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Implicações de fatores ambientais na deposição de plásticos no ambiente praial de um ecossistema estuarino.

Orientadora: Dr. Monica Costa

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Sumário

Resumo

O lixo marinho constitui todo aquele material de origem antropogênica, como plástico, papel, vidro, madeira e outros, que chega aos ambientes marinho e costeiro por diversas fontes, e é um dos principais poluentes marinhos do século XXI. As praias são os ambientes mais estudados com relação à contaminação por lixo marinho, mas praias estuarinas são raramente foco de estudos sistemáticos. Uma praia estuarina localizada no estuário do Rio Goiana (PE/PB) foi monitorada entre abril de 2006 e março de 2007. Foram monitorados três transectos de 20m de largura, divididos em dois estratos, a praia (ou estirâncio) e a pós-praia, que foram amostrados separadamente. Mensalmente, os transectos foram monitorados e totalmente limpos, sendo observadas quantidades, composição, categorias de tamanho (1-10cm², 11-100cm², 101-1000cm², >1001cm²) e estimadas as principais fontes mais prováveis do lixo marinho. Parâmetros meteorológicos, morfológicos e físico-químicos foram registrados. Uma estação chuvosa (abril a setembro de 2006) e uma estação seca (outubro de 2006 a março de 2007) foram definidas. No período de chuva, a praia estava significativamente mais contaminada. O plástico foi o tipo de item mais amostrado em todos os meses. As fontes identificadas foram o Rio Goiana (63,2%) e a atividade de pesca (37,5%), para a qual foram encontradas diferenças significativas entre a temporada da pesca da lagosta (Maio-Agosto) e os outros meses do ano. Apesar de o balanço sedimentar ao final de 12 meses ter sido neutro, houve deposição e erosão da praia em diferente meses do ano. A categoria 11-100cm² representou 56% dos resíduos coletados, seguido por 1-10cm² (26%), 101-1000cm² (15%) e >1001cm² (3%). Foram encontradas diferenças significativas entre o Rio Goiana e a categoria de >1001 cm² e fontes mistas e as categorias 101-1000 e >1001 cm². Houve diferença significativa, em número total de itens, entre a praia e a pós-praia, entre os meses de chuva e seca e entre as categorias de tamanho amostradas. Os itens predominantes foram fragmentos e embalagens de plástico mole, fragmentos de isopor, fragmentos de copo, fragmentos e embalagens de plástico duro e sacolas plásticas na praia e pós-praia, para cada uma das categorias de tamanho. Os plásticos moles com fontes no Rio Goiana e mistas são mais encontrados na praia, enquanto plásticos rígidos com fontes no Rio Goiana e na pesca são mais encontrados na pós-praia. Itens foram analisados separadamente, e para o estuário do Rio Goiana, foi estimado o risco potencial de cada um deles para a comunidade biológica local (ingestão, emaranhamento, incrustação) e a população ribeirinha (qualidade estética da praia, atividades de pesca e outras embarcações, problemas de saúde pública). As sacolas plásticas e as embalagens de plástico mole de >1001cm^2 foram consideradas os itens mais perigosos. No geral, a ingestão e a perda da qualidade estética são os principais impactos previstos nessa análise. Recomenda-se como prioridade de ação para o abatimento desse tipo de poluição no estuário do Rio Goiana a disponibilização de infra-estrutura básica para recolhimento de lixo e esgoto para as embarcações e população das vilas de Acaú e Carne de Vaca.

Palavras-chave: lixo marinho, Estuário do Rio Goiana, Nordeste do Brasil.

Abstract

Marine debris are materials from anthropogenic sources, such as plastics, paper, glass, wood and others, that enter the marine and coastal environments from multiple sources, and are considered as one of the most important marine pollutants by the turn of the XXI Century. Sandy beaches are usually more studied because they are relatively easy to be monitored, but estuarine beaches are rarely the focus of systematic works. An estuarine beach on the Goiana River estuary (PE/PB) was monitored from April 2006 to March 2007. Three 20m wide replicate transects divided into two strata, foreshore and backshore, were individually monitored. Monthly, transects were monitored and cleaned, being registered quantities, composition, size categories (1-10cm², 11-100cm², 101-1000cm², >1001cm²) and, the most probable sources were estimated. Meteorological, morphological and physico-chemical parameters were registered. A rainy season (April to September 2006) and a dry season (October 2006 to March 2007) were defined. In rainy season, the beach was significantly more contaminated by marine debris. Plastics were the prevalent type of item in all monitored months. Identified sources were the Goiana River estuary (63.2%) and fishing activities (37.5%), and significant differences in the number of fishing-related items were registered between the lobster fishing months (May to August) and the other months. In spite of the neutral sedimentary balance in a one year cycle, there is deposition and erosion of the beach in different months. The most common category was 11-100cm² with 56% of the total items, followed by 1-10cm² (26%), 101-1000cm² (15%) e >1001cm² (3%). There were significant differences between the Goiana River source and >1001 cm² size category, and between mixed sources and 101-1000 e >1001 cm² categories. There were significant differences, in the total number of items, between foreshore and backshore, the rainy and dry months and the size categories sampled. Prevalent items were fragments and soft packaging, polystyrene fragments, fragments of cups, fragments and rigid plastic containers and plastic bags on the foreshore and backshore for each size categories. Soft plastics from the Goiana River and from mixed sources were more sampled on the foreshore, while rigid plastics from the Goiana River and from fishing activities were more sampled on the backshore. The most sampled items were individually analyzed and the potential risk of each one was estimated to both the biota (ingestion, entanglement, fouling) and the riverine population (scenic quality, boating and fishing, human health). For this particular size, plastic bags and soft packaging with >1001cm² are considered the most dangerous items. In general, ingestion and degradation of the scenic quality were the most important impacts. It is recommended, as priority actions to the reduction of this type of marine pollution in the estuary, the introduction of alternatives to the collection of solid wastes and sewage from fishing boats and from the riverine population from Acaú and Carne de Vaca.

Key-words: marine debris, Goiana River estuary, Northeast Brazil.

Introdução

Objeto de estudo

O termo “marine debris” pode ser traduzido para a língua portuguesa como lixo marinho, ou resíduo sólido marinho, e pode ser entendido como sendo qualquer resíduo sólido (plástico, isopor, papel, vidro, madeira e outros) que tenha sido introduzido nos diversos habitats dos ambientes marinho e costeiro por qualquer fonte (Coe e Rogers, 2000[1]). O lixo marinho, juntamente com os poluentes orgânicos sintéticos, constitui um grupo de poluentes de origem exclusivamente antrópica, o que implica na ausência natural destes do meio ambiente, mesmo que em pequenas concentrações, sem a intervenção humana. Porém, devido aos sistemas inadequados de coleta e estocagem de resíduos sólidos domésticos, comerciais ou industriais, desde a sua produção até o seu descarte, diversos fatores convergem para condenar um resíduo sólido a se tornar um contaminante marinho.

Talvez nenhum outro tipo de contaminante seja tão familiar à sociedade (Coe e Rogers, 2000[1]) e, dentre eles, provavelmente nenhum é tão familiar quanto os plásticos. Este fato, aliado à idéia dos oceanos terem sido no passado considerados como depósitos adequados de resíduos produzidos pelo homem, fizeram com que os efeitos deletérios relacionados ao lixo marinho fossem por muito tempo desconhecidos e subestimados. Entretanto, atualmente, estes são considerados como um dos principais poluentes marinhos do século XXI (Ivar do Sul e Costa, 2007[2]).

O crescimento acelerado da população, o desenvolvimento desordenado de cidades, principalmente nas zonas costeiras, e o aumento da produção e uso de plásticos em escala global, agravam ainda mais o cenário atual e indicam um futuro incerto. Sendo assim, o presente estudo se justifica: (1) pela geração de informações de base referentes à contaminação por lixo marinho, essenciais para a deliberação e adequação de medidas preventivas e mitigadoras, que podem ser aplicadas em escalas local, regional e nacional; (2) abertura de uma nova linha de pesquisa focada no monitoramento sistemático de lixo marinho em praias estuarinas, até então inexistente em nível nacional e reduzida a estudos esparsos em nível internacional.

No Brasil, estudos em praias são limitados a poucos setores do litoral, embora novos grupos estejam desenvolvendo metodologias e avaliando novas regiões e habitats (Ivar do Sul e Costa, 2007[2]). Por isso, foi desenvolvido um desenho amostral que envolvesse

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[1] Coe, J.M. & Rogers, D.B. (Eds). 2000. Marine Debris: sources, impacts and solutions. New York: Springer. 431p.
[2] Ivar do Sul, J.A. & Costa, M.F. 2007. Marine debris review for Latin America and the Wider Caribbean Region: from the 1970 until now and where do we go from here? Marine Pollution Bulletin, 54, 1087-1104.

não só a quali-quantificação do lixo marinho por tipo de material e/ou fonte, mas também outra variável, pouco medida, mas de grande importância: o tamanho dos itens. O conhecimento desta variável fornece pistas importantes sobre o tempo de exposição dos itens no ambiente, os riscos associados à biota marinha e costeira e, por fim, auxilia na tomada de decisões gerenciais e na remediação e/ou prevenção relacionadas ao lixo marinho no ambiente.

Na determinação do tamanho do lixo marinho em uma área, os itens são individualmente medidos, e geralmente classificados e agrupados em categorias ou classes de tamanho. Estas categorias indicam a escala de tamanho utilizada no estudo (µm, mm, cm, m) e determinam a acuracidade dos resultados, o que depende principalmente dos objetivos, mas também do local de trabalho e das características do lixo marinho a ser amostrado. Como a bibliografia internacional sobre lixo marinho engloba estudos de objetivos diversos, em múltiplos ambientes (praia, assoalho oceânico, superfície do mar), e que podem variar desde a amostragem de um transecto até o monitoramento de centenas de km, é observada uma discrepância em relação às categorias de tamanho de lixo marinho utilizadas e, sobretudo, não há um consenso em relação à nomenclatura empregada (Tabela 1).

Tabela 1: Exemplos de nomenclaturas e categorias de tamanho utilizadas em estudos sobre lixo marinho.

Nomenclatura	Ribic (1990)[a]	Gregory (1990)[b]	Ribic et al. (1992)[c]	Gregory (1999)[d]	Boland e Donohue (2003)[e]
Mega	> 2-3 cm	Visível por um observador a bordo	> 1m	Visível por um observador a bordo	> 25 m^2
Macro	5 mm a 2-3 cm	Fragmentos	> 10 cm e ≤ 1m	Visível por um observador na praia	11 a 25 m^2
Meso	< 5 mm	Esférulas plásticas	≥ 2,5 cm e ≤ 10 cm	5mm - 1cm	5 a 10 m^2
Micro	Invisível a olho nú	< 5 mm	< 2,5 cm	63 µm - 500 µm	< 5 m^2

(a) Ribic, C.A. 1990. Report of the working group on methods to assess the amount and types of marine debris. In Shomura, R.S. & Godfrey, M.L. (Eds.), Proceedings of the Second International Conference on Marine Debris, 2-7 April 1989, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154; (b) Gregory, M.R. 1990. Plastics: accumulation distribution and environmental effects of meso-macro- and megalittre in the surface waters and on shores of the Southwest Pacific. In Shomura, R.S. & Godfrey, M.L. (Eds.), Proceedings of the Second International Conference on Marine Debris, 2-7 April 1989, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154; (c) Ribic, C.A., Dixon, T.R. & Vining, I. 1992. Marine Debris Survey Manual. NOAA Technical Report NMFS 108, 92 pp; (d) Gregory, M.R. 1999. Plastics and South Pacific Island shores: environmental implications. Ocean and Coastal Management 42, 603-615; (e) Boland, R.C. & Donohue, M.J. 2003. Marine debris accumulation in the nearshore marine habitat of the endangered Hawaiian monk seal, Monachus schauinslandi 1999–2001. Marine Pollution Bulletin 46, 1385-1394.

Para o presente estudo foi escolhida a unidade cm² e quatro categorias de tamanho: 1-10cm², 11-100cm², 101-1000cm², >1001cm². A determinação da área de cada item, e não de sua medida linear como descrito na bibliografia internacional (Tabela 1) permite uma melhor avaliação individual de cada tipo de item e apresenta ainda vantagens, já que fornece informações não só do tamanho do lixo, mas também de outras características como:

- Comportamento do lixo marinho nos diversos ambientes, como por exemplo, sua dispersão (transporte) e tempo de permanência no ambiente;
- Riscos associados à presença dos itens nos diversos ambientes, como riscos à biota (ingestão, emaranhamento e outros) e às populações humanas (ferimentos, cortes, gastos com limpezas públicas);
- Informações sobre medidas mitigadoras (limpeza da praia) e preventivas (educação e conscientização ambiental da população) mais eficazes para problemas relacionados ao lixo marinho de cada região.

