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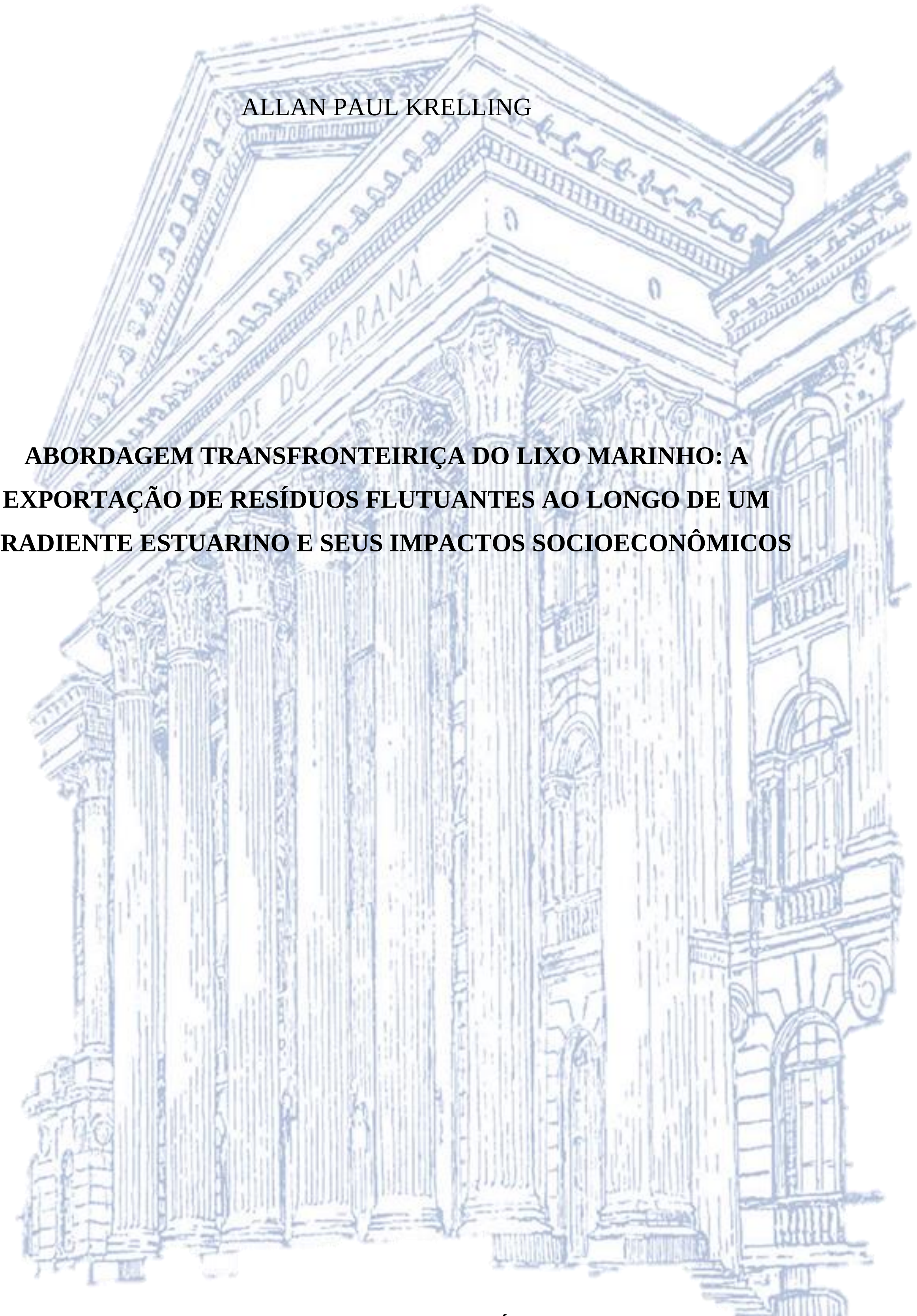

ABORDAGEM TRANSFRONTEIRIÇA DO LIXO MARINHO: A EXPORTAÇÃO DE RESÍDUOS FLUTUANTES AO LONGO DE UM GRADIENTE ESTUARINO E SEUS IMPACTOS SOCIOECONÔMICOS

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Orientador: Prof. Dr. Alexander Turra

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TERMO DE APROVAÇÃO

Os membros da Banca Examinadora designada pelo Colegiado do Programa de Pós-Graduação em SISTEMAS COSTEIROS E OCEÂNICOS da Universidade Federal do Paraná foram convocados para realizar a arguição da tese de Doutorado de **ALLAN PAUL KRELLING** intitulada: **ABORDAGEM TRANSFRONTEIRIÇA DO LIXO MARINHO: A EXPORTAÇÃO DE RESÍDUOS FLUTUANTES AO LONGO DE UM GRADIENTE ESTUARINO E SEUS IMPACTOS SOCIOECONÔMICOS**, após terem inquirido o aluno e realizado a avaliação do trabalho, são de parecer pela sua APROVADO.

Pontal do Paraná, 31 de Março de 2017.

ALEXANDER TURRA
Presidente da Banca Examinadora (UFPR)

EDUARDO MARONE
Avaliador Interno (UFPR)

LUIZ FELIPE MENDES DE GUSMAO
Avaliador Externo (UNIFESP)

MAIKON DI DOMENICO
Avaliador Externo (UFPR)

DANIEL HAUER QUEIROZ TELLES
Avaliador Externo (UFPR)

Dedico esse trabalho àqueles que não fazem a gestão adequada dos resíduos sólidos, nem na terra, nem no mar. Sem eles esse trabalho não seria necessário.

