is analysed for each species separately, *S. brasiliensis* shows significant differences among size classes in the number of plastic fragments ingested (Tab. 1). The highest number of fragments was ingested by adults (mean 0.33 ± 0.08) (Fig. 2b). Moreover, *S. brasiliensis* showed significant differences among seasons for the weight of plastic debris ingested (Tab. 1), with the highest values occurring during the late rainy season (mean 0.048 ± 0.018 mg) (Fig. 3b). The number and weight of the plastic fragments in the stomach contents of *S. stellifer* differed significantly among areas (Tab. 1), with the highest values occurring in the middle estuary (means 0.52 ± 0.13 and 0.064 ± 0.018 mg) (Fig. 2c and 3c).

4 Discussion

The species of the present study are hyperbenthophagous (Barletta and Blaber 2007). They feed selectively on small-sized prey items that occur just above the sediment. The ingestion of plastic debris by *S. brasiliensis* and *S. stellifer* probably occurred during the normal feeding activities of the fish. These species are estuarine residents (Barletta and Blaber 2007), feeding inside the estuary and occasionally in adjacent coastal areas. Both species were found most frequently in the middle estuary. They move downstream during the rainy season, when the salinity drops, even in coastal waters (Barletta et al. 2005, 2008). In this situation, an ecological event (the presence of drums) and a pollution event (the flushing of nylon fragments) occur in the same place (the middle estuary) at the same time (the end of the rainy season). Because these conditions all coincide, the ingestion of plastic debris occurs as described.

This study found that the greatest ingestion of plastic debris occurred in the middle estuary during the rainy season. The increase of freshwater discharge during the rainy season could transport plastic particles from the mangrove forest and the upper portion of the estuary to the main channel. Fish and other organisms would then be exposed to this form of pollution. According to Ivar do Sul (2008), significantly higher amounts of fishing gear (*e.g.,* buoys, ropes, nets) are found during the lobster fishing season. This period coincides with the peak of the rainy season (May to August). Another source of pollution is the raw domestic sewage and solid waste discharged into the estuary. However, no plastic fragments from this source of pollution were found in the stomach contents of the species analysed. The greater size of the fragments occurring in sewage near the source of the discharge probably explains their absence from the stomach samples.

Individuals of all three size classes were found with nylon fragments in their stomachs. Adult individuals ingested the greatest amount of plastic fragments. The standard lengths of the sampled fish ranged from 2.2 cm to 13.5 cm. The fish have very small mouths, less than 2 cm in width for adults of both species. The plastic items ingested by all size classes of both species were likewise very small and/or fragmented (< 1 mm). Plastic fragments of smaller sizes (< 1 mm) are likely to be more abundant than larger items. These fragments are associated with a higher risk of ingestion by a range of organisms with different feeding strategies (Browne et al. 2010). According to Possatto et al. (2011), all of the life history phases of the catfish in the Goiana Estuary are exposed to plastic marine debris and are suffering from the impacts of the debris.

Only one type of plastic debris was found in the stomachs of the two species: fragments of polyfilament blue nylon. According to Costa et al. (2011), polyamide nylon (monofilament) was commonly found buried in the intertidal plain of the Goiana Estuary. Nylon threads (polyfilament) were frequently found in the gut contents of benthic fish in this estuary (Possatto et al. 2011). According to these authors, the ingestion of nylon threads by fish is a documented aspect of pollution in this estuary and has been shown to occur in different groups (species and sizes) of demersal fish.

A detailed examination of the stomach contents of fish strongly suggests fisheries as the most likely source of this sort of pollution. The fishery activities in the Goiana Estuary are responsible for a significant part of the marine debris found on the sandy beaches and in the mangrove forest and the main channel (Costa et al. 2011; Possatto et al. 2011; Ramos et al. 2011). The physiological effects of nylon ingestion by fish cannot yet be easily predicted (Hoss and Settle 1990; Browne et al. 2010). However, these species are the prey of larger-sized important commercial fish, and they may be transmitting their plastic contamination to their predators (Erikson and Burton 2003). Moreover, it is well known that in other animals, such as turtles, seabirds and seals (Ivar do Sul and Costa 2007; Gregory 2009; Laist 1997), the ingestion of plastic debris may cause a number of internal injuries, such as faecalomas, and the false impression of a full digestive tract, which reduces their feeding activity and can cause the animal to die of starvation (Guebert-Bartholo et al. 2011b). The current study demonstrates seasonal and spatial variation in the ingestion of polyfilament blue nylon fragments by estuarine drums, and it suggests that small-scale fisheries probably contribute to this form of pollution. The authorities and management agencies may be able to promote efficient policies, education and investments to reduce this form of impact on this estuarine ecosystem by taking positive steps to manage gear choice, maintenance and replacement.