A determinação da área (cm²) dos itens do lixo marinho mostra-se ainda uma medida mais interessante, já que as medidas lineares são normalmente imprecisas e limitadas, avaliando erradamente o real tamanho dos diversos tipos de itens. Somando-se os dois capítulos deste volume a dois trabalhos pré-existentes (ref. a Madzena e Lasiak, 1997[3]; Ivar do Sul, 2005[4]) que utilizaram as mesmas categorias, tem-se no total pelo menos quatro estudos que podem ser comparados entre si quanto a variável tamanho, e que podem ser utilizados como base para estudos posteriores. Acredita-se que a utilização de intervalos englobando categorias de tamanho e não uma nomenclatura pouco específica (Tabela 1) também facilitaria futuras comparações com outros estudos.

O presente trabalho apresenta os primeiros dados sistemáticos sobre o lixo marinho no estuário do Rio Goiana (PE/PB), e por se tratar de uma pesquisa de base, foi priorizada a amostragem de itens >1cm². Itens <1cm², não facilmente visíveis a olho nu durante as amostragens em praias, não foram considerados neste momento, mas provavelmente estão presentes no local de estudo, já que são resultado de sucessivos processos de fragmentação de itens maiores. Já itens muito maiores que >1001cm² são muito raros, apesar de estarem incluídos nesta categoria.

Área de estudo

Os estuários da costa semi-árida do nordeste do Brasil, com exceção do rio São Francisco (AL/SE), são em geral pequenos, e as águas que deságuam no Oceano Atlântico são de bacias costeiras de áreas reduzidas (poucas centenas de km) e nem sempre perenes. Esses estuários foram os primeiros pontos de chegada e instalação dos europeus, que já os encontraram habitados e explorados pelas populações nativas. Uma das principais formas de uso e ocupação do solo desde então foi a retirada da Mata Atlântica para estabelecimento de feitorias, exploração de madeiras nobres e o cultivo da

[3] Madzena, A. & Lasiak, T. 1997. Spatial and Temporal variations in beach litter on the Transkei coats of South Africa. Marine Pollution Bulletin 34, 900-907.
[4] Ivar do Sul, J.A. 2005. Lixo marinho na área de desova de tartarugas marinhas no litoral norte da Bahia: conseqüências para o meio ambiente e moradores locais. Monografia, Fundação Universidade Federal do Rio Grande, 62 pp.

cana-de-açúcar. As áreas de restinga também foram desmatadas para o cultivo do côco-da-Bahia. Essas transformações, que ocorreram desde o século XVI, há mais de 500 anos, podem ter modificado severamente as áreas costeiras e principalmente os seus recursos hídricos.

Outros ecossistemas, associados ao bioma da Mata Atlântica, extremamente modificados foram os bosques manguezais e as planícies alagadas costeiras, esses um pouco mais tarde do que as terras firmes, devido à instabilidade de seu terreno. No entanto, sabe-se que grandes áreas também foram desmatadas, aterradas e ocupadas ao longo de todo o litoral brasileiro, principalmente no nordeste. As modificações sofridas pelo entorno dos estuários levaram, e ainda levam a profundas modificações de sua qualidade de águas. Essa situação se agrava em corpos d'água pequenos, com pequeno poder de diluição e recuperação, como é o caso dos estuários da costa semi-árida nordestina. Recentemente, o desenvolvimento de técnicas agrícolas mais agressivas (principalmente a utilização de adubos químicos e produtos sintéticos na lavoura da cana-de-açúcar) e a carcinocultura, aumentaram os impactos físicos e químicos sobre os recursos estuarinos. O crescimento populacional desenfreado e a grande concentração populacional nas áreas costeiras, que levam à formação de áreas urbanizadas não planejadas e, consequentemente, ao lançamento de efluentes domésticos e industriais, também contribuem com a contaminação dos diversos habitats do ecossistema estuarino e costeiro. As pequenas bacias da costa semi-árida nordestina dependem em curto prazo (escala intra e inter-anual) do regime de chuvas tropicais que domina o clima da região. Dessa forma, além das pressões antrópicas, também estão sujeitas às variações climáticas de médio prazo (ciclos de alguns anos).

A bacia hidrográfica do Rio Goiana, formada pelas sub-bacias dos rios Tracunhaém e Capibaribe Mirim, localiza-se quase que inteiramente no estado de Pernambuco. Possui área de cerca de 2.900km^2 e abriga uma população predominantemente (60%) urbana de 500.000 habitantes, distribuídos em 25 municípios (sendo sete sedes cortadas pelos afluentes). O uso e ocupação do solo incluem urbanização parcialmente ou não planejada, indústrias de base, agro-indústria canavieira (plantio, moagem e produção de açúcar e álcool), policulturas (côco, mandioca, frutas tropicais e agricultura de subsistência), pecuária, reservas da Mata Atlântica e, no seu estuário, florestas de mangue, aqüicultura (carcinocultura) e pesca (www.cprh.gov.pe.br). O uso da água desta bacia destina-se ao abastecimento doméstico e das atividades econômicas acima, assim como à preservação dos ecossistemas costeiros que dela dependem (manguezais, estuário, prados de capim marinho e recifes costeiros).

A área estuarina do Rio Goiana estende-se por aproximadamente 17 km e é uma região de águas transfronteiriças, pois esse trecho forma a divisa costeira entre Pernambuco e Paraíba (aproximadamente 7º 30' Sul e 34 º 48' Oeste). É um estuário relativamente pequeno (~10 m^3 s^{-1} de vazão média mensal do rio), mas de grande importância econômica para a região (http://www.sectma.pe.gov.br). No estuário predomina o clima tropical, com duas estações (chuvosa e seca) bem marcadas. A temperatura do ar e da água variam pouco, permanecendo em torno de 24-27 ^oC e >25 ^oC respectivamente. Já a salinidade varia bastante ao longo do ano, oscilando entre um regime de águas quase permanentemente doces a completamente marinhas/costeiras em um intervalo de seis meses. O estuário, por ser raso e curto, é pouco estratificado e bem misturado. A região está sob a influência de marés semi-diurnas de aproximadamente 2m de amplitude (http://www.dhn.mar.mil.br).

O estuário do Rio Goiana é um dos estuários mais bem preservados do estado de Pernambuco e abriga uma das maiores áreas contínuas de bosques de mangues, adjacente a remanescentes da Mata Atlântica. Estas evidências são corroboradas pela alta produtividade biológica e pela presença de espécies da fauna estuarina e marinha de relevante interesse ecológico como o peixe-boi, tartarugas, peixes, crustáceos e moluscos. Dessa bacia, de recursos hídricos limitados, depende diretamente uma ampla gama de atividades econômicas, desde o abastecimento da população e indústrias, até a pesca na região costeira adjacente.

Desde o final dos anos 1960, estudos vêm sendo realizados no estuário do Rio Goiana e nas águas costeiras imediatamente adjacentes, avaliando-se principalmente sua potencialidade de produtividades primária e secundária. Os estudos destacam ainda as atividades pesqueiras no estuário e litoral deste rio; os aspectos geomorfológicos e sedimentológicos do baixo curso do Rio Goiana; os aspectos do fitoplâncton e microfitoplâncton do estuário e na praia de Carne de Vaca; o zooplanctôn e microzooplâncton no estuário; os impactos da carcinocultura sobre a bacia do Rio Goiana; a pesca de camarões peneídeos no litoral de Pitimbú; a análise dos resultados físico-químicos de qualidade da água dos relatórios de monitoramento da bacia produzidos pela CPRH; mercúrio total em *Centropomus undecimalis*, *Mugil curema* e *Achirus lineatus* do estuário do Rio Goiana; mercúrio total em *Trichiurus lepturus*; movimentos espaciais e temporais de bagres marinhos, entre outros (Barbosa, 2007[5)].

Recentemente, em setembro de 2007, uma área de 6.680 hectares, que corresponde ao estuário do Rio Goiana (exceto as terras firmes da Ilha do Tiriri), foi

[5] Barbosa, S.C.T., 2007. Contaminação de *Trichiurus lepturus* (Peixe-Espada) por mercúrio total no estuário do Rio Goiana (PE/PB). Monografia de Bacharelado em Ciências Biológicas / Modalidade Ciências Ambientais. Centro de Ciências Biológicas, Universidade Federal de Pernambuco.

declarada como Reserva Extrativista (RESEX) denominada Acaú-Goiana (Decreto Presidencial de 26 de setembro de 2007. D.O.U. no. 187, Seção 1:2-5). Segundo o decreto de sua formação, a Reserva Extrativista Acaú-Goiana tem por objetivo "proteger os meios de vida e garantir a utilização e a conservação dos recursos naturais renováveis tradicionalmente utilizados pela população extrativista das comunidades de Carne de Vaca, Povoação de São Lourenço, Tejucupapo, Baldo do Rio Goiana e Acaú e demais comunidades incluídas na área de sua abrangência". Essa reserva foi inicialmente cogitada devido à intensidade da exploração de *Anomalocardia brasiliana* (Mollusca Bivalvia). Contudo, já os primeiros estudos, e a intrínseca dependência das populações ribeirinhas com o estuário, revelaram a grande importância do conjunto dos recursos vivos do estuário para as comunidades tradicionais do seu entorno.

Objetivos

Sendo assim, o objetivo geral do presente estudo é quantificar e qualificar o lixo marinho presente em uma praia do baixo-estuário do Rio Goiana durante um ciclo anual.

Os objetivos específicos são:

(1) Identificar as categorias de tamanho e fontes do lixo marinho, reconhecendo seus padrões temporais e a sua composição quanto ao tipo de material e/ou fonte, além de investigar as relações entre as categorias de tamanho e fontes do lixo marinho.

(2) Identificar o lixo marinho por tipo de ambiente deposicional (praia e pós-praia), com ênfase nos tipos predominantes de itens, reconhecendo suas relações com as variáveis ambientais que ocorrem, além de classificar os riscos ambientais associados a estes itens, estimados em uma escala decimal (0 - 10).

O presente trabalho está, portanto, dividido em dois capítulos, que correspondem respectivamente aos objetivos específicos 1 e 2. Os Capítulos foram escritos no modelo do periódico para onde se pretende submetê-los para publicação. Após os dois capítulos, algumas conclusões e recomendações englobando ambos os trabalhos são colocadas.

Capítulo I

Temporal patterns of sources contribution and size categories of marine debris on an estuarine beach.

Abstract

Although the amounts and distribution of plastics are world-wide known for beaches, systematic studies on estuarine environments are still scarce and restricted to a handful of basins scattered around the World. Marine debris were monitored at an estuarine beach of the Goiana River Estuary (Northeast Brazil – 7^o 30'S and 34^o 50'W) for one year (April 2006 - March 2007). This beach is almost deserted and near to a seasonal lobster harbour (May to August). The beach is under the direct influence of tidal currents and river flow which changes according to the rainy (April-September) and dry (October-March) seasons. All items were removed from transects on every sampling event. Three replicate of 20m wide transects which covered back and foreshores during low tide (~100m) were used. The removed items were counted, measured and identified according to their most probable source. As expected, plastics were the main category of marine debris on the beach. The predominant size category was 11-100cm^2, which accounted for 56% of the sampled items, followed by 1-10cm^2 (26%), 101-1000cm^2 (15%) and >1001cm^2 (3%). There were items related to fishing activities (37.5%) all year long, but they were significantly reduced during the dry season. The other source identified was the Goiana River (62.3%). A link between sources and their predominant size categories was made.

Keywords: plastics at sea; size assessment, sources, fishing debris, statistical analysis.

1. Introduction

Plastics and other persistent petroleum products were recognized as one of the most important marine pollutants by the turn of the XXIst Century (Pruter, 1987; Goldberg, 1995; Ivar do Sul and Costa, 2007). They frequently represent the main fraction of debris on marine and coastal environments (Madzena and Lasiak, 1997; Derraik, 2002; Santos et al., 2005; Araújo et al, 2006), which crudely reflects the wide utilization of this material by almost every human activity. The presence of debris on coastal environments is associated with a combination of deleterious consequences, and although some of them were well documented in the international literature, others have been poorly explored so far.

Estuarine regions are closely related to marine environments, since they represent the transition between river basins and the adjacent coastal area, showing characteristics from marine, coastal and land-based habitats. However, estuaries also have particular characteristics that promote the successful retention and subsequent controlled release of nutrients and organic matter to the adjacent platform waters (Kennish, 1992). Estuarine environments are susceptible to daily physical (landscape) and chemical (most water proprieties) changes, since they are driven by several environmental variables i.e. climate, rainfall, winds, tide, longshore currents, wind generated waves and river discharges.