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“ Quando não existe caminho para fora, existe sempre um caminho através. ”

Eckhort Tolle

Resumo Geral

O presente estudo adotou uma abordagem multidisciplinar para investigar o lixo marinho ao longo do Complexo Estuarino de Paranaguá (CEP) e adjacências. Este trabalho está fundamentado em três capítulos baseados em abordagens complementares: investigar a dispersão e a trajetória do lixo marinho usando modelos hidrodinâmicos associados a coletas de campo (Capítulo 1); analisar a influência de eventos oceanográficos e meteorológicos [altas vazões de rios (AV), Sistemas Frontais (SF) e condições meteorológicas regulares (CMR)] sobre a quantidade e a qualidade do lixo marinho (Capítulo 2); e compreender a percepção e a reação dos usuários de praia à presença de lixo marinho (atual e futura) para estimar seus efeitos econômicos (Capítulo 3). No gradiente do CEP, três setores foram estabelecidos para realizar as análises espaciais: Interno (dominado por marés); Mediano (dominado por ondas com influência de desembocadura) e Externo (dominado por ondas). Os resultados das rodadas de modelagem indicaram um tempo de residência menor do que 5 dias do lixo marinho flutuante no interior do CEP, antes de ser exportado pela desembocadura. Uma vez no oceano aberto, o lixo marinho apresenta uma deriva inicial no sentido Sul, seguida por uma dispersão no sentido Norte. Ao longo dessa trajetória o lixo marinho pode ser espraiado, dependendo da ocorrência de condições oceanográficas ou meteorológicas específicas. Esses resultados indicam que o lixo marinho é um problema transfronteiriço no CEP. Demonstrou-se que a influência dessas condições é importante para a distribuição do lixo marinho, tanto espacial quanto temporalmente. Altas vazões (AV) foram determinantes para o aumento da abundância geral de itens, riqueza de tipos e para a quantidade da maioria das fontes estudadas. Os menores valores de abundância variaram se comparados os setores interno (CMR) e externo (SF). De maneira geral, a influência de cada condição sobre o lixo marinho do setor dominado por marés pode ser observada, entretanto, as influências no ambiente dominado por ondas são mais complexas. Considerando que as condições de AV são mais frequentes durante o verão, maiores quantidades de lixo marinho são esperadas no mesmo momento em que ocorre o aumento no número de usuários de praia. A percepção e a reação de proprietários de segunda residência (Veranista) e de Turistas não-recorrentes (Turista) em duas praias (Pontal do Sul, praia de desembocadura estuarina; Ipanema, praia oceânica) indicaram que estes grupos se diferenciam pelos gastos diários (Turista>Veranista), frequência de viagens (Veranista>Turista) e tempo de permanência (Veranista>Turista). A praia oceânica (Ipanema) foi pior avaliada considerando a qualidade geral da praia e a principal origem do lixo nas praias foi atribuída aos “usuários de praia” (>75%). Na praia de desembocadura (Pontal do Sul), os usuários citaram a origem “marinha” quatro vezes mais frequentemente (>35%). Mais de 85% dos usuários afirmaram não ir mais àquela praia, caso mais de 15 itens/m^2 fossem observados. As praias alternativas seriam fora do Estado (>50%) ou fora do município de Pontal do Paraná (>80%), gerando efeitos econômicos negativos. Foi estimada uma redução potencial de aproximadamente 39% da receita do turismo, levando a uma perda anual de até US$8,5 milhões para o município e US$5,7 milhões para o estado. Concluiu-se que o lixo marinho é uma preocupação transfronteiriça para o CEP, especialmente pela exportação de resíduos flutuantes e perdas potenciais de receita, sendo extremamente influenciado por eventos meteorológicos e oceanográficos. Recomenda-se a aplicação de métodos de gestão, baseados em conhecimentos derivados de abordagens transfronteiriças, especialmente em zonas de transição terra-água, como é o caso do CEP.

Palavras-chave: *lixo marinho, transfronteiriça, modelagem hidrodinâmica, condições oceanográficas, condições meteorológicas, efeitos econômicos, estuário*

General Abstract

This study adopted a multidisciplinary approach to investigate marine debris along the Paranaguá Estuarine Complex (PEC) and adjacent areas. The rationale of this study was structured in three chapters with complimentary approaches: investigating dispersal and the trajectories of marine debris using hydrodynamical modelling associated to *in situ* sampling efforts (Chapter I); analyzing the influence of discrete oceanographic and climatic events [High Riverine Discharges (HRD), Frontal Systems (FS) and Regular Weather Conditions (RWC)] on marine debris quantity and quality (Chapter II); and comprehending the perception and reactions of beach users to actual and eventual marine debris abundance, respectively, thus estimating its potential negative economic effects (Chapter III). In the Paranaguá Estuarine Complex gradient, three sectors [Internal (I, tide-dominated), Median (M, wave-dominated/outlet) and external (E; wave-dominated)] were considered for analysis of spatial variances. Results of modeling indicate a residence time shorter than 5 days for floating marine debris before being exported through the estuary mouth. In the open-ocean, floating debris tend to drift firstly southward, followed by a northerly dispersion. Along this trajectory marine debris can be stranded due to meteorological and oceanographical conditions. These findings reveal that floating marine debris is a transboundary concern for the PEC. The influence of these conditions was demonstrated to play an important role in marine debris spatial and temporal distribution. Higher Riverine Discharges (HRD) were determinant in increasing overall abundance, richness of types and quantities of most of the sources. The lowest records for overall abundance varied among internal (RWC) and external (FS) sectors. By identifying the influences of each factor in the internal sector, it was possible to postulate the process of influence of each condition over the tide-dominated sector. However, influences in the external sector might be more complex. Considering that the HRD conditions are more frequent during summer periods, greatest amounts of debris may be seen during periods with more beach users. The perceptions and reactions of second-home owners and users (SHOU) and non-recurrent tourists (T) in two beaches (Pontal do Sul, PS, estuarine-outlet beach; Ipanema, I, open-ocean beach) indicate that these groups were different due to daily expenses (T>SHOU), period of permanence per trip (SHOU>T) and frequency of trips (SHOU>T). The open-ocean beach (I) was worse rated regarding overall beach quality and marine debris generation was mainly attributed to local beach users (>75%). In the estuarine beach (PS), users cited the “marine” source four times more frequently (>35%). More than 85% of beachgoers would avoid a polluted beach with more than 15items/m^2 and alternative destinations would be out of the state (>50%) and out of the municipality (>80%), thus generating transboundary negative economic effects. A potential reduction for local tourism income of 39% was estimated, leading to a decrease in tourism revenue of up to US$8.5 and US$5.7 million per year for the municipality and the state, respectively. In conclusion, the marine debris is a transboundary concern for the PEC due to the exportation of floating debris and the potential losses of income for the municipality and the state. The dispersion is highly influenced by oceanographic and meteorological events. The application of innovative management methods based on the knowledge derived from the transboundary approach is recommended, especially in land-sea transition zones, like PEC.