5 Conclusions

The ingestion of nylon threads by fish is a documented form of pollution in the Goiana Estuary and varies demonstrably over time and space. The highest ingestion of plastic fragments by *S. brasiliensis* and *S. stellifer* was observed in adult fish during the rainy season in the middle estuary. The increase of freshwater discharge during the rainy season could transport plastic particles from the mangrove forest and the upper portion of the estuary to the main channel. Fish and other organisms would then be exposed to this type of pollution. The physical and toxicological consequences of such exposure are unknown, as is the true extent of the problem worldwide. Physical effects, such as gut blockage or injuries (e.g., the perforation or tearing of the stomach and intestine) and the transfer of persistent organic pollutants adsorbed onto plastics to the blood stream and central nervous system of fish, can only be assessed through controlled experiments.

The occurrence of plastic ingestion in fish inhabiting Goiana Estuary is most certainly not unique. The same type of pollution is likely to affect estuaries elsewhere, judging from published reports of contamination by fragments from fishing gear and shipyards. The solutions to this problem are in the hands of authorities and communities alike because the good care and timely replacement of gear requires education, investment and effective policies. These measures would improve not only environmental quality but also human safety at sea and during working hours along the estuary.

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Figure captions

Fig. 1 Goiana Estuary. ⬚= upper (U), middle (M) and lower (L) estuaries, where the fish samples were taken. The municipalities of Goiana (GO), Caaporã (CP) and Pitimbú (P) border the study area. The Acaú (A), Carne de Vaca (CV), Congaçari (CG) and Barreirinhas (BA) fishing harbours are potential sources of marine debris. (——) Main channel. Modified from Barletta and Costa (2009)

Fig. 2 Mean (± standard error) of the number of plastic debris fragments ingested by all fish (a), *S. brasiliensis* (b) and *S. stellifer* (c) for each size class: juveniles (*red square*), sub-adults (*white square*) and adults(*black square*). The data are presented for each area of the estuary (upper (U), middle (M) and lower (L)) and season (early dry, late dry, early rainy and late rainy)

Fig. 3 Mean (± standard error) of the weight (mg) of plastic debris ingested by all fish (a), *S. brasiliensis* (b) and *S. stellifer* (c) for each size class: juveniles (*red square*), sub-adults (*white square*) and adults (*black square*). The data are presented for each area of the estuary (upper (U), middle (M) and lower (L)) and season (early dry, late dry, early rainy and late rainy)

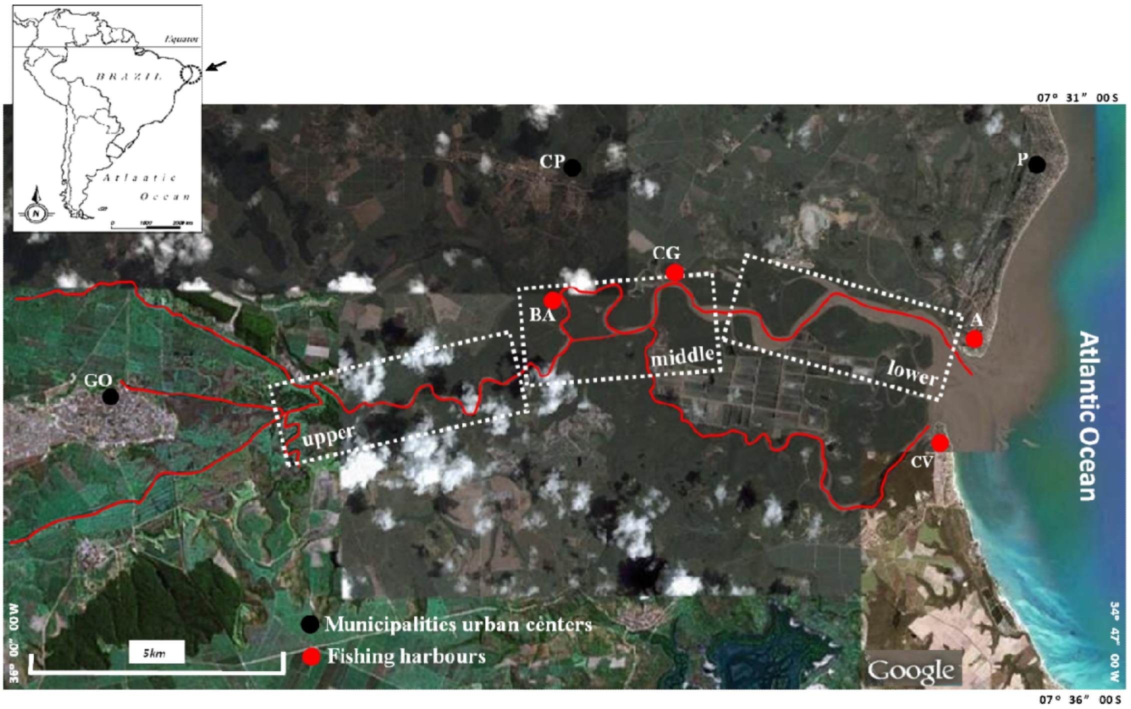
Equator
BRAZIL
Atlantic Ocean
N
0
1000
2000 km
07° 31'' 00 S
CP
P
CG
BA
A
GO
upper
middle
lower
CV
Atlantic Ocean
36° 00'' 00 W
5km
● Municipalities urban centers
● Fishing harbours
Google
34° 47' 00 W
07° 36'' 00 S