Estuarine regions also shelter several biota species, which live or use the protected waters to feed, grow, reproduce and hide. Some species have great importance for our societies as food and other sorts of resources. Estuaries also house the development of a wide range of human activities, such as industry, fishing, tourism and urban areas, which contribute with significant inputs of a large variety of solid and liquid wastes.

The most common sources of marine debris cited by the international literature are marine-based (e.g. boats and offshore operations), and land-based (e.g. beach users, rivers and sewage inputs). Debris from both sources can be trapped, remaining in different habitats of the estuarine environment, or transported and exported to the sea, being easily accessible to the biota. Studies concerning the qualification and the quantification of debris, its temporal and spatial patterns and even its main consequences to estuarine (and riverine) regions are still poorly explored in the scientific literature (Williams and Simmons, 1997; Thornton and Jackson, 1998; Iribarne et al., 2000; Acha et al., 2003; Wilson and Randall, 2005; Araújo and Costa, 2007).

The Goiana River Estuary is located on the Equatorial Atlantic Ocean at the latitude of approximately 7^{o} south and is located in the northern coast of Pernambuco State, forming the division with Paraíba State, Northeast Brazil (**Fig. 1a**). The area is governed by a tropical humid climate. On average (±standard deviation), rainfall during the rainy season (April-September), winter, reaches 533.1 $\pm$ 98.5mm in June (2000-2007), and during the dry season (October to March), summer, it is 43.3 $\pm$ 31.4mm in November (2000-2007) (http://www.inmet.gov.br). Tides are semi-diurnal with a mean range of 2m (http://www.dhn.mar.mil.br).

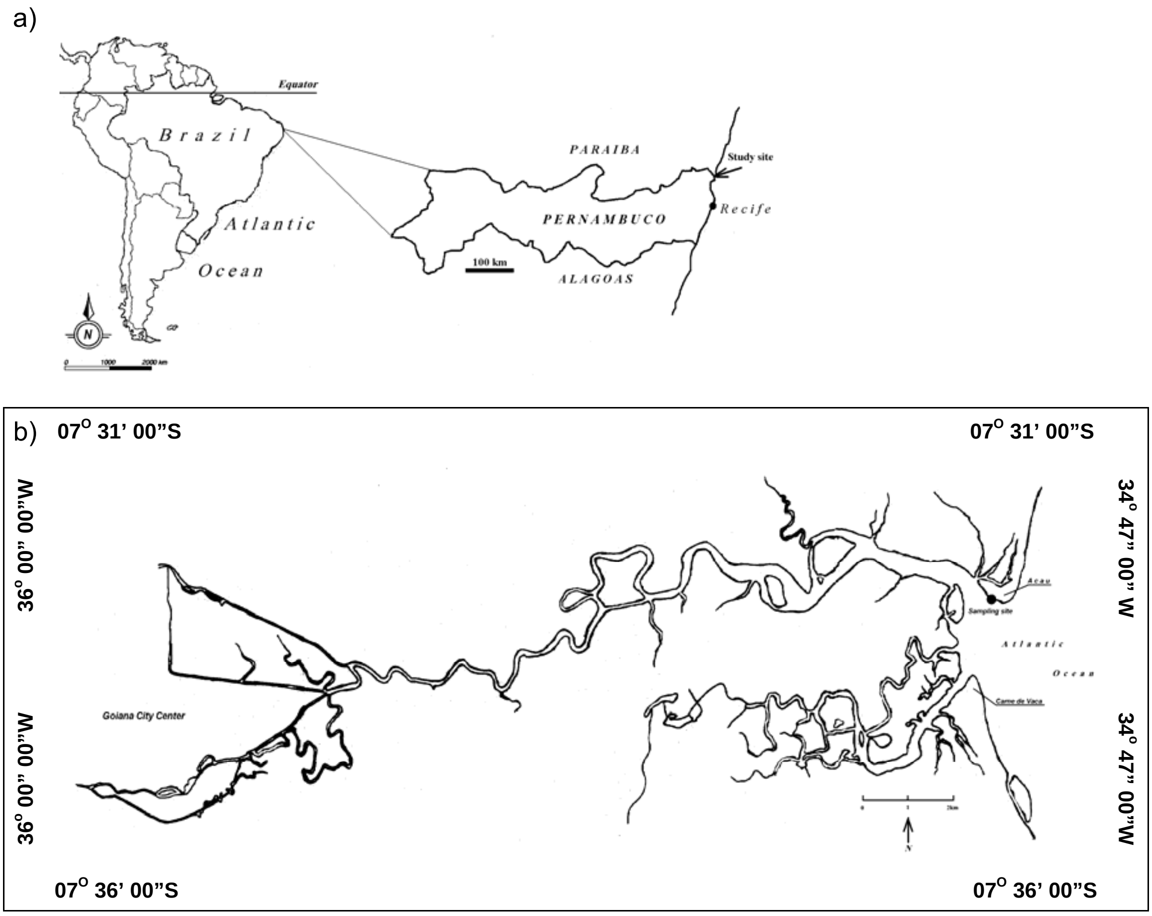

Figure 1: a) Map of the study area. b) the Goiana River Estuary and (•) the sampling site.

The Goiana River is formed at Goiana City, after its basin is fed by a number of small rivers which comprise a network of small drainage channels covering almost 3,000km² and sheltering 500,000 inhabitants, industries, cattle-raising, mining, sugar cane and aquaculture activities. The main channel of the estuary (17km) is subject to domestic and industrial sewages inputs, effluents from sugar cane mills, and to solid debris discharges which are dumped along its entire route. Population centers and economic activities however occur mainly in the vicinity of Goiana City, while the route between it and the river mouth remains almost pristine.

The lower estuary has well-preserved mangrove-lined islands, sand banks and associated with it occurs a varied biota, including the marine manatee *Trichechus manatus.* Crustaceans, fish and molluscs have an important role to the local population, mainly related to subsistence activities. The lowest reaches of the estuary are limited by a beach rock, coral and algal reefs. Sea grass meadows are also common in the shallow parts of this area. Artisanal and commercial fishery activities occur mainly in Acaú and Carne de Vaca villages (**Fig. 1b**). Acaú is an important local port for lobster fishing landings, which occur mainly from May to August. During the dry season, it is frequented by local beach-users, but there are almost no commerce or street vendors on the beach. Carne de Vaca is also an important tourist destination within the Pernambuco State territory during the dry summer months. There, the presence of jetties on the beach probably changed the marine debris deposition/exportation on the estuarine sandy beach areas.

Estuarine sandy beaches occur near the river mouth, adjacent to the shoreline. In Acaú village (**Fig. 1b**), the foreshore width varied from 80 to 110m during the low tide and dune vegetation is observed on the backshore.

This study aimed at identifying sizes and sources of marine debris, especially the petroleum products, on an estuarine beach, recognizing its temporal patterns and composition during a seasonal cycle. We also investigated relationships between the major sources and size categories.

2. Materials and Methods

Three 20m wide replicate transects, extending from the waterline to the backshore dunes, were identified through *in situ* reference levels located in the middle of each transect and sampled for marine debris. This width was considered ideal for monitoring source-related categories of plastics in the region (Araújo et al., 2006). Transects were completely cleared in April 2006. The procedure was repeated monthly until March 2007, always at low tide.

A specific sheet was used to register debris quantities, classes of materials, especially the petroleum products (plastic and nylon, polystyrene, rubber, foam), and size categories. Plastics, expected to be the major class, were grouped according to the stiffness of the material, being rigid (broken plastics), soft (packaging, which can not be broken), ropes, fishing nets and cigarette butts.

Debris sampled each month resulted from the contribution of one or more sources, balanced by natural and anthropogenic removal and burial processes. In addition, dilution processes which re-distributed the debris on the surface of the beach were also active. Results are expressed in items.100m^{-2} to facilitate visualization of very small items.m^{-2} figures.

Categories of size (1-10cm², 11-100cm², 101-1000cm², >1001cm²) were based on Madzena and Lasiak (1997) and Ivar do Sul (2005). The size categories chosen represent consistently the most common sizes of debris found on beaches. The very small items (<1cm^2), could not be easily sampled all the time due to the varying precision in their detection when the beach is covered by organic debris and were not measured. Very large items (larger than a human being) are very rare and are not significant in surveys which consider mainly the number of items. We have chosen to use only the categories which would cover the larger majority of items and for which we could guarantee the maximum measurement precision.

The most probable source of debris in the studied area was estimated through scores (3=highly probable, 2=probable, 1=possible, 0=unlikely), considering mainly type and use of debris (Whiting, 1998) and diagnosis about each type of item were made. Land-based sources were the Goiana River basin and fishing activities. Fishing is commonly cited as a marine-based source (Jones, 1995; Ivar do Sul and Costa, 2007), but in the Goiana River estuary it was considered a land-based source, since items are generated in the estuary at the fishing harbour, during fisheries within the estuary and at the immediately adjacent coastal area, being subject to ~1km radius river transportation. Fishing related items were ropes, nets, 60-100L plastic material ice bags, plastic sashes and polystyrene, and were relatively easy to be identified (Jones, 1995; Silva-Iñiguez and Fisher, 2003; Araújo and Costa, 2006). Beach users were insignificant and were not considered as a source of debris to this beach.

Data were tested for normality, and when it was not the case, non-parametric analysis were used. The one-way ANOVA was used to assess significant differences among rainy (April to September) and dry (October to March) months, considering the total number of items. The two-way ANOVA was used to evaluate significant differences among size categories (1-10cm², 11-100cm², 101-1000cm², >1001cm²) and among all the sampling months (April 2006 to March 2007). When ANOVA showed a significant difference ($\alpha=0.05$) an *a posteriori* Tukey's test was used to determine which means were significantly different (Callegari-Jacques, 2003).

A non-parametric Kruskal-Wallis test was performed to detect a significant difference ($\alpha=0.05$) between the lobster fishing season (May to August) and the other months of the year (September to April), considering only the fishing related debris.

Chi-square analysis was used to determine patterns of size categories (1-10cm², 11-100cm², 101-1000cm², >1001cm²) within the identified sources (Goiana River basin, fishing and mixed). We also subdivided the contingency table to determine where the significant differences ($\alpha=0.01$) were (Zar, 1996). All the analyses were carried out using BioEstat 4.0 (Ayres et al., 2005).

3. Results and Discussion

During the study year, rainfall ranged from 432 mm in June to 8.7 mm in October. Wind direction was predominantly SE in winter months and E/NE in summer months. Wind velocities varied between 2.9m.s^{-1} in November and 1.6m.s^{-1} in April.

Temporal patterns of contamination and marine debris composition

The monthly counts of items presented a global average of 10.8±1.63 items.100m^{-2}. May was the month which presented the largest counts of items on the beach (18.7 items.100m^{-2}), followed closely by August and October (17.2 and 14.9 items.100m^{-2} respectively). November and January were the months with lesser number of items found on the beach (4.0 and 4.2 items.100m^{-2}, respectively) (**Fig. 2**). The one-way ANOVA indicated a significant difference among rainy (April to September 2006) and dry (October 2006 to March 2007) months (**Fig. 2**).

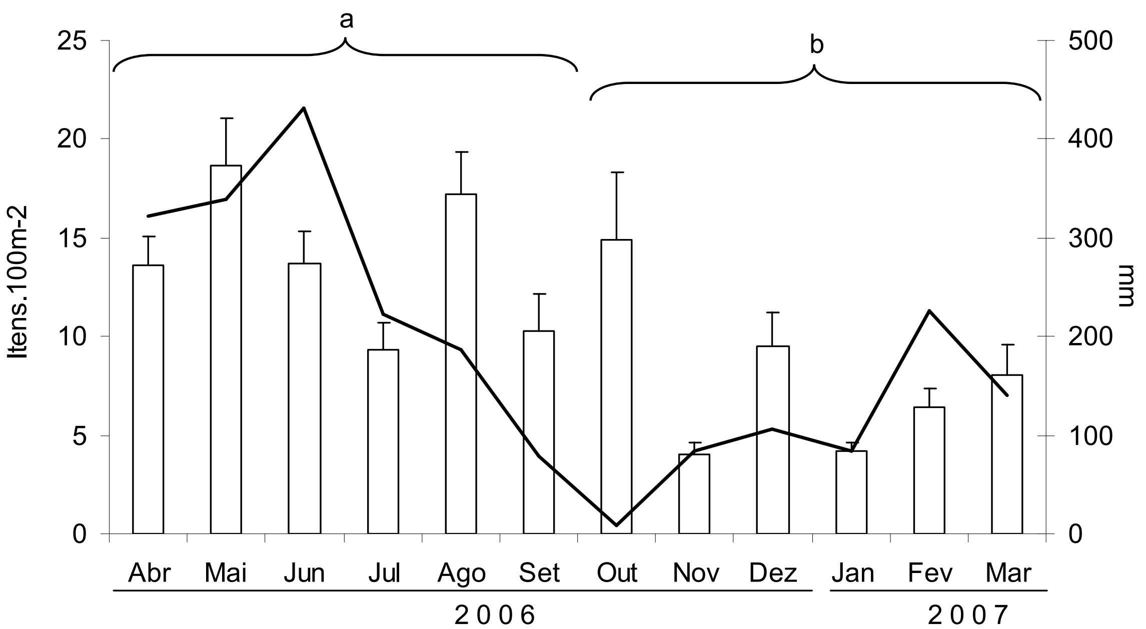

Figure 2: Temporal patterns of debris (items.100m-²) during the sampled months (April 2006 to March 2007) and rainfall (mm) on the studied beach. (a) the rainy season and (b) the dry season, significantly different.