Keywords: *marine debris, transboundary, modeling, oceanographical conditions, meteorological conditions, economic effects, estuary*

Prefácio

Esta tese foi elaborada seguindo o modelo proposto pelo manual do doutorando do Programa de Pós-Graduação em Sistemas Costeiros e Oceânicos da Universidade Federal do Paraná. Em sua parte inicial, redigida em português, o documento apresenta uma introdução geral sobre a contextualização do problema de pesquisa, as justificativas para a seleção do objeto de estudo e os objetivos da pesquisa. Cada um dos três capítulos, que estão redigidos em inglês, se referem a artigos a serem submetidos a periódicos científicos. Dessa forma, as hipóteses, a área de estudo e os materiais e métodos são apresentados nos próprios capítulos, de acordo com a temática abordada em cada artigo.

No primeiro artigo (capítulo 5), publicado no periódico Marine Pollution Bulletin, foi avaliada a movimentação entre fontes e sumidouros do lixo marinho no gradiente estuarino do Complexo Estuarino de Paranaguá (CEP), utilizando-se modelos hidrodinâmicos e coletas *in situ*. Através da associação dessas metodologias buscou-se avaliar a exportação do lixo marinho entre os municípios do CEP, caracterizando a necessidade de que o lixo marinho seja abordado de maneira transfronteiriça e não territorial.

No segundo artigo (capítulo 6), o qual será submetido a Marine Pollution Bulletin, é documentada a presença de lixo marinho nas praias arenosas estuarinas e oceânicas, no gradiente do Complexo Estuarino de Paranaguá e áreas adjacentes. A variabilidade temporal foi abordada de maneira inovadora, considerando eventos oceanográficos e meteorológicos. Para isso, analisou-se a influência de eventos geralmente apontados como especialmente determinantes para a composição do lixo marinho encontrado em praias: o aumento de vazão de rios e episódios de vento Sul (sistemas frontais).

No terceiro artigo (capítulo 7), publicado no periódico Marine Policy, foi realizada a caracterização do perfil do usuário de praia, isto é, Turistas e Veranistas, focando nas diferenças de percepção e reação em relação a presença do lixo marinho em praias. Os possíveis efeitos econômicos para o munícipio e para o estado do Paraná foram estimados a partir de cenários de dissuasão dos frequentadores da praia devido ao aumento do lixo marinho nas praias de Pontal do Paraná.

No último capítulo, são apresentadas as conclusões do trabalho e as contribuições com o conhecimento sobre três aspectos: (i) a aplicação de modelagens em pequena escala, dedicada ao lixo marinho; (ii) a influência dos eventos meteorológicos e oceanográficos, isto é, Sistemas Frontais e de altas vazões de rios, sobre a quantidade e qualidade do lixo marinho em praias de um gradiente estuarino e (iii) potenciais perdas de receitas para o turismo com o aumento do lixo marinho em praias. Em nível local, a contribuição científica esperada é (i) a compreensão dos processos de circulação e dos fatores que influenciam a distribuição do lixo marinho de maneira transfronteiriça, entre municípios, no Complexo Estuarino de Paranaguá e (ii) a estimativa dos potenciais efeitos sobre os usuários de praia e seus econômicos do aumento do lixo marinho na região.

Sumário

1. Introdução Geral

Lixo marinho é um tema novo e, por isso, desafiador. Visto com preocupação por muitos, é ainda estudado por poucos. Mesmo assim, diversos estudos importantes vêm sendo realizados e alguns padrões são já conhecidos, desde os primeiros estudos iniciados em meados da década de 1970.

O lixo marinho é todo resíduo sólido, tipicamente inerte, manufaturado ou processado que entra no ambiente marinho, independentemente de sua fonte (Coe e Rogers, 1997). Os resíduos encontrados nos diferentes compartimentos dos ambientes marinhos/costeiros vêm, em sua grande maioria, de fontes terrestres (Windom, 1992). Destacam-se os itens plásticos, dos mais variados tipos, formatos, tamanhos e fontes (GESAMP, 2015; Jambeck *et al.*, 2015; Li *et al.*, 2016; Moore, 2008; Williams *et al.*, 2003). O plástico é especialmente onipresente (Thompson *et al.*, 2009), mas, da mesma forma, outras composições são também comumente observadas em praias, estuários, mares e oceanos, ilhas remotas e ambientes abissais (Barnes *et al.*, 2009; Gregory, 2009; Law *et al.*, 2010; Peters e Siuda, 2014; Possatto *et al.*, 2015; Sadri e Thompson, 2014; Silva-Iñiguez e Fischer, 2003).