Fig. 1

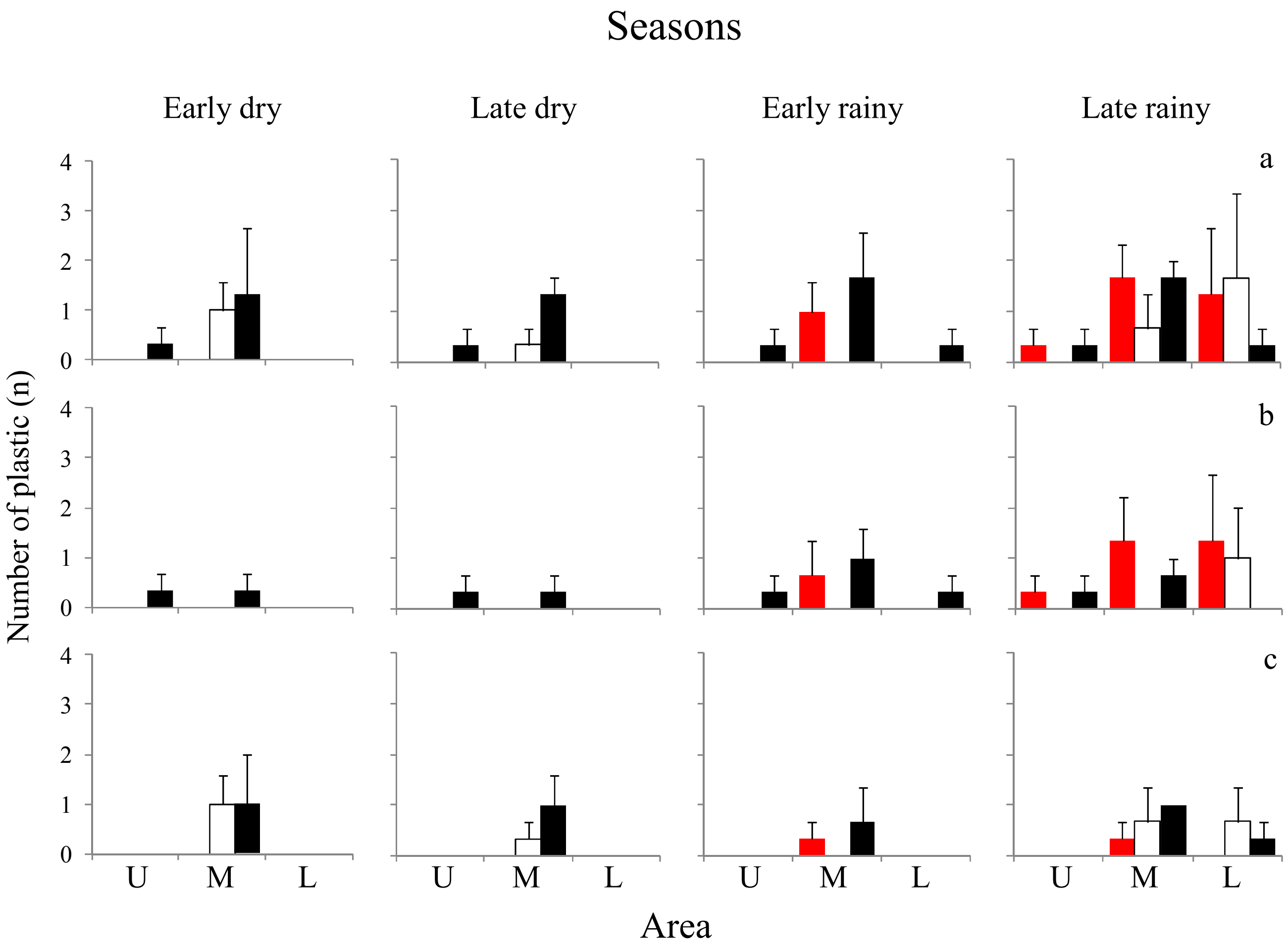
Seasons
Early dry
Late dry
Early rainy
Late rainy
a
b
c
Number of plastic (n)
0
1
2
3
4
U
M
L
Area