Based on the international literature on marine debris area, no estuarine beach where debris, especially plastics, were quantified showed neither lower or similar degrees of contamination in terms of items.100m^{-2}. Other estuarine habitats reported in the literature also scored high numbers of items.100m^{-2} when compared to the beach studied here (Thornton and Jackson, 1998; Acha et al., 2003; Araújo and Costa, 2007). Beaches and other estuarine habitats might be less studied, in respect to their contamination by plastics (Derraik, 2002; Ivar do Sul and Costa, 2007), but are no less ecologically important, especially in the conservation of some key species as turtles, manatees and other living resources.

Plastic was the most common type of debris sampled on the studied beach (77%). Rigid and soft plastics were the majority (37 and 33%, respectively) followed by ropes and nets (6%) and cigarette butts (1%) (**Fig. 3**).

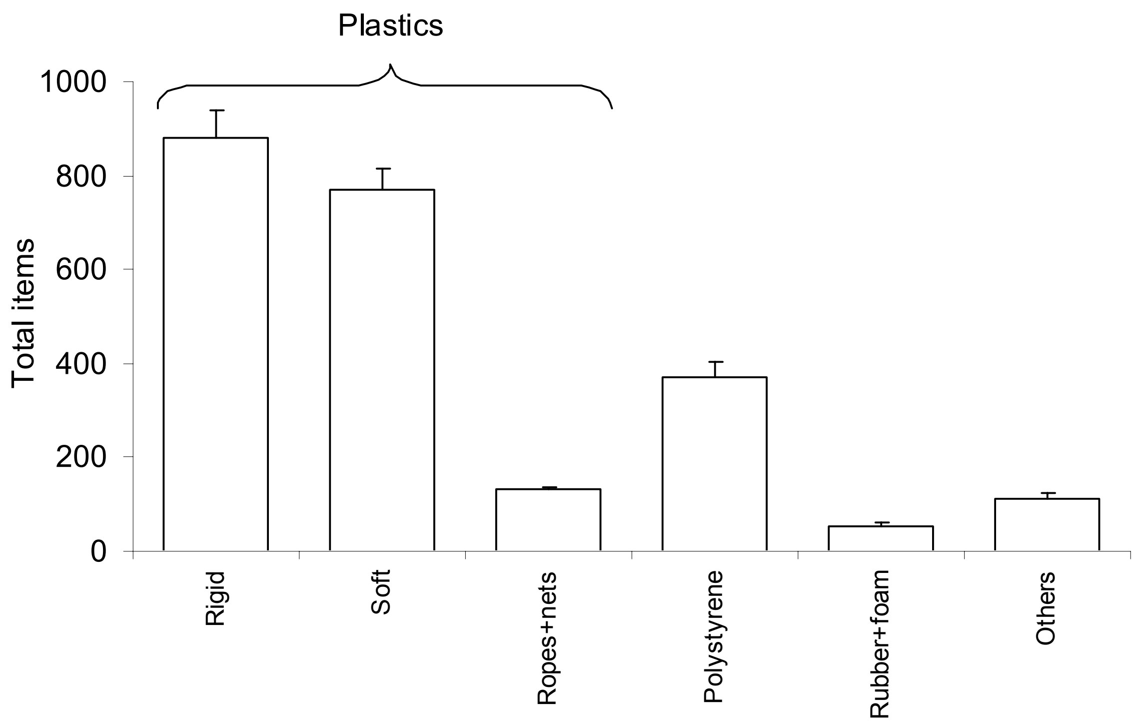

Figure 3: General composition (average of total number of items) of the sampled debris. Plastics separated according to their stiffness.

Rigid plastic containers and objects, more than the soft ones, were easily moved on the beach by waves and tides. After a long period of exposure, when the plastic material became dry and brittle, these items break in smaller pieces, resulting in large amounts of fragments sampled on the beach. Food packaging and soft items were commonly observed partially buried on the foreshore. They are moved by winds mainly when they are new (recently deposited and not wet) and fragment slowly. Cigarette butts, classified as plastics because of its composition, were typically from beach users and were rarely found on the studied beach. Petroleum products in general accounted for 95% of all sampled items (**Fig. 3**).

Debris size

Most of the sampled debris had surface areas between 11 and 100cm² (56%). Smaller items, with up to 10cm², accounted for 26% of the total amount. Fifteen per cent had 101 to 1000 cm², and only 3% of the items were in the >1001cm² category (**Table 1**).

The two-way ANOVA indicated significant differences of total number of items among size categories ($F=41.39$; $p<<0.01$) and among months ($F=3.78$; $p<<0.01$). An *a posteriori* Tukey's test showed significant differences ($p<0.01$) between the most sampled category, 11-100cm², and all the other size categories (1-10cm², 101-1000cm² and >1001cm²). A significant difference ($p<0.01$) was also registered between 1-10cm² and >1001cm² size categories. Among months, the test showed that there was significantly less debris sampled in November and January when compared with May ($p<0.01$) and August ($p<0.05$) (**Fig. 2**).

The 1-10cm² size category corresponded mainly to fragments of objects and also to small items such as caps, straws, cigarette butts, lollipop sticks cotton-buds and, representing 26% of the total sampled items (**Table 1**). Most of these items were fragments of polystyrene and food packaging (5.58 and 5.22%, respectively). The 11-100cm² category was represented mostly by fragments and the majority of them were food packaging fragments (12.58%), fragments of plastic cups (12.48%) and polystyrene fragments (8.78%). The other two size categories (101-1000 cm² and >1001cm²) were less expressive, detailing food packaging in a whole (4.3%), plastic bags (3.2%), rigid containers (2.5%), polystyrene blocks (1.6%) and ropes and fishing nets (1.5%) (**Table 1**). It is notable that fragments were the majority (they were separated by the dashed line on table 1), and in fact represent 83% of all marine debris on the studied beach. In general, fragments of food packaging, plastic cups and polystyrene accounts for 49% of all the sampled debris.

To the biota, the risk of ingestion and entanglement is most certainly present. Although there are no present hard evidences on the studied site, the size of the majority of the debris sampled during this study shows that ingestion is possible, especially for vertebrates. Entanglement, however, was observed near the studied site. A catfish entangled in a fragment of fishing net with 11-100cm² was captured in May 2006.

Indeed, the very large items (larger than a human being) were measured (>1001cm² size category) but were very rare. During the one year survey only one of these occurred on the studied beach, a couch, which was observed moving from one transect to another, was partially buried and recovered, deteriorating slowly.

Table 1: Average percent frequencies of types of debris, divided according to the size categories, during the whole year. Items are roughly arranged according to increasing frequency (within each size category) and size (each column). The dashed line divides the two largest groups of items according to their size.

Size categories	1-10cm²	11-100cm²	101-1000cm²	>1001cm²
Items/Total amounts	n =603±44.6	n=1282±97.9	n=356 ±25.0	n=73±5.5
Cotton-buds	0.32			
Lollipop	0.47			
Cigarette butts	0.68			
Plastic sashes (fragments)	0.13	0.16		
Rubber/foam (fragments)	0.26	1.38		
Others (fragments of glass, metal, paper, wood, clothes)	0.40	1.89		
Ropes (frag. and filaments) and nets (fragments)	0.88	3.25		
Plastic bags (fragments)	1.14	5.42		
Rigid fragments of containers	3.72	7.46		
Cups (fragments)	4.27	12.48		
Soft fragments of food packaging	5.22	12.58		
Polystyrene fragments	5.58	8.78		
Caps	2.95	1.11	0.42	
Dead animals		0.03		
Straws		1.00		
Cups		0.17	0.97	
PET bottles		0.28	0.14	0.52
Nappies			0.32	
Plastic sashes			0.01	0.01
Shoes			0.58	0.10
Rubber/foam			0.67	0.05
Ropes and nets			0.83	0.64
Others (glass, metal, paper, wood, clothes)			0.91	0.30
Polystyrene			1.47	0.14
Rigid containers			2.27	0.18
Plastic bags			2.72	0.48
Food packaging			3.68	0.58
Total (%)	26.0	56.0	15.0	3.0

Sources

The most probable sources of the 19 major categories of items, which were sampled during all the studied year, were classified according to a scored scale based on Whiting (1998). Five were from fishing activities, 4 were called from mixed origin (not have their source asserted), and 10 were from the Goiana River basin as a whole (**Table 2**).

Table 2: Items sampled on the beach and their probable identified sources: fishing and river sources. Scores used were 3=highly probable, 2=probable, 1=possible, 0=unlikely based in Whiting, 1998.

Items / Most possible source	Fishing		River		Diagnosis
	Scores	%	Scores	%	
Polystyrene	3	15.9	0		Fishing
Ropes and monofilaments	3	4.9	0		Fishing
Nets and nylon fragments	3	0.7	0		Fishing
Ice bags	3	0.5	1	0.15	Fishing
Plastic sashs	3	0.3	0		Fishing
Plastic bags	2	4.9	2	4.9	Mixed
PET and fragments	2	0.9	2	0.9	Mixed
Caps	2	2.2	2	2.2	Mixed
Anthopogenic wood	2	0.34	2	0.34	Mixed
Cigarret butts	1	0.2	3	0.5	River
Cups, plates and fragments	0		3	17.8	River
Soft packaging and fragments, strawls	1	4.5	3	18	River
Rigid containers and fragments	1	1.8	3	11.4	River
Glass, metals, paper, tetra pack	0		3	1.6	River
Rubber, foam	1	0.4	3	2	River
Clothes, shoes	0		3	1.8	River
Sewage (nappys and cotton-buds)	0		3	0.6	River
Others	0		3	0.1	River
Dead animals	0		3	0	River
Total (%)		**37.5**		**62.3**	**100**

Fishing items (polystyrene, ropes, nets, ice bags and plastic sashes) were 22.3% of the total sampled. Their largest occurrence coincided with the lobster fishing season (Kruskal-Wallis; $p<0.05$) which lasted from May to August (peak of the rainy season) (**Fig. 4**).

Mixed sources were also attributed to some items when even the most probable source (fishing or the Goiana River basin) of them could be identified. This happened to very common items as plastic bags, caps and PET bottles, including their fragments, which have a wide range of applications.

The other items could be considered from river sources since beach users and marine-based sources are very restricted, the last one confirmed by the absence of items with fouling. Floating and larges items could travel longer distances (Derraik, 2002; Silva-Iñiguez and Fischer; Wilson and Randall, 2005; Whiting, 1998), in the case of the present study the course from Goiana City to the lower estuary (17km), and finally be deposited on estuarine beaches. On the other hand, fragments and small items could be transported and dispersed, but are more commonly trapped on the riverine vegetation (Williams and Simmons, 1997; Whiting, 1998; Wilson and Randall, 2005). Taking into account the prevalence of fragments (**Table 1**), it is expected that they were more generated on the estuarine beach or on the adjacent areas, as a result of fragmentation process, and less from distant sources in the river basin.