Entretanto, conhecer o material que compõe um item do lixo marinho e indicar se este se originou em terra ou no oceano, não pressupõe o conhecimento da sua origem geográfica, seu mecanismo de transporte ou sua trajetória. Apenas indica a partir de qual setor da economia ou atividade humana aquele item foi, provavelmente, gerado (Veiga *et al.*, 2016). A compreensão completa do processo que envolve o ciclo de vida desse item, desde a fonte até o sumidouro, é uma lacuna importante a ser preenchida pelos estudos sobre o lixo marinho (Cheshire *et al.*, 2009; Juying *et al.*, 2016). Especialmente em ambientes estuarinos esse conhecimento é extremamente limitado (Kataoka *et al.*, 2013; Vermeiren *et al.*, 2016; Williams e Simmons, 1997). Diversas metodologias vêm sendo testadas para se reduzir as incertezas sobre o processo de identificação de fontes e origens geográficas. Desde soluções baseadas em análises estatísticas (Tudor e Williams, 2004), redes neurais e inteligência artificial (Balas *et al.*, 2006, 2004), até modelagens computacionais (Carson *et al.*, 2013; Lebreton *et al.*, 2012) vêm sendo adotadas. A modelagem, em especial, tem demostrando grande utilidade na identificação de origens geográficas. Diversas abordagens em médias (mares regionais) e grandes escalas (oceanos e movimentações por tsunamis) auxiliaram na compreensão das trajetórias do lixo marinho (Carson *et al.*, 2013; Duhec *et al.*, 2015; Lebreton e Borrero, 2013; Mansui *et al.*, 2015; Maximenko *et al.*, 2012; Yoon *et al.*, 2010). Porém, a aplicação destas em pequenas escalas, por exemplo, em ambientes transfronteiriços regionais como os estuários, são extremamente raros (Kataoka *et al.*, 2013; Vermeiren *et al.*, 2016). O presente trabalho busca contribuir para a redução dessa lacuna específica, através da aplicação de modelagem em pequena escala (dezenas de quilômetros) ao longo do Complexo Estuarino de Paranaguá (CEP), associada a amostragem *in situ*, a qual será abordada no capítulo 1. Os resultados desse trabalho contribuem para a literatura internacional, uma vez que existe escassez de publicações na temática descrita e abordagens similares podem ser reproduzidas em diferentes áreas estuarinas. Além disso, traz contribuições para a escala local, pois descreve o processo de dispersão do lixo marinho ao longo do CEP e identifica o caráter transfronteiriço de exportação de lixo flutuante.

A contribuição da modelagem pode ser ainda mais significativa considerando-se que as condições ambientais que definem a trajetória do lixo marinho são pouco estudadas (Ryan *et al.*, 2009). Sabe-se que os campos de ventos, a topografia, a presença de *biofouling* e os processos de decomposição dos itens influenciam, não apenas a circulação e dispersão desses itens, mas também seu espraiamento (Critchell e Lambrechts, 2016; Vermeiren *et al.*, 2016; Walker *et al.*, 2006). Sabe-se também que a entrada de água doce tem um papel fundamental, especialmente em ambientes estuarinos (Kataoka *et al.*, 2013; Rech *et al.*, 2014), sendo os rios pontos chave de entrada de lixo marinho para os oceanos (UNEP, 2016). Porém, há dificuldades logísticas em realizar abordagens de longo prazo considerando esses aspectos. Consequentemente, estudos descritivos sobre as quantidades e qualidades do lixo marinho, tendem a realizar avaliações temporais adotando as estações do ano (verão, outono, inverno e primavera) como fator (Ali e Shams, 2015; Morishige *et al.*, 2007; Possatto *et al.*, 2015; Rosevelt *et al.*, 2013; UNEP, 2016). Ainda, existem programas de monitoramento que preveem a utilização da abordagem sazonal, com coletas mensais, bimensais ou trimestrais (Cheshire *et al.*, 2009). Porém, ao utilizar a abordagem por estação as variações “intra-estações” como por exemplo as oscilações diárias, semanais ou mensais de vazões (UNEP, 2016), tem sua compreensão limitada. Consequentemente a real influência desses parâmetros oceanográficos e meteorológicos sobre a composição do lixo marinho ainda precisa ser investigada. Mesmo nos estuários, onde geralmente se conhece a direção prevalecente de ventos e os principais sentidos de fluxo de água (Browne *et al.*, 2010) – o que os torna locais ideais para a realização de estudos dessa natureza – poucas pesquisas utilizando essa abordagem foram realizadas (Browne *et al.*, 2010; Sadri e Thompson, 2014; Williams e Simmons, 1997). Nesse sentido, o presente trabalho busca promover um maior entendimento sobre a influência de fatores oceanográficos e meteorológicos na quantidade e na qualidade do lixo marinho encontrado em praias ao longo do gradiente estuarino. Ao abordar categoricamente as situações de altas vazões no estuário e intensos ventos do quadrante Sul no capítulo 2, o presente trabalho contribui para a literatura internacional, ao abstrair a influência desses fatores sobre a qualidade e a quantidade de lixo marinho ao longo de gradiente estuarino. Os padrões observados no CEP podem servir de referência para futuros estudos em ambientes com conformações similares. Por outro lado, o trabalho preenche uma lacuna de conhecimento em pequena escala, ao interpretar a influência desses fatores sobre fenômenos locais de acúmulo de lixo marinho ao longo do gradiente estuarino. Os resultados reforçam também a análise sobre o caráter transfronteiriço do lixo marinho no CEP, destacando a influência desses fatores sobre o aumento na abundância de lixo marinho nas praias turísticas dos municípios a jusante no gradiente estuarino.

O impacto do lixo marinho presente em praias turísticas é vastamente apontado como um fator negativo para usuários de praia (Ivar do Sul e Costa, 2007; Nelson *et al.*, 2000; Williams *et al.*, 2003). É também, um dos fatores mais importantes para a seleção de destino em diversos países, inclusive o Brasil (Botero *et al.*, 2013; Cervantes *et al.*, 2008; Rangel-Buitrago *et al.*, 2013; Santos *et al.*, 2005). Sabe-se que a quantidade e a qualidade de lixo marinho encontrado em um ambiente, especialmente em praias, depende de diferentes fatores, incluindo-se os hábitos dos usuários (Claereboudt, 2004; Thiel *et al.*, 2013; Walker *et al.*, 2006). Levando-se em conta que existem diferentes hábitos entre os usuários de praia, considerá-los um grupo homogêneo parece incoerente, inclusive com estudos anteriores que reconhecem a formação de subgrupos (Botero *et al.*, 2013; Cervantes *et al.*, 2008; Roca e Villares, 2008; Slavin *et al.*, 2012). Porém, as divisões observadas entre usuários são frequentemente baseadas no objetivo de pesquisa (Williams e Micallef, 2009) de um investigador, enquanto, para a gestão, os usuários são geralmente abordados de maneira uniforme. Entretanto, há uma segregação de usuários que tem importância tanto para ciência quanto para gestores e que é ainda pouco explorada em regiões costeiras: a diferenciação entre turistas e proprietários de segunda residências.