Fig. 2

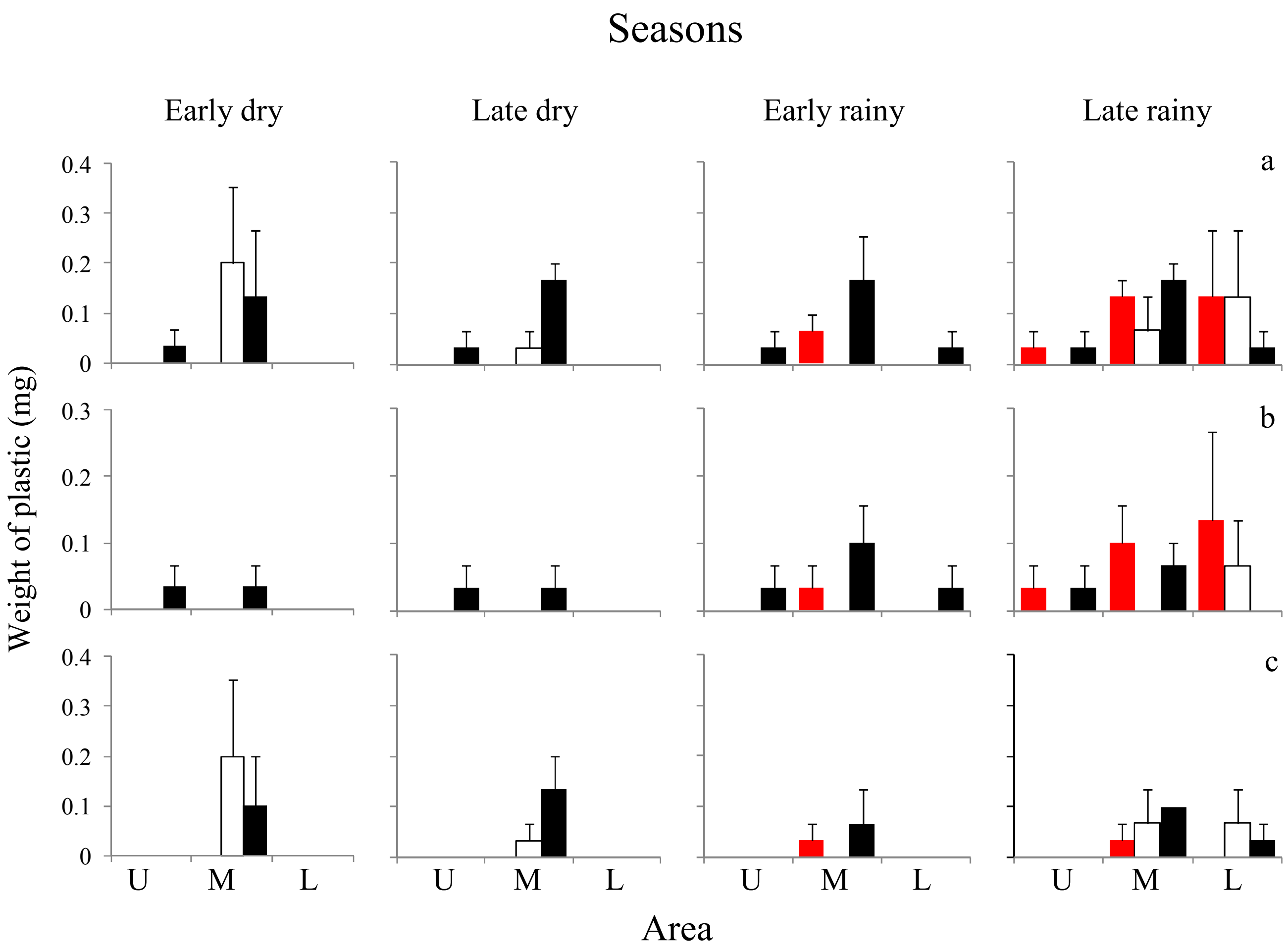
Seasons
Early dry
Late dry
Early rainy
Late rainy
a
b
c
0.4
0.3
0.2
0.1
0
0.3
0.2
0.1
0
0.4
0.3
0.2
0.1
0
Weight of plastic (mg)
U
M
L
Area