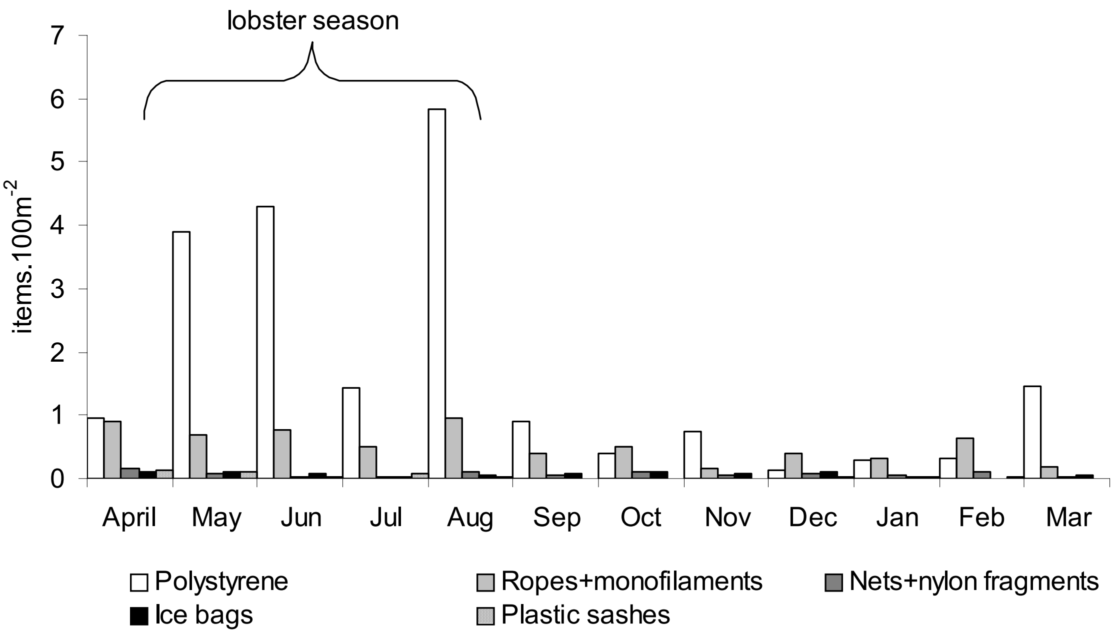

Figure 4: Temporal distribution of fishing related debris along the sampling year (April 2006 to March 2007) on the studied beach. Lobster fishing season was significantly different ($p<0.05$; Kruskal-Wallis) when compared with the other months.

Source identification is the most important step towards a definitive solution of the marine debris problem (Santos et al., 2008). Although, reliable identification of sources is complicated in some areas and for some items (Whiting, 1998; Silva-Iñiguez and Fisher, 2003; Santos et al., 2008), this is not always true. In the case of the Goiana River Estuary, the sources are reduced to a handful of possibilities (riverine sources and fishing), facilitating their positive identification. The relative importance of fishing as a positively identified source of debris for the low estuary environment is a rare case in the literature of marine debris on beaches (Nash, 1992; Jones, 1995). Also, if one considers the sum of the three scores (highly probable, probable and possible) fishing can account for up to 37% of the debris found on this estuarine beach (**Table 2**). Goiana River basin sources were, consequently, the most important source of debris (62.3%) to the studied beach, with both whole items and fragments, being the majority of the fragments although a result of fragmentation process on the beach and adjacent areas.

Size categories within each source

Measurements of surface areas can give reliable information of residence time of debris (fragmentation process), its transport in the environment, potential impacts to the marine biota and information for solving the problem of beach contamination by marine debris. We investigated the distribution of size categories within each source (*Ho*: the occurrence of the size categories is independent of the sources) (**Fig. 5**), in order to independently confirm the assumption that the debris accumulated on the study beach have been transported from the sources (aloctone) until deposition, and therefore have suffered partial fragmentation.

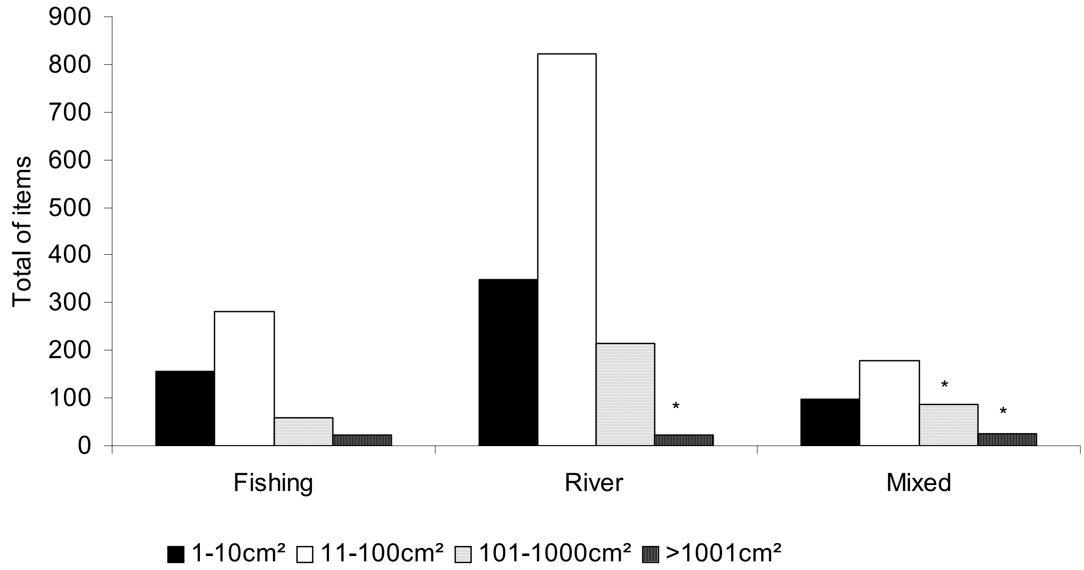

Figure 5: Average total number of items from each source and their individual size categories. Chi-squared test and the divided contingency table showed significant differences which were highlighted (*=P<<0.01).

The Chi-squared test showed a significant difference in the size distribution among the different identified sources (χ^2= 59.381; p<<0.001), rejecting the null hypothesis and showing that the distribution of the size categories varied within the identified sources. The subdivision of the contingency table (**Fig. 5**) showed significant differences for river sources on >1001cm^2 size category and mixed sources on 101-1000cm^2 and >1001cm^2 size categories, being these three interactions the major responsible for the significant effect showed on Chi-square analysis.

4. Conclusions

The identification of debris sources is widely recognized as the first, and most important, step in the direction of solving the problem of beach contamination by marine debris. We add to this scenario the need to also determine the size of the debris within each positively identified source. This will be important as a tool to assess the distance and time that each type of item can be transported before settling on an estuarine beach, or beyond. Considering these two variables will give the true scale of the managerial actions needed to cease the marine debris sources and to protect local marine and estuarine biota.

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Capítulo II

Prevalent types of marine debris and their depositional behaviour at estuarine habitats: relationships with environmental variables.

Abstract

Marine debris were monitored on an estuarine beach at the Goiana River estuary (7°S), Northeast Brazil. A pilot sampling (March 2006) showed that 20 m wide transects were ideal to monitoring plastics on estuarine beach strata, foreshore and backshore, separately. Three replicate transects were them completely cleared in April 2006 and monitored until March 2007. Composition, most probable sources, stiffness (rigid, soft) and size categories (1-10 cm², 11-100 cm², 101-1000 cm², >1001 cm²) of debris on the foreshore and backshore were registered. Meteorological (rainfall, wind direction and velocity, river flow), morphological (beach profile, sediment grain size) and physico-chemical (water temperature, salinity and Secchi depth) parameters were concomitantly measured. Most items had 11-100 cm² (56%), followed by 1-10 cm² (26%), 101-1000 cm² (15%) and >1001 cm² (3%). Identified sources were the Goiana River basin and fishing. A pattern with two well defined seasons was determined, with rainy winter months from October to March, and dry summer months from April to September, and significant differences between these seasons were reported for all environmental variables, except wind velocity. The beach presents a sedimentary equilibrium in a one year cycle, considering all replicate transects and all monitored months. Plastics were the most sampled items. Significant differences were reported, considering the total number of items, between the foreshore and backshore, between rainy and dry months and between the sampled size categories. On the foreshore, soft items from the Goiana River basin and from mixed sources were the majority, while on the backshore most items were rigid, from the Goiana River basin and from fishing. The most common items (fragments of cups, polystyrene, caps, PET bottles, rigid containers, ropes, soft packaging and plastic bags) were individually analyzed, considering each beach strata, rainy and dry months and the other environmental variables. The potential risk to the local biota (ingestion, entanglement, fouling) and to humans (scenic quality, boating and fishing, public health) was then estimated. Finally, the most important consequences to the monitored area are discussed.

Key-words: plastics, size categories, environmental variables, foreshore and backshore, risk assessment.

1. Introduction

The recognition of the importance of marine debris as a global pollutant is quite recent (Pruter, 1987; Goldberg, 1995; Ivar do Sul and Costa, 2007), but its trajectories along coastal and ocean environments are as old as the first polyethylene plastic production in the 1930s (Spokas, 2008). Although at that time, marine debris monitoring was rare, a crescent number of items started to travel at local, regional and world-wide scales. In the early 1970s, when the first studies were carried out, impacts related to plastic marine debris were already 40 years-old, and were destroying marine and coastal environments and its biota. Nowadays, risks from contact with marine debris represent a well-known sort of study, although scientists are always widening the understanding of the potential consequences of some items (e.g. Eriksson and Burton, 2003; Thompson et al., 2004).

Marine debris are solid wastes from multiple anthropogenic sources that reach coastal and marine habitats (Coe and Rogers, 2000). Sources are commonly categorized into land- (beach users, rivers, sewage inputs) and marine- (boats, offshore platforms) based sources. Plastics, polystyrene, rubber, foam, paper, glass and other types are usually identified. Marine debris are ingested or are responsible for entanglement of biota (Laist, 1997; Derraik, 2002), as seabirds (Vilestra and Praga, 2002; Mallory et al., 2006), turtles (Bugoni et al., 2001; Tomas et al., 2002), mammals (Arnold and Croxall, 1995; Secchi and Zarzur, 1999) and fishes (Sazima et al., 2002; Santos, 2006), as well as sessile animals such as coral (Donohue et al., 2001; Chiappone et al., 2005). Some items are also susceptible to be colonized by invertebrates, and transported across the oceans (Barnes, 2002). Impacts on humans are as diverse as possible, and can be landscape quality degradation (Gregory, 1999; Balance et al., 2000), health problems frequently associated with beach users (Santos et al., 2005), and damages to boating and fishing activities (Nash, 1992).

Several methods are used to monitor plastics and other debris, either floating or deposited on beaches and on the ocean floor (Ribic et al., 1992; Coe and Rogers, 2000; Spengler and Costa, 2008). Differences among works considering environmental characteristics, methods and analysis techniques make comparisons difficult (Velander and Mocogni, 1999, Araújo et al., 2006). Estuaries, although conspicuous focuses of other types of marine pollution studies, are rarely monitored for marine debris contamination (Williams and Simmons, 1997a) and, in Brazil, this lack of information is also true (Ivar do Sul and Costa, 2007).

At the Goiana River estuary (7° S), Northeast Brazil (**Fig. 1a**), estuarine sandy beaches occur near the river mouth and adjacent shoreline. In Acaú village (**Fig. 1a**) the foreshore width varies from 80 to 110m, characterized by a gentle slope. A narrow backshore covered with typical dune vegetation with a steeper slope, affected by waves only during severe storms, is also present.

The lower estuary has well-preserved mangrove-lined margins and islands, sand banks and, associated with it, occurs a varied biota, including the marine manatee *Trichechus manatus*. Crustaceans, fish and molluscs have an important role for the local population, mainly in subsistence fisheries and other activities. The lowest reaches of the estuary are limited by a beachrock, coral and calcareous algal reefs. Seagrass meadows and seaweeds banks are also common in the shallow parts of this area. Artisanal and commercial fishery activities occur mainly in Acaú and Carne de Vaca villages (**Fig. 1a**). Acaú is an important local port for lobster landings, mainly from May to August. Beach users are rare, even during summer months.

The area is governed by a tropical humid climate, with rainy winter months from April to September and dry summer months from October to March. Tides are semi-diurnal with mean amplitude of 2m (http://www.dhn.mar.mil.br).

The aims of the present work were to identify sizes, sources and the depositional behaviour of marine debris on the foreshore and backshore of a tropical estuarine beach, recognizing relationships with environmental variables as rainfall and beach morphology. In addition, the environmental risks associated to the most sampled items were estimated and ranked.