A aquisição de propriedades à beira-mar como segunda residência é prática comum em regiões costeiras (Monteiro, 2013), havendo indicações de que essa categoria representa a maior parte dos visitantes do litoral paranaense, 70,5% (Paraná Turismo, 2008). Estudos internacionais, voltados para áreas não costeiras, indicam que proprietários de segunda residências, possuem um maior grau de ligação local (Stedman, 2006), tendem a realizar visitas repetidamente por satisfação (Alegre e Cladera, 2006) e valorizam a qualidade dos atributos ambientais locais (Hiltunen, 2007; Huhtala e Lankia, 2012; Long e Hoogendoorn, 2013; Wyles *et al.*, 2016). Sugere-se assim que os turistas não-recorrentes tem uma ligação mais frágil com o destino de viagem (Stedman, 2006). Essa menor fidelidade ao destino pressupõe uma maior liberdade na escolha de destinos. Dessa forma, investigar se esses dois grupos se diferenciam como usuários de praia, pode trazer resultados relevantes e que ampliem o entendimento dos efeitos do lixo marinho na atividade turística. Por exemplo, considerando o cenário de crescimento da quantidade de lixo marinho (GESAMP, 2015), entender a percepção e a reação desses usuários aos resíduos encontrados em praias, *i.e.* dissuasão de frequentadores de praia, pode auxiliar na estimativa de consequências que afetam o município e a região.

Estudos focados na importância da praia e de sua qualidade para seus usuários são comuns, permitindo-se inferir a importância da manutenção da sua “limpeza” (Blakemore e Williams, 2008). Porém, estudos que avaliam quais perdas econômicas ocorreriam caso o lixo marinho permanecesse na praia (Ballance *et al.*, 2000; Jang *et al.*, 2014; Ofiara e Brown, 1999) são poucos, mas indicam que o aumento do lixo marinho é um risco real para áreas costeiras turísticas. Esse risco é percebido, de forma anedótica, pela gestão. Isso torna-se evidente pelos altos valores investidos em limpeza de praias em diversos lugares do mundo (Araújo e Costa, 2006; Mouat *et al.,* 2010; Prefeitura Municipal de Pontal do Paraná, 2015). Dessa forma, a análise sobre as potenciais perdas de receita pela não realização dessas limpezas, associada ao caráter crescente de lixo marinho em praias, é ainda um campo a ser explorado. De fato, não apenas a exportação do lixo marinho pode ocorrer de maneira tranfronteiriça, mas a evasão de visitantes também. Considerando esse panorama, a avaliação das possíveis diferenças de percepção e de reação dos grupos de usuários poderá elucidar se uma possível dissuasão gerará perdas de receita do turismo e se essas perdas podem ser transfronteiriças. Esse trabalho se insere nesse contexto, abordando o tema no capítulo 3, e busca trazer à luz o potencial de dissuasão que o lixo marinho tem sobre os diferentes grupos de usuários, gerando perdas de receita na região do CEP. Os resultados têm primeiramente implicações locais, pois indicam as possíveis perdas de receita para a localidade estudada, considerando os diferentes contextos ao longo do gradiente estuarino. Mas também traz inovação em escala internacional, pois se insere em lacunas do conhecimento, não apenas sobre uma nova categoria de diferenciação entre usuários de praia, mas também sobre o caráter transfronteiriço da dissuasão de visitantes. Ambas as temáticas – pouco investigadas em regiões costeiras e em outras regiões onde segundas residências são fenômeno recorrente – poderão ser futuramente investigadas utilizando a mesma abordagem aqui adotada, gerando resultados comparáveis.

Assim, o presente trabalho utiliza uma abordagem multidisciplinar para investigar o problema do lixo marinho ao longo do Complexo Estuarino de Paranaguá. Ao aplicar modelagens em pequena escala, para determinar os padrões de circulação, e ao investigar as influências que fatores oceanográficos e meteorológicos têm sobre quantidade e a qualidade do lixo marinho ao longo do gradiente, busca-se compreender se o lixo marinho e seus impactos transcendem as barreiras geopolíticas municipais. Busca-se observar ainda se existem fatores que podem amplificar seus impactos transfronteiriços, seja pela simples exportação de resíduos flutuantes entre municípios, ou ainda pela dissuasão de frequentadores da praia pela sua poluição (causando perdas de receita). Pretende-se assim apoiar a formação de uma base científica para a discussão de uma nova abordagem, transfronteiriça, de um problema que geralmente é tratado de forma paliativa por gestores e, por vezes, descritiva por pesquisadores. Ao utilizar uma associação de abordagens e técnicas de pesquisa para analisar a distribuição e os fluxos espaço-temporais do lixo marinho e seus impactos socioeconômicos, buscou-se inovar para preencher algumas dessas lacunas de conhecimento.

2. Revisão Teórica

2.1 A problemática do resíduo sólido e o lixo marinho

Existe, atualmente, uma crescente preocupação com o ambiente marinho e os impactos aos quais os oceanos estão expostos. Dentre estes impactos, destaca-se o comprometimento da qualidade estética e de recreação dos ambientes marinhos e costeiros pelo aumento da quantidade de lixo marinho. Em um padrão mundial, os resíduos sólidos chegam ao mar por meio de atividades realizadas em terra (como turismo em zonas costeiras e drenagens urbanas) e também por atividades realizadas no mar, como a pesca e o transporte mercante (Derraik, 2002). Apesar de serem poucos os trabalhos robustos que suportam conclusões acerca da quantidade de resíduos sólidos que entra no sistema marinho, alguns apontam que aproximadamente 80% tem origem das atividades desenvolvidas em terra (Windom, 1992). Em 2005, estimou-se que 6,4 milhões de toneladas de resíduos entram nos mares e oceanos anualmente (UNEP, 2005). Em estudo mais recente, estimou-se que a taxa anual de entrada de resíduos plásticos pode chegar a até 12,7 milhões de toneladas (Jambeck *et al.*, 2015). Este crescimento observado na quantidade de itens plásticos entrando no ambiente marinho em um período de aproximadamente 10 anos, acompanha o crescimento da produção mundial de plástico (derivado de petróleo), a qual dobra a cada 11 anos (Hardesty *et al.*, 2015).