Fig. 3

Table 1 Summary of the ANOVA (*F-values*, df: degree of freedom. *p-value* and *Post-hoc* comparisons) for significant results for plastic debris ingestion (number and weight (mg)) for different size classes and total (a) of *S. brasiliensis* (b) and *S. stellifer* (c) for the factors season, area, species and phase. Differences among factors were determined by Bonferroni's Test *post hoc* comparisons. (italics and bold indicate homogeneous groups). ED: early dry season; LD: late dry season; ER: early rainy season; LR: late rainy season; Areas of the Goiana Estuary (U: upper; M: middle; L: lower); Juv: juveniles; Sub: sub-adults; Adu: adults. (**$p < 0.01$; *$p < 0.05$).

Variables	**Factor**	***F***	**df**	***p-value***	***Post-hoc***
Plastic debris (number)					
Total (a)	Area	12.036	2	0.0001	** *U L* **M**
	Season	3.7723	3	0.01210	* *LD ED* ***ER*** **LR**
	Size class	6.4092	2	0.00216	** *Sub* ***Juv*** **Adu**
S. brasiliensis (b)	Size class	5.3230	2	0.00698	** *Sub* ***Juv*** **Adu**
S. stellifer (c)	Area	14.595	2	0.000005	** *U L* **M**
Plastic debris (weight)					
Total (a)	Area	8.3884	2	0.00036	** *U L* **M**
	Interaction (area *vs* specie)	3.1744	2	0.04476	*
S. brasiliensis (b)	Season	2.9910	3	0.03650	** *ED LD* ***ER*** **LR**
S. stellifer (c)	Area	9.3854	2	0.00024	** *U L* **M**

Capitulo 6

Conclusões

Conclusões

A descarga fluvial resultante das chuvas sazonais foi importante para definir a utilização dos habitats pelas diferentes fases ontogenéticas das espécies estudadas ao longo do canal principal do Estuário do Rio Goiana. Durante o presente estudo foi observado que a porção intermediária do estuário foi importante como local de berçário e alimentação para jovens, além de ser utilizada para alimentação por todas as espécies estudadas. Durante o final da estação seca as espécies *C. spixii* e *C. agassizii* utilizaram a porção superior do estuário como área de reprodução, desova e proteção dos ovos, larvas vitelínicas e pré-juvenis. Durante o ínicio das chuvas as duas espécies de bagres passaram a utilizar a porção intermediária para esta função. Ainda no ínicio da estação chuvosa, foi observada a liberação dos jovens de *C. spixii* e *C. agassizii* na porção intermediária do estuário, que passou a exercer também a função de berçário para estas duas espécies. No final da estação chuvosa a porção inferior do estuário passou a exercer a função de berçário para a espécie *C. spixii*. Os ariideos são predominantemente zoobentívoros, mas ao longo do seu ciclo de vida, e entre os diferentes locais e estações do ano, sua guilda trófica pode mudar para zooplanctívoro ou até mesmo oportunista. Durante o início da estação seca, nas porções superior e intermediária do estuário, sub-adultos e adultos de *C. spixii* demonstraram sobreposição alimentar, principalmente pela elevada ingestão de Polychaeta e Ostracoda. No final da seca, no estuário superior, os adultos da espécie *C. spixii* apresentaram sobreposição alimentar entre os jovens e adultos da espécie *C. agassizii*, devido à elevada ingestão de Gastropoda, Ostracoda e Calanoida. Durante o início da chuva, na porção superior do estuário, foram observadas sobreposições na dieta entre jovens e sub-adultos das duas espécies, e entre jovens e sub-adultos de *C. agassizii*, influenciada pela alta ingestão de Ostracoda e Calanoida. Durante o final da chuva, no estuário intermediário, esta sobreposição foi observada entre jovens e sub-adultos de *C. spixii* e *C. agassizii*, com alta ingestão de Gastropoda, Calanoida e Harpacticoida. Durante este período, na porção inferior do estuário, *C. spixii* e *C. agassizii* jovens e sub-adultos demonstraram sobreposição alimentar, com elevada ingestão de Gastropoda, Calanoida e Ostracoda. As espécies *S. brasiliensis* e *S. stellifer* utilizaram preferencialmente a porção intermediária do estuário como berçário para os jovens, principalmente durante a estação chuvosa. As espécies *S. brasiliensis* e *s. stellifer* são especialmente zoobentívoras, mas ao longo do ciclo de vida, e entre as estações do ano e diferentes habitats esta guilda trófica pode variar para oportunista ou até mesmo zooplanctívora. Durante o final da estação chuvosa na porção inferior do estuário todas as fases ontogenéticas de ambas as espécies, com exceção de jovens de *S. brasiliensis* e adultos de *S. stellifer*, apresentaram sobreposição alimentar indicando a similaridade na utilização das presas. Esta sobreposição foi influenciada pelo consumo de Calanoida, Polychaeta e Eucarida por todas as fases das duas espécies. O conhecimento dos hábitos alimentares e a utilização dos habitats pelas diferentes fases ontogenéticas é essencial para entender o papel ecológico das populações de peixes, sendo uma ferramenta fundamental para o desenvolvimento de planos de manejo e conservação.