2. Materials and methods

2.1. Pilot sampling

Araújo et al. (2006) considered 20 m transects ideal for monitoring source-related categories of plastics on beaches instead of 5 to 10 m transects, noted as being the most commonly used on studies world-wide (Ivar do Sul and Costa, 2007). To test if this width is also valid to monitor plastics on different beach strata, a pilot sampling was carried out in March 2006. A 50 m wide area was vertically divided into five 10 m wide transects and each one was horizontally divided into backshore (fixed in 8 m down from the dunes) and foreshore (from the bottom limit of the backshore to the water line). All debris were collected, counted and classified. The data was Log-transformed since it was not normally distributed, and one-way ANOVA and Tukey’s test were carried out with a 1% level of significance. Sources of debris were not considered, but only the total counts of the most common types of items (polystyrene; ropes and monofilament; plastic bags; caps; cups, plates and fragments; soft packaging and fragments, straws; rigid containers and fragments) (Ivar do Sul and Costa, 2008), which were than tested for the backshore and foreshore individually (Araújo et al, 2006). To the foreshore there was no difference among widths ($F=3.5821$, $p>0.01$) and 10 m wide would be good enough to the sampling purposes of the present study. However, the backshore analysis ($F=12.8604$, $p<<0.01$) showed significant difference among widths. Tukey's test showed a significant difference between 10 m and 30, 40 and 50 m wide, while 20 m wide was not different from the larger ones. So, 20 m wide transects were adequate to monitoring plastics on transects, which would be later divided into two strata, backshore and foreshore.

2.2. Environmental variables

Environmental variables were measured concomitantly with marine debris samples, taken for the year round study in order to better characterize the environment, and try to establish possible relationships between marine debris deposition and the current estuarine environment characteristics. Beach profiles were measured according to Andrade and Ferreira (2006) for the three replicate transects. Sediments were collected on the foreshore (next to the water line), at the same time as beach profiles measurement, also in all replicate transects. Grain size analysis was carried out by sieving (at phi intervals) and results were analyzed with SysGran (Camargo, 2005). Surface water temperature and salinity were measured with a thermometer and a refractometer, respectively. Secchi depth was measured with the help of Secchi disc and measuring tape. The organic matter deposited on the beach was qualitatively classified according to its main source (marine or riverine) and photographed. River flow (simulations from 1973 to 1984) (www.sectma.pe.gov.br), rainfall and wind direction and velocity (www.inmet.gov.br) were obtained from official sources. Together, these variables provided enough information for depicting the tropical estuarine environment and the cyclic changes occurring upstream in the river basin to be linked with data on marine debris.

a)

b)

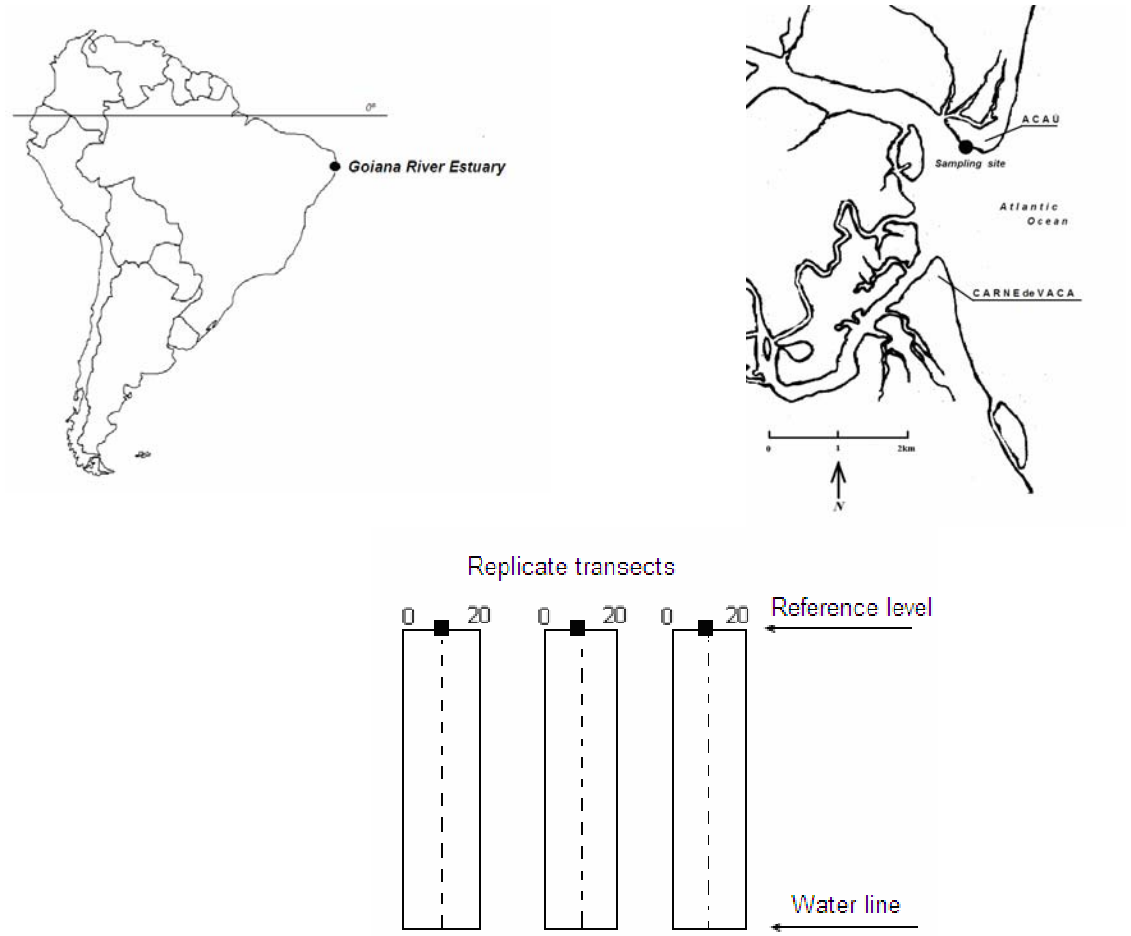


Figure 1: a) Study area and the sampling site; b) situation of the 20m wide replicate transects.

2.3. Marine debris

An area on the estuarine beach, extending from the backshore dunes to the waterline, was randomly selected. Three replicate transects 20m wide, were identified through *in situ* reference levels fixed in the middle of each transect (**Fig. 1b**). Transects were completely cleared from marine debris in April 2006. The procedure was monthly repeated until March 2007, always at low tide (Ivar do Sul and Costa, 2008). Horizontally, transects were divided into two beach strata: backshore, the area of shore lying between the average high-tide mark and the vegetation, fixed in 8m down from the dunes; and foreshore, the area between the backshore and the water line, exposed only at low tide.

Debris were collected and individually counted and classified on each of these strata. Composition, where plastics items were also divided according to its stiffness (rigid and soft), most probable use, and size categories (1-10 cm², 11-100 cm², 101-1000 cm², >1001 cm²), based on Madzena and Lasiak (1997) and Ivar do Sul (2005) were registered. Identified sources were the Goiana River basin and fishing activities (Ivar do Sul and Costa, 2008). The most common items were used to characterize the foreshore and the backshore deposition patterns, and each one was also individually analyzed, considering each beach strata, rainy and dry seasons, and the size categories.

Data were tested for normality, and when it was not the case, non-parametric analysis were used. One way ANOVA or Kruskall-Wallis were carried out to assess differences (α=0.05) of environmental variables and sand volume between rainy and dry months. Pearson's correlation analysis was performed between all variables, but only significant differences (α=0.05) are reported here.

To assess significant differences (α=0.05) between the number of items on each size category, the beach strata (foreshore and backshore) and the rainy and dry months, multivariate analysis of variance (MANOVA) was carried out. MANOVA was also carried out for significant differences on depositional patterns of the most common types of items, considering the same variables (size categories, beach strata and rainy and dry months). All data were previously transformed (ln(x)) to increase the normality of distribution.

3. Results

3.1. Environmental variables

A pattern showing two well-defined seasons could be identified in the region, and significant differences were observed for all variables, except wind velocity, between rainy (April-September) and dry (October-March) months (**Fig. 2**). During rainy months mean rainfall was 263.3 mm with a standard deviation of ±125.8 mm, and presented the water lowest temperatures (23±2.5 ºC) and salinities (11.8±5.4), low Secchi depth readings (0.4±0.3 m) and SE winds with 2.1±0.3 m s^{-1} velocities were registered. Dry months (108.3±72.3 mm) were characterized by higher water temperatures (29±0.4 ºC) and salinities (26.7±5.3), higher Secchi depth readings (0.9±0.2 m) and NE winds with 2.4±0.3 m s^{-1} velocities. River flow simulated values were also significantly different between rainy (13.6±6.8 m^3 s^{-1}) and dry (3.7±2.9 m^3 s^{-1}) seasons, and a positive correlation could be observed between it and rainfall (r=0.6118).

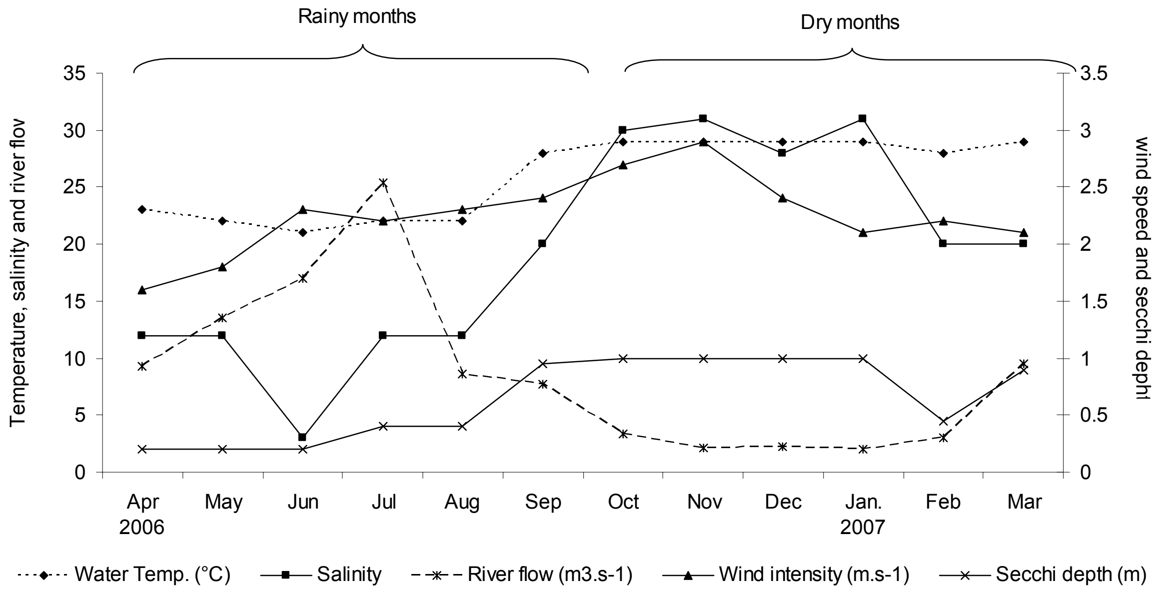
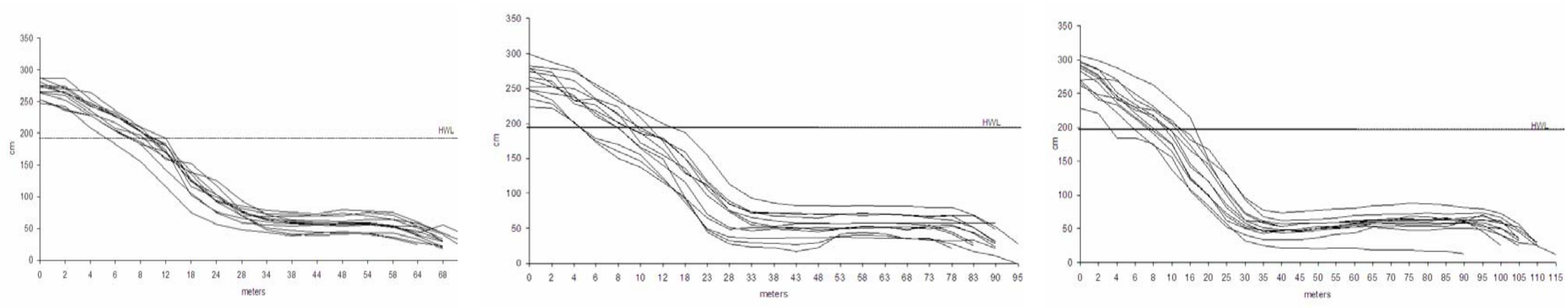


Figure 2: Physico-chemical and meteorological parameters for the sampling site from April 2006 to March 2007.