Independentemente do estabelecimento preciso das quantidades de entrada, é unânime que o plástico domina os ambientes aquáticos, sejam eles rios (Rech *et al.*, 2014), mares ou oceanos (Lippiatt *et al.*, 2013; UNEP, 2005). O trabalho de Thompson *et al.* (2004) aponta que entre 60% e 80% de lixo marinho é composto por plásticos. Ainda, diversos autores indicam em revisões bibliográficas que alguns estudos encontraram proporções maiores que 90% de itens plásticos (Barnes *et al.*, 2009; Gall e Thompson, 2015; Gregory e Ryan, 1997; Ribic, 1998). No Brasil, proporções semelhantes são observadas (Widmer e Hennemann, 2010). Em um estudo recente sobre a composição do lixo no litoral paranaense, Possatto *et al.* (2015) observaram que 92% dos itens encontrados no sedimento de fundo do Complexo Estuarino de Paranaguá (PEC) é composto por plásticos. Ainda no Paraná, mas em estudo focado em praias com baixa frequência de usuários, Ferrari (2009) encontrou proporções também próximas a 90% de itens plásticos.

Essa onipresença do plástico ocorre principalmente pelos seguintes fatos: ser vastamente utilizado em processos produtivos – especialmente na produção de embalagens (PlasticsEurope, 2015) que não têm descarte adequado; ser facilmente transportado, visto que possui capacidade significativa de flutuação (Barnes *et al.*, 2009) e ser altamente durável em comparação com a grande maioria dos outros compostos do lixo marinho como tecidos, metal, madeira, entre outros. Ainda que apenas 46% do plástico produzido seja flutuante (Stevenson, 2011), essa qualidade permite que os impactos dos itens plástico não se restrinjam aos locais onde são produzidos ou gerados. Ryan *et al.* (2009) observaram que a dominância dos itens plásticos aumenta proporcionalmente com o maior distanciamento das fontes geradoras. Ou seja, o plástico possui capacidade de causar impactos, inclusive, em locais distantes e isolados, com baixa intensidade de utilização humana (Carson *et al.*, 2013; Maximenko *et al.*, 2012). Estudos realizados em ambientes inabitados, como ilhas subantárticas (Walker *et al.*, 1997) e nas ilhas do Pacífico Sul (Benton, 1995) ou dentro de Unidades de Conservação de Proteção Integral no Brasil (Ferrari, 2009) indicaram a poluição de praias predominantemente por itens plásticos, reafirmando o seu caráter de alta disseminação no ambiente marinho.

Essa proporção global da contaminação por plástico pode ser observada, ainda, pela concentração de itens dessa composição nos grandes giros oceânicos. Maximenko *et al.* (2012) descreveram estas concentrações, usando simulações com modelos probabilísticos da distribuição do lixo marinho. Os autores concluíram que existem cinco grandes regiões, os chamados giros, onde há acúmulo de lixo marinho, que estão instalados próximos aos 30º de latitude, nas zonas subtropicais. Estes grandes giros oceânicos, especialmente os do Pacífico e Atlântico Norte já eram conhecidos, entretanto os do Atlântico Sul, do Índico e do Pacífico Sul tiveram suas extensões confirmadas apenas por meio de levantamentos *in loco* no ano de 2010 (Maximenko *et al.*, 2012). Não surpreendentemente, esses giros também apresentaram dominância por itens plásticos. No Giro do Atlântico Norte, as proporções chegaram a 83% (Law *et al.*, 2010) e no Giro do Atlântico Sul a 97% de itens plásticos (Ryan, 2014).

A distribuição destes pontos de acúmulo, tendo áreas preferenciais nas zonas subtropicais, indica a importância de processos oceanográficos na distribuição do lixo marinho em grande escala. A distribuição do lixo marinho está associada, também, a processos oceanográficos de transporte que acoplam as grandes escalas às médias e pequenas escalas (Frost e Cullen, 1997). Em uma pesquisa conduzida por Corcoran *et al.* (2009), os autores observaram que microplásticos ocorriam apenas na face leste da ilha Kauai (Havaí). Este resultado foi atribuído à circulação no sentido horário do giro do Pacífico Norte (grande escala), que traz os itens até as praias do nordeste de ilha. Uma vez ali, o transporte longitudinal à linha de costa distribui esse material para as águas costeiras próximas às praias da face leste (média escala), onde são espraiados durante momentos de maior agitação do mar (pequena escala; Corcoran *et al.*, 2009). Estes resultados ilustram como os processos oceanográficos de diferentes escalas espaciais e temporais se complementam e que a contribuição dos resíduos encontrados em terra, gerados ou não localmente, também é influenciada pelos mesmos processos. Carson et al (2013) observou que o lixo marinho local havaiano também contribui para a contaminação local, chegando às praias a partir dos canais de escoamento das cidades, e concluiu que esses resíduos podem circular por centenas de quilômetros até chegarem às praias locais, inclusive tendo sido observada a exportação entre ilhas. Com isso, observa-se também a contribuição dos processos de pequena escala para o aumento do lixo marinho em escalas regionais e globais. Destaca-se assim a importância de se conhecer o caminho seguindo pelo lixo desde sua fonte até seu sumidouro. Dentre os processos de pequena escala que contribuem para a entrada do resíduo sólido no ambiente aquático estão o lançamento de esgoto não tratado ou o transbordamento de sistemas de tratamento de esgoto, lixões a céu aberto e o descarte difuso de resíduos sólidos diretamente nos corpos hídricos (Sheavly, 2005).