Para a realização de um manejo sustentável no Estuário do Rio Goiana, as épocas do ano (principalmente a estação chuvosa) e as áreas do estuário, devem ser levadas em consideração na tomada de decisões a respeito do uso destes habitats. Estas espécies estudadas apresentam pequena importância para a pesca artesanal porém, devido a sua grande abundância, principalmente de jovens, elas representam uma importante fonte de proteína animal para predadores e outros animais marinhos que visitam o estuário para se alimentar, inclusive diversas espécies com alto valor comercial, como por exemplo as espécies do gênero *Centropomus* spp. (Robalos), *Trichiurus lepturus* (Peixe-espada), *Pterengraulis atherinoides* (Anchovia) e *Trachurus symmetricus* (Carapau).

Além disso, o problema ambiental da ingestão de plástico e fios de nylon provenientes da pesca, observado em todas as fases ontogenéticas de todas as espécies estudadas durante o presente estudo, deve ser discutido pelas autoridades e pela comunidade para que se possa chegar a um consenso a respeito de formas de manejo que ajudem ao menos a minimizar este impacto.

Este estuário ainda se mantém preservado, embora a poluição hídrica de origem industrial e doméstica, além do corte e aterros de manguezais para a implantação de grandes projetos de carcinicultura, e a atividade da cana de açúcar, representem uma ameaça à sua preservação. Os municípios costeiros de Goiana (PE), Caaporã e Pitimbu (PB) margeiam o estuário do Rio Goiana, utilizando diretamente os recursos disponíveis neste ecossistema. O município de Goiana, em 2007, foi responsável por 29% da produção de Pernambuco, com 19% referente ao desembarque pesqueiro (IBAMA 2009). Esses dados demonstram a importância deste estuário, e das áreas continentais e costeiras adjacentes, para a produtividade pesqueira artesanal e comercial. Além disso, é importante destacar que esse estuário também apresenta um papel importante para a pesca de subsistência, pois, muitos ribeirinhos dependem diretamente desse ecossistema para a sua sobrevivência.

Recentemente foi criada a Rexex Acaú-Goiana, pelo decreto presidêncial s/nº de 26 de setembro de 2007. Essa Resex é uma unidade de conservação federal categorizada como reserva extrativista, e se estende por uma área de 6.678ha, abrangendo os municípios de Caaporã e Pitimbu na Paraíba e Goiana em Pernambuco. A Reserva Extrativista (REx) de domínio mínimo é uma área utilizada por populações tradicionais, cuja sobrevivência baseia-se no extrativismo e, complementarmente, na agricultura de subsistência e na criação de animais de pequeno porte. Tem como objetivos básicos proteger os meios da vida e a cultura dessas populações, e assegurar o uso sustentável dos recursos naturais da unidade. No Brasil, a Reserva Extrativista é gerida por um conselho deliberativo, presidido pelo órgão responsável por sua administração e constituído por representantes de órgãos públicos, de organizações da sociedade civil e das populações tradicionais residentes na área, conforme se dispuser em regulamento e no ato de criação da unidade. As reservas extrativistas federais são administradas pelo Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio).