Sediment grain size also showed significant difference between rainy and dry months. However, all samples were classified as fine sand. Beach profile of the three replicate transects during the twelve months survey is shown on **Figure 3a**. It varied between replicate transects and also between months within each transect. The elevation of each profile varied between months, indicating erosion and deposition rates during monthly cycles. In length, transect 3 was longer than transect 2 and 1, respectively, in all months (**Fig. 3a**). Sand volume varied between transects and monitored months, but there was no difference from the first to the last month of the sampling period, implying in a sedimentary equilibrium of the beach, considering the three replicate transects (**Fig. 3b**). Organic matter was present in all sampling months. In general, riverine source was dominant in rainy months, when the majority of the material was concentrated on the strandline, upper foreshore. In dry months, marine sources were most frequent and deposition commonly occurred on larger areas of the foreshore. April and March seems to be transition months, when both riverine and marine organic matter appeared on the beach.

a)



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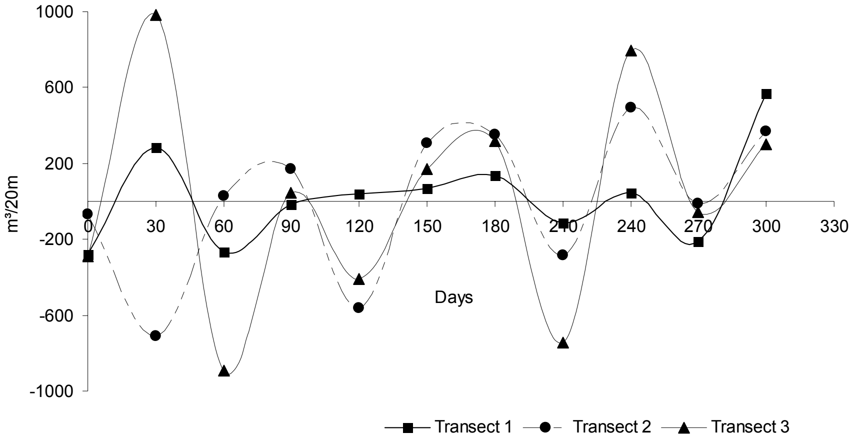

Figura 3: (a) Beach profiles of transects 1, 2 and 3 for the twelve monitored months (April 2006 to March 2007). Please note the different x and y scales. (b) Sediment volume variation between each two consecutive sampling months from April 2006 to February 2007.

3.2. Marine debris

Total number of items

A total of 6,944 items were sampled along the twelve months in the three replicate transects. The mean number of items from the three replicate transects is used. The total mean number of items was 2,314.3 ± 516.5. Plastics (rigid and soft items, ropes and nets) were responsible for 77% of all items, followed by polystyrene (15.9%) and rubber/foam (2.4%). All other materials accounted for 4.9%. Within the four size categories analyzed, 11-100 cm^2 comprises 56% of all debris. The other categories followed 1-10 cm^2 (26%), 101-1000 cm^2 (15%) and >1001 cm^2 (3%). Identified sources were the river basin (62.3%) and fishing activities (37.5%).

On the foreshore were collected 64.5% of all items (**Fig. 4**) and significant differences were reported between the foreshore and the backshore, considering the total number of items. MANOVA also showed significant differences between rainy and dry months and between size categories (**Table 1**).

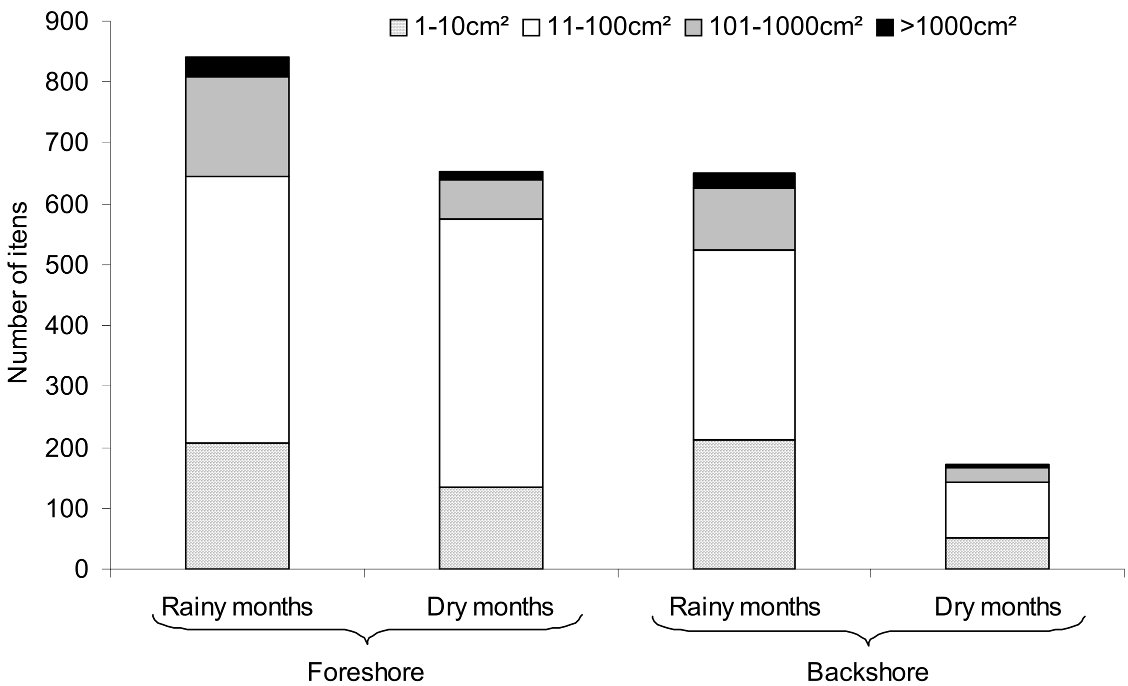

Figure 4: Comparison between the mean total number of items sampled during rainy (April-September) and dry (October-March) months on the foreshore and backshore, respectively.

On the foreshore, 59% of all items had 11-100 cm², followed by 1-10 cm² (23%), 101-1000 cm² (15%) and >1001 cm² (3%). On the backshore, relatively fewer items were from the 11-100 cm² category (49%), followed by 1-10 cm² (32%), 101-1000 cm² (15%) and >1001 cm² (3%). The two larger categories had the same relative contribution on both strata and when the whole beach was considered.

Table 1: Results of statistical analysis (MANOVA), considering the total number of items, to rainy and dry months, beach strata and size categories.

Variables	df	F	p-level
Rainy/dry months	1	10.53328	p<0.001
Foreshore/backshore	1	10.68134	p<0.001
Size categories	3	25.31785	p<0.001
Rainy/dry months X Foreshore/backshore	1	1.963178	NS
Rainy/dry months X Size categories	3	0.743518	NS
Foreshore/backshore X Size categories	3	4.148829	NS
Rainy/dry months X Foreshore/backshore X Size categories	3	1.210652	NS

Most common items

The most representative types of items in each size category, its stiffness (if plastic), and its most probable source based on a previous analysis (Ivar do Sul and Costa, 2008), were used as a study case of marine debris contamination on an estuarine beach. A general diagnosis was also done, to better characterized sources, stiffness and probable types of items that might be monitored on the foreshore and backshore of this type of environment (**Table 2**). On the foreshore, fragments of cups, soft plastics and polystyrene characterize the 1-10 cm² size category. Cups and soft plastic fragments were also the majority in the 11-100 cm² category, followed by fragments of plastic bags. Larger items (101-1000 cm²) were plastic bags, soft packaging and whole or partially broken rigid containers. The >1001 cm² category was represented by plastic bags, PET bottles and soft plastic packaging.

On the backshore, 1-10 cm² items were polystyrene fragments, PET caps and rigid fragments of containers. Fragments of polystyrene, rigid plastic containers and cups, characterized the 11-100 cm² size category. The 101-1000 cm² category was represented by fragments and blocks of polystyrene, rigid plastic containers and soft food packaging. Only two items were more common in the >1001 cm² category: PET bottles and ropes (**Table 2**).

A diagnosis, considering foreshore and backshore separately, recognized the predominance of soft plastic material from the river basin and mixed sources on the foreshore and; rigid plastic material from the river basin and fishing sources on the backshore.

Table 2: Percentage contribution and sources of the different size categories and types of items to the contamination of the foreshore and backshore, considering only the most commonly sampled items.

Size class	Foreshore	%	Plastic stiffness	Sources	Backshore	%	Plastic stiffness	Sources
1-10cm²	Cups fragments	23.8	Rigid	River	Polystyrene fragments	32.8	–	Fishing
	Soft fragments	17.5	Soft	River	PET Caps	12.5	Rigid	Mixed
	Polystyrene fragments	12.1	–	Fishing	Rigid fragments	9	Rigid	River
11-100cm²	Cups fragments	27	Rigid	River	Polystyrene fragments	29.6	–	Fishing
	Soft fragments	14.5	Soft	River	Rigid fragments	12.7	Rigid	River
	Plastic bags	13.2	Soft	Mixed	Cups fragments	8.1	Rigid	River
101-1000cm²	Plastic bags	24.6	Soft	Mixed	Polystyrene	21.7	–	Fishing
	Soft packaging	15.3	Soft	River	Rigid fragments	13.6	Rigid	River
	Rigid containers	12.8	Rigid	River	Food packaging	9.9	Soft	River
>1001cm²	Plastic bags	22.6	Soft	Mixed	PET bottles	19.8	Rigid	Mixed
	PET bottles	15.8	Rigid	Mixed	Ropes	17.4	–	Fishing
	Soft packaging	14.3	Soft	River	–	–	–	
Diagnosis			**Soft**	**River and Mixed**			**Rigid**	**River and Fishing**

MANOVA showed significant differences in total number of items between rainy and dry months for polystyrene, caps, PET bottles, ropes and soft packaging (**Table 3**). Significant differences were also registered between foreshore and backshore for cups, polystyrene, soft packaging and plastic bags. All types of items, except caps, had significant differences among the four size categories. The interaction between seasons (rainy/dry months) and beach strata (foreshore/backshore) showed a significant difference to fragments of cups, these items being more sampled in dry months, on the foreshore. For soft packaging, significant differences were reported in the interaction between beach strata (foreshore/backshore) and size categories, being items from the 11-100cm² size category more sampled on the foreshore.

Table 3: Results of statistical analysis (MANOVA) to the most common types of items, considering rainy and dry months, beach strata and size categories.

Variables	Items							
	Cups	Polystyrene	Caps	PET bottles	Rigid containers	Ropes	Soft packaging	Plastic bags
1 - Rainy/dry months		**	**	**	**	**	**	
2 - Foreshore/backshore	**	**					**	**
3 - Size categories	**	**		*	**	**	**	**
1 X 2	*							
1 X 3								
2 X 3							**	
1 X 2 X3								

* p<0.05
** p<0.01

4. Discussion

4.1. Marine debris and environmental variables

The predominance of plastics within marine debris deposited on the Goiana River estuarine beach was evident, and is a consequence of the word-wide occurrence of the group within marine debris (Derraik, 2002). This is directly related to the large diversity of uses of these materials, with a wide range of different types of items (Spokas, 2008). Other identified items, as polystyrene, rubber and foam, are also petroleum-based materials, having long residence-times in the river basin and adjacent shores, since plastics are only chemically degraded (not biodegradable) (Williams and Simmons, 1996) and fragment in smaller pieces with time (Velander and Mocogni, 1999).

At the Goiana River Estuary, the most sampled size category (11-100 cm²) was mostly represented by fragments of items. Whole objects were PET caps, straws and 50 mL coffee cups, which represented only 4.1% of the items. The large number of fragments and the absence of whole containers were also noted on other river-dominated beaches (Williams and Simmons, 1997a; Santos et al., 2008). In these environments, dynamics seems to privilege plastic transport inside estuaries, which consequently promotes the fragmentation of rigid items. These items easily break drown, as showed here for cups and polystyrene, for example. Soft items also fragment and tear, but are light and mobile being mainly exported to coastal beaches and/or trapped on the fringe vegetation (Williams and Simmons, 1996, 1997a; Wilson and Randall, 2005).

Size measurements are not commonly reported in the international literature on marine debris (Ivar do Sul and Costa, 2007; Madzena and Lasiak, 1997) and, as expected, its importance was not yet discussed accordingly. The assessment of size through specific categories provides a wide variety of information, such as residence time of debris in the environment, dispersion through oceanic and estuarine areas, depositional patterns, potential of items to be buried or ingested by the biota, and others. It is also useful to management actions, such as cleaning services and preventive measures (Silva-Cavalcanti et al., 2008, Santos et al., 2008), aiming to abate impacts on the biota and human populations. In addition, due to the lack of data on marine debris sizes, studies are required to try to establish common categories, respecting sample methods and local characteristics, and common nomenclatures to assign marine debris sizes, since until now no consistent patterns exist (Ribic et al., 1992; Gregory, 1999).