De maneira geral, observa-se na literatura que os principais fatores ambientais que modulam essa entrada dos resíduos no meio aquático, bem como o deslocamento e espraiamento do lixo marinho são: as direções e intensidades de ventos (Browne *et al.*, 2010; Walker *et al.*, 2006); a direção das correntes oceânicas e de deriva (Corcoran *et al.*, 2009; GESAMP, 2015; Isobe *et al.*, 2014); o aporte de rios, canais urbanos e águas superficiais (Araújo e Costa, 2006; Moore *et al.*, 2011; Rech *et al.*, 2014; Stevenson, 2011; Williams e Simmons, 1997); e características morfodinâmicas dos ambientes, incluindo o seu tipo de vegetação (Critchell e Lambrechts, 2016; Ivar do Sul *et al.*, 2014; Walker *et al.*, 2006). Há ainda alguns fatores culturais e sociais que também modulam a quantidade e a qualidade de lixo marinho observados em praias, destacando-se: características socioeconômicas e hábitos dos usuários (Eastman *et al.*, 2013; Krelling *et al.*, 2014; Santos *et al.*, 2005; Slavin *et al.*, 2012), a proximidade de centros urbanos

(Leite *et al.*, 2014) e práticas de gestão adotadas em terra (Liu *et al.*, 2013; Neves *et al.*, 2011). Entretanto é frequente que alguns dos moduladores ambientais, como por exemplo o aumento no aporte de água doce nos sistemas costeiros ou ainda o aumento da intensidade de ventos, não sejam analisados de maneira aprofundada. Estes acabam figurando apenas como “possíveis responsáveis” pelos padrões encontrados nos estudos, ficando geralmente sob a égide generalista da “sazonalidade”. É fundamental compreender a efetiva contribuição de cada fator ambiental (especialmente as contribuições de rios e dos ventos) bem como suas interações nas mudanças de composição do lixo marinho encontrado em praias, pois com isso torna-se possível planejar de forma mais efetiva a gestão.

A importância da contribuição por rios e canais foi destacada por vários estudos (Araújo *et al.*, 2007; Koelmans *et al.*, 2014; Neves *et al.*, 2011) que observaram uma relação direta entre a proximidade destes corpos d’água e a quantidade de lixo nas praias. Estas variações espaciais são observadas também na coluna d’água em áreas costeiras. No estado americano da Califórnia, observou-se que as águas mais próximas à costa e a centros urbanos apresentavam maiores proporções de partículas plásticas (84%), se comparados a águas mais distantes. Estas proporções são associadas ao aporte de águas superficiais que escoam do continente durante a ocorrência de tempestades (Stevenson, 2011). Há também indícios, que aproximadamente 10% do peso total do que é transportado pelos escoamentos das cidades seja constituído de plástico (Thompson *et al.*, 2009), representando um grande aporte diário de resíduos sólidos originados diretamente das cidades costeiras. Dessa forma, a importância da contribuição destes “meios de conexão” entre as fontes em ambientes terrestres com os sumidouros em ambientes aquáticos (estuários e mares) deve ser melhor compreendida visto que existem poucos estudos, especialmente em estuários (Ivar do Sul e Costa, 2007).

Dentre os três principais destinos, isto é, sumidouros onde o lixo se acumula no meio marinho – praias, coluna d’água e assoalho marinho (Stevenson, 2011) – as praias apresentam a literatura mais volumosa. Observa-se essa diferença entre os compartimentos ambientais, pois há uma maior facilidade logística no desenvolvimento de pesquisas neste ambiente, se comparado aos outros compartimentos (Gregory, 2009).

Essa abundância de literatura em relação às praias induz à certeza de que há maiores avanços do conhecimento dos processos relacionados ao acúmulo de lixo marinho nesses ambientes. Entretanto, a literatura é repleta de estudos descritivos em relação a variações espaciais e temporais (Ryan *et al.*, 2009) e são, em sua grande maioria, concernentes exclusivamente às localidades onde foram desenvolvidas as pesquisas (Derraik, 2002). Por exemplo, Williams e Simmons (1997) citaram que os estudos sobre o lixo marinho na interface rios/praias ainda estariam em sua infância, fazendo referência à escassez de trabalhos na área. Dez anos depois, Ivar do Sul e Costa (2007) fizeram uma revisão da literatura sobre lixo marinho na América Latina e Caribe e constataram que apenas três, dos 70 trabalhos analisados, dedicavam-se a regiões estuarinas. Mesmo com o recente aumento no número de estudos sobre os tipos, quantidades, fontes e impactos do lixo marinho (Hardesty *et al.*, 2015), os estudos dessa natureza que contemplam corpos d’água da interface água doce e água salgada, ainda continuam incipientes. Soma-se a essa limitação de estudos, a ausência de padrões de amostragem nas pesquisas realizadas em praias. A falta de coordenação e integração dos esforços inviabiliza comparações fazendo com que perdure ainda a necessidade de gerar conhecimentos comparáveis, mundialmente, sobre lixo marinho em praias (Barnes e Milner, 2005; Bowman *et al.*, 1998; Lippiatt *et al.*, 2013; Velander e Mocogni, 1999). Para que a quantidade reflita em aumento de conhecimento sobre os processos de poluição, é fundamental que as pesquisas contribuam para a criação de uma base de dados consistente em nível global, de forma coordenada e comparável em relação às variações monitoradas (UNEP, 2005) .

No sentido de integrar as pesquisas sobre lixo marinho em nível mundial, três autores (Cheshire *et al.*, 2009; Galgani *et al.*, 2013; Lippiatt *et al.*, 2013) se destacam propondo metodologias aplicáveis a programas regionais de longo prazo. Cheshire *et al.* (2009) elaboraram diretrizes para a pesquisa e o monitoramento de lixo marinho, aplicáveis para o Programa de Mares Regionais da UNEP. Esse programa já possui 19 iniciativas de integração entre países e vem apresentando resultados técnicos interessantes sobre o monitoramento das variações nas quantidades de lixo nos ambientes marinhos desses países em longo prazo (Schulz *et al.*, 2013).

Já Galgani *et al.* (2013) descrevem metodologias para o monitoramento do lixo marinho nos países da União Europeia, voltadas ao cumprimento da nova Diretiva Europeia para o Ambiente Marinho (EU, 2008). Nessa Diretiva, o lixo marinho é apontado como um dos descritores ambientais qualitativos de mares e oceanos. Na diretiva se prevê ainda a necessidade de avaliar o estado ambiental atual e de se utilizar métodos e abordagens comparáveis entre os países e regiões marinhas, reafirmando a importância da geração de dados comparáveis. Também Lippiat *et al.* (2013) propõem metodologias para o monitoramento e pesquisas voltados para o lixo marinho nos Estados Unidos, buscando gerar comparabilidade entre os dados obtidos. Os três autores abordam metodologias voltadas para amostragens em todos os compartimentos ambientais onde o lixo marinho se acumula: praia, fundo e na coluna d'água, especialmente superfície, e são voltados para uma unificação dos esforços de monitoramento, o que facilita a comparabilidade dos dados.

Contudo, estes são esforços recentes de integração e de realização de estudos mais compreensivos sobre o assunto. A integração pode trazer respostas em níveis globais para questionamentos que permanecem sem respostas como: as reais quantidades de resíduos sólidos que entram no sistema marinho anualmente, as consequências do acúmulo de lixo no ambiente marinho, os detalhes sobre o ciclo do plástico quando entra no meio marinho ou ainda o estabelecimento, com maior precisão, da relação entre fontes e sumidouros de lixo marinho (STAP, 2011; UNEP, 2005). Dentre estas perguntas não respondidas, talvez a última seja a mais intrigante: como reconhecer, a partir do lixo marinho encontrado em sumidouros, as principais fontes – e trajetos realizados pelo lixo marinho – com precisão suficiente para promover medidas eficientes de prevenção?

Esforços na tentativa de responder essa questão foram feitos por diversos autores, valendo destacar o trabalho de Tudor *et al.* (2002) que buscou estabelecer parâmetros para associar o lixo encontrado nas praias com fontes específicas através da análise de componentes principais. A conclusão dos autores foi de que alguns itens funcionam como indicadores, por exemplo, cotonetes indicam resíduos relacionados a esgoto; brinquedos, bitucas de cigarros ou embalagens de doces são indicadores de lixo originado por usuários da praia e; linhas, boias, contêineres ou redes são indicadores de lixo originado em embarcações (Tudor *et al.*, 2002). Balas *et al.* (2004) lançaram mão de redes neurais para reduzir a subjetividade apontada no trabalho de Tudor et al (2002) e determinar as fontes mais prováveis e assim conseguir propor estratégias de gestão. Houve melhora na determinação das fontes através destes e outros trabalhos, incluindo a utilização da lógica difusa (Balas *et al.*, 2006), entretanto se reconhece ainda a necessidade de associar mais informações e metodologias para aumentar a precisão sobre fontes. Essas metodologias aprimoram a identificação da atividade geradora desses resíduos, entretanto não auxiliam diretamente na determinação da sua origem geográfica ou no estabelecimento dos caminhos percorridos pelos itens encontrados em praias. Essa determinação geográfica da fonte é fundamental para compreender os fluxos entre as atividades geradoras e os sumidouros, de forma que medidas de gestão sejam adotadas adequadamente, prevenindo, diretamente na fonte, a entrada desses resíduos no ambiente aquático. Visando precisamente determinar as fontes geográficas mais prováveis, outros estudos adotaram diferentes abordagens, como a utilização do lançamento de derivadores nas praias do Havaí (Carson *et al.*, 2013). Tendo sido feito de forma local, os resultados deste trabalho apontaram que as fontes terrestres contribuem significativamente para a poluição local das praias. Porém, mais uma vez, o estudo destacou que há necessidade de complementações no conhecimento. Reitera-se assim a importância de se gerar avanços na compreensão dos impactos do lixo nos diferentes locais de acúmulo.

Ainda assim, há poucos estudos que associam a identificação de prováveis fontes e composição dos itens, combinando métodos descritivos, já largamente conhecidos em observações *in situ*, com os resultados de simulações dos prováveis caminhos realizados pelos itens quando no meio aquático. Dentre estes poucos estudos, Duhec *et al.* (2015) conseguiram identificar origens prováveis de lixo marinho encontrados em uma ilha remota do Oceano Índico através da associação desses métodos. Maes e Blanke (2015), associaram informações contidas em rótulos das embalagens encontradas a padrões de circulação utilizando modelos e conseguiram estabelecer suas potenciais origens geográficas. Estes trabalhos destacam a utilidade da associação de resultados obtidos através de métodos diferentes. Porém, permaneceu a dificuldade em se propor medidas de gestão pois, em ambas situações, a escala utilizada para os trabalhos apontou para origens transoceânicas. Neste contexto internacional, existem esforços significativos de formação de redes para o desenvolvimento conjunto de novas abordagens de gestão, especialmente para problemas globais, como o lixo marinho. De fato, o estabelecimento preciso de aspectos como a forma de circulação do resíduo nos corpos d’água e seus principais pontos de entrada, em uma escala em que seja possível a proposição de medidas de prevenção, é fundamental para a redução do lixo marinho (Critchell *et al.*, 2015). Contudo é sabido, também, que há uma tendência generalizada, na atual sociedade, em se priorizar o tratamento de aspectos ambientais que gerem impactos socioeconômicos. Como exemplo, observa-se que as limpezas paliativas de praia ocorrem de forma mais intensa naquelas que possuem maior frequência de turistas para mitigar os impactos estéticos (Araújo e Costa, 2006). Mesmo que isso seja tautológico, visto que turistas são afetados pelo, mas também geram lixo marinho em ambientes praiais.

Uma vez que a geração de soluções factíveis para os impactos do lixo marinho é um objetivo intrínseco daqueles que estudam o