De acordo com estas informações, o presente estudo representa uma importante contribuição para os futuros planos de manejo que objetivem a sustentabilidade da recém criada Resex Acaú-Goiana. Qualquer plano de manejo sugerido pelo conselho deliberativo, que administra os recursos dessa Unidade de Conservação, deve estar baseado em informações científicas consolidadas a respeito da ecologia e da dinâmica espaço-temporal dos diferentes habitats do estuário do Rio Goiana. Além de apresentar importantes informações a respeito da ecologia das espécies mais abundantes deste ecossistema em questão, este estudo apresenta também informações a respeito de impactos ambientais que a fauna dessa região esta sorendo pelas ações antrópicas decorrentes da falta de gestão apropriada dos seus recursos.

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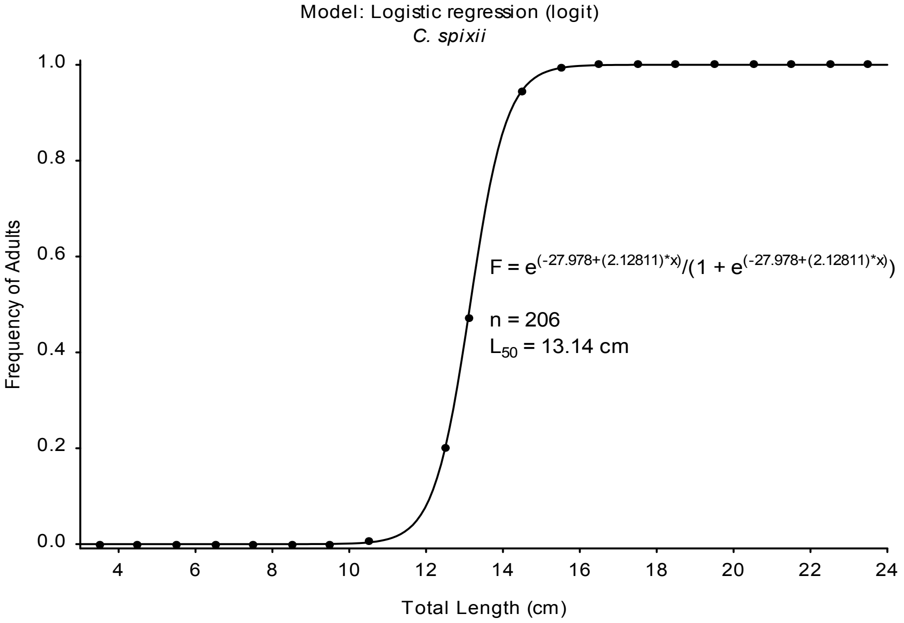
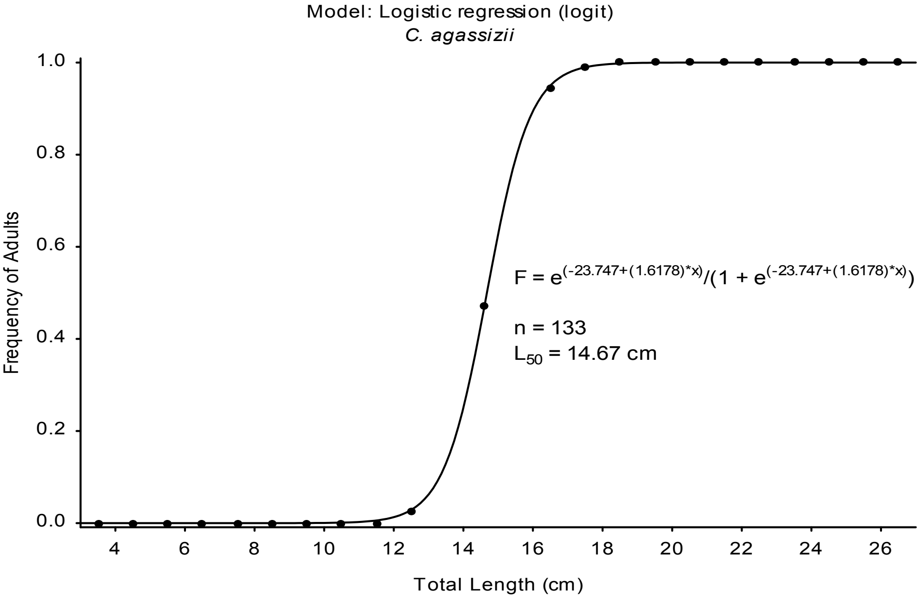
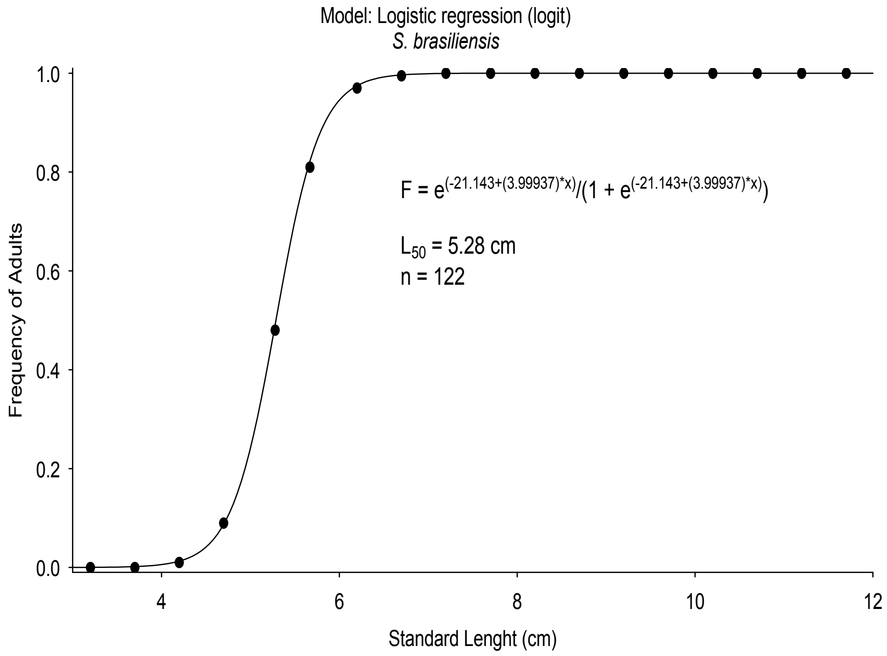
ANEXOS

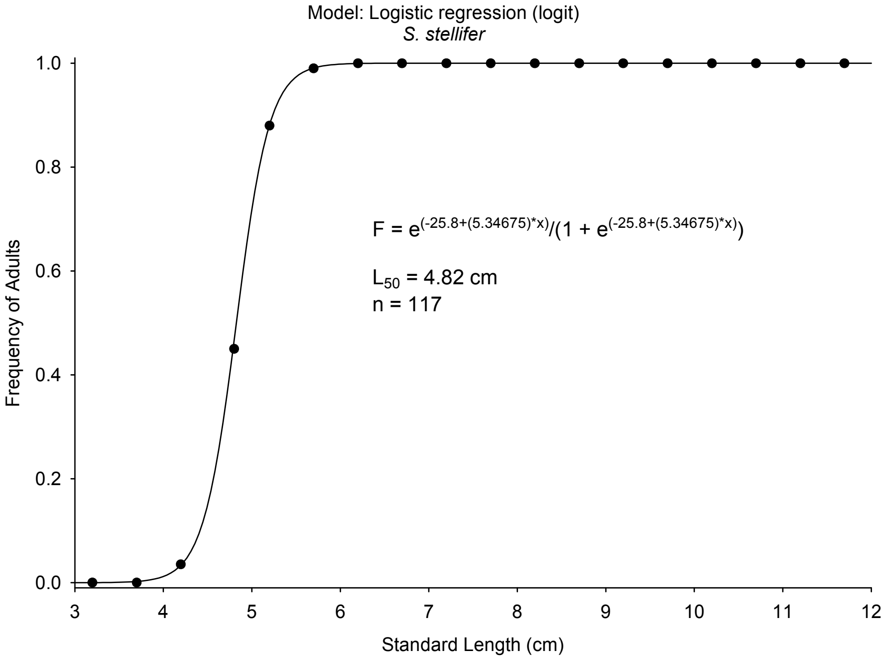




Anexo I. Curva logística da frequência relativa de adultos por comprimento total das espécies: *Cathorops spixii* e *Cathorops agassizii*. L_{50} indica o comprimento em que 50% dos indivíduos atingem a maturação.

ANEXOS





Anexo II. Curva logística da frequência relativa de adultos por comprimento padrão das espécies: *Stellifer brasiliensis* e *Stellifer stellifer*. L_{50} indica o comprimento em que 50% dos indivíduos atingem a maturação.