Marine debris deposition on beaches is certainly influenced by meteorological (Williams and Simons, 1997a, Araújo and Costa, 2007) and morphological (Bowman et al., 1998, Thornton and Jackson, 1998, Silva-Cavalcanti et al., 2008) parameters. On estuarine beaches, the importance of these parameters is accentuated, as physico-chemical oceanographic variables are an essential component of this transition regime. At the Goiana River estuary, as along the rest of the northeastern Brazilian coast (Ekau and Knoppers, 1999), a pattern with two well defined seasons highlights the importance of rain, which influences the deposition of total amounts of debris and also of specific types of items. The other environmental variables (water salinity, temperature and Secchi depth, organic matter, river flow, wind velocity) follow the same seasonal pattern along the year (with significant differences between rainy and dry months) and its measurements/estimations could be used to underline seasonal differences, and not to directly correlate with marine debris depositional patterns. Tides may also influence general patterns of movement of marine debris on riverine environments (Wilson and Randal, 2005) and on the Goiana River Estuary it re-suspend mainly floating items deposited on the foreshore, because this strata is completely submerged during high tides, facilitating transport and re-location.

In relation to the beach morphological parameters, some predictions can be made. The monitored estuarine beach seems to be in a sedimentary equilibrium along the year, with equal erosion and deposition rates. Although, in a monthly cycle, new and old marine debris could be removed from or deposit on the beach following the erosional and depositional patterns of sediments. Probably, these patterns also transported marine debris between sub aerial (foreshore and backshore) and submerged (surf zone) environments. Sand transport between two consecutive months, considering the three replicate transects, varied from 8.6 m^3 20 m^{-1} (Transect 2, jan-feb) to 982.8 m^3 20 m^{-1} (Transect 3, may-jun). These differences in the behaviour of sediment and beach morphology between months may also facilitate the burial of debris (Ivar do Sul and Costa, 2007), and possibly re-exposition, a process which also accelerates fragmentation. Burial of debris was also common due to the presence of the organic matter on the Goiana River estuarine beach. The organic matter commonly covered an extensive portion of the foreshore during low tides, and marine debris, mainly small items and fragments, became also trapped by it.

A limited number of works (Thornton and Jackson, 1998, Williams and Simmons, 1997b; Cunninghan and Wilson, 2003) considered foreshore and backshore separately as parameters for monitoring plastics on beaches. Cunninghan and Wilson (2003) found significant differences in the total number of items among upper, medium and lower beach strata, but specific types of items and its sizes were not considered. The expected influence on quantities of marine debris sampled on the foreshore and on the backshore could not be detected on the present study, but speculations about the most common types of items were done. This analysis is essential to predict types, sizes and sources of items on each strata of the beach (**Table 2**), and consequently its risks (**Table 4**).

On the foreshore, more fragments of cups were sampled in dry months, and they were commonly associated with the organic matter deposition, both from riverine and marine sources. Its deposition was not related to rainy periods because they were probably generated near to the sampling area, being independent of river flow. More caps were sampled in rainy months, since these items, with mixed sources, seems to be more efficiently transported by the river. Plastic bags and their fragments were deposited along all the monitored year on the foreshore. In addition, soft packaging was also deposited on the foreshore, most in rainy moths, which means that in the Goiana River estuary these items are successfully transported by higher river fluxes (Williams and Simmons, 1996, Cunninghan and Wilson, 2003). Although lightweight, these items were not moved by the wind to the backshore because they were constantly wet and partially buried on the beach.

On the backshore, more polystyrene blocks and fragments were sampled in the rainy months, characterizing floating transportation of these items by the more intense river flow in this season and also the intense use during lobster fishing months (May to August). Caps and PET bottles were more sampled in rainy months, also transported by the river flow. Soft packaging can be easily transported by the wind because it was not wet on the backshore.

4.2. Damage of specific types of items to the biota and humans

In general, impacts concerning marine debris are related to how much common they are and size, as stiffness can provide reliable information about the item behaviour in the ocean and coastal environments (floating, deposition, exportation and fragmentation). Size could supply information about what kind of biological group or species are potentially endangered trough ingestion, entanglement and fouling, or if marine debris affects human activities, as the scenic quality of beaches, boating and fishing activities or human health. This work used both size and stiffness (soft/rigid) of plastics (and polystyrene), which were the majority of the debris sampled on a tropical estuarine beach and had potential to be in contact with the estuarine and marine biota, boating and fishing fleet as well as deposited on the beach (**Table 4**).

In general, ingestion and health impacts are evident at the Goiana River Estuary. Soft items were predominant on the foreshore (**Table1**), the strata of the beach which is submerged during high tide. The estuarine and marine biota are then exposed to be in contact with these items, accentuating the ingestions risk. On the backshore, the strata exposed on high and low tides, rigid items were the majority and represent a constant harmful risk to people on the beach.

As an attempt to quantify and discuss the risk offered by the most common types and sizes of plastics at the Goiana River Estuary, an average score combining type of item and size category was calculated from 0 (no associated risk) to 10 (high associated risk) attributed grades to each possible combination observed in the area (**Table 2**). The scores were based on the international literature and on the knowledge and field experience of the authors. To the present study, the scoring given was based on the site-specific characteristics of the Goiana River estuary, to better establish local potential risks. Some characteristics considered were the near inexistence of large seabirds species (low caps ingestion risk), the presence of a manatee population (a high risk of ingestion for plastic bags) and the frequent occurrence of full, tied up, plastic bags on the beach (high risk for human health of large plastic bags), for example.

Table 4: Most common items sampled on the Goiana River estuarine beach, size categories and the most frequent impacts related to marine debris, on the biota and on human populations. Level of risk (0-10) ranked the potential damage of these items.

		Impacts on the biota			Impacts on humans			0=minimum 10=maximum
Items	Size (cm²)	Ingestion	Entanglement	Fouling	Scenic quality	Boating and fishing	Human health	Level of risk
Cups	1-10	10	0	0	10	0	0	3
	11-100	5	0	0	10	0	0	3
Polystyrene	1-10	10	0	0	10	0	0	3
	11-100	10	0	0	10	0	0	3
	101-1000	3	0	0	10	0	0	2
Caps	1-10	3	0	0	7	0	0	2
PETs	11-100	5	0	0	5	0	5	3
	101-1000	0	0	5	10	0	10	4
	>1001	0	0	10	10	0	10	5
Rigid containers	1-10	10	0	5	6	0	0	4
	11-100	6	0	10	8	0	5	5
	101-1000	4	0	10	10	0	10	6
	>1001	0	0	10	10	0	10	5
Ropes	1-10	5	0	1	8	8	2	4
	11-100	3	0	3	8	8	5	5
	101-1000	2	5	5	10	10	7	7
	>1001	1	10	7	10	10	7	8
Soft packaging	1-10	10	0	1	4	0	0	3
	11-100	8	0	3	6	0	3	3
	101-1000	6	6	5	8	10	6	7
	>1001	4	8	5	10	10	10	8
Plastic bag	1-10	10	0	1	4	0	0	3
	11-100	10	0	1	6	0	3	3
	101-1000	10	8	1	8	10	6	7
	>1001	10	10	2	10	10	10	9

Large plastic bags (level of risk 9 in 10), soft packaging and ropes (level of risk 8 in 10) have shown the highest levels of risk and should maybe considered as priority items to be dealt with by local managers, considering impacts on both the estuarine biota and human populations. Although, soft fragments and plastic bags may seem to be the same and still have the same characteristics in the environment, here plastic bags are those specific bags commonly distributed at supermarket and other retailers checkouts. As the international literature cited mainly cases of plastic bags ingestion by large marine animals (Beck and Barros, 1991; Laist, 1997), the present study highlights the damages related to this type of marine debris, as they may look different to each animal (in our case the manatee population).

In the Goiana River estuary, landscape scenic degradation and ingestion by the aquatic biota were the most important consequences of marine debris deposition on the beach. The first is due to practically every one of the eight most common items, specially the large sizes. The second due to the prevalence of small items (11-100 cm²) which can be easily ingested by fish, marine turtles and manatees living in or entering the estuary. On adopting the same method in other situations, the local characteristics (most common types of items, sizes, biota and human activities) will need to be well know and taken into consideration.

5. Conclusions

The most important environmental factor influencing marine debris sizes, types, and preferred deposition habitat was rainfall, and consequently all the other environmental variables governed by it. Secondly was probably sand transport/burial and organic matter, which traps/releases debris on/from the beach.

We determined that rigid items tend to deposit more on the backshore, and soft items on the foreshore. Although these items were also influenced by rainfall (and the other environmental variables) and by its sources.

Plastics and its fragments are the majority of the sampled marine debris on the studied estuarine beach. As marine debris monitoring is important to support management actions, size characterization could consistently optimize these procedures and is relatively easy to be measured. Size also gives fundamental information on real potential risk, and it is important to highlight that all size categories have an associated risk. The focus of the impact to the same original item though, tends to change with time. A rigid container, for example, impacts the scenic quality on a beach. But when it starts to fragment, the focus changes, and the impact is more related to ingestion by the biota and human injuries (cuts). So, once in the environment, marine debris of all kinds and sizes can be a risk to the biota and human populations.

Sampled items were a fraction of the river basin generated debris, as a part of it is probably directly exported to the coast through the main channel. The estuarine beach is most probably a short-term deposition area, as items tend to move in the river basin and fragment rapidly.

In the Goiana River Estuary, the priority of action would be plastic bags and soft packaging because they represent the highest risks to the biota and human populations. These items must be carefully treated, independent of the size category.

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Conclusões

O plástico foi o material mais encontrado na praia amostrada no estuário do Rio Goiana, corroborando um padrão global de contaminação, já que os plásticos constituem uma ampla gama de objetos presentes no nosso dia-a-dia, se dispersam facilmente quando no ambiente (ventos, ondas, rios), se fragmentam em itens cada vez menores e degradam lentamente. A grande ocorrência de plásticos também reforça a idéia da predominância de fontes baseadas em terra – rios, como fontes incessantes de lixo marinho para regiões costeiras adjacentes.

No estuário do Rio Goiana, o regime de chuvas tem grande importância como determinante na qualificação e quantificação da contaminação por lixo marinho, com um aumento no número de itens, principalmente oriundos da bacia hidrográfica, nos meses chuvosos. Como o padrão de invernos chuvosos e verões secos, controlados pelo clima tropical úmido, provavelmente existe também um padrão no transporte, deposição e exportação de lixo marinho, sujeito a mudanças em anos de eventos climáticos globais.

Atualmente, em tempos de mudanças globais (efeito estufa, elevação da temperatura média da Terra, El Ninõ), alterações no comportamento das chuvas e dos ventos podem modificar mesmo pequenas bacias como a bacia do Rio Goiana. Deste modo, o comportamento do lixo marinho presente no estuário se tornaria menos previsível, principalmente quando consideradas as fontes destes itens.

A atual situação de contaminação por lixo marinho no estuário do Rio Goiana é comum para outros estuários da costa leste do Brasil. Apesar de pequenas e concentradas em uma estreita faixa próxima ao litoral, estas bacias têm grande importância social, econômica e ecológica, já que se encontram em áreas de grande densidade populacional, e abrigam populações ribeirinhas que realmente dependem de seus recursos naturais. Estudos sobre a contaminação por lixo marinho e o conhecimento de suas fontes são essenciais para o manejo e mitigação desta situação de conflito.

Diferentes tipos de itens representam riscos potenciais diferenciados para a biota residente e a população local. O conhecimento da composição do lixo marinho e de suas categorias de tamanho pode ajudar na escolha de prioridades (medidas preventivas) relacionadas a tipos de itens mais comuns e danos potencias maiores (usuários de praia, presença de aves marinhas, etc). Diante do exposto, recomenda-se como prioridade de ação para o abatimento desse tipo de poluição no estuário do rio Goiana disponibilização de infra-estrutura básica para recolhimento de lixo esgoto para as embarcações e população das vilas de Acaú e Carne de Vaca.

O estuário do Rio Goiana pode ser considerado poluído por resíduos sólidos, principalmente plásticos e outros materiais derivados do petróleo, apesar de grandes fontes próximas serem escassas. Acredita-se que a atividade pesqueira, principalmente associada à pesca da lagosta, e seus desdobramentos (serviços urbanos em geral) sejam as maiores fontes de lixo marinho para a região. Atividades de subsistência, como a mariscagem e a pesca de caranguejo e peixe também são fontes de lixo marinho para o estuário, e conseqüentemente, suas áreas adjacentes. A população local deve ser orientada, já que é a principal fonte de lixo para o ambiente, e são também diretamente afetados pelos impactos relacionados a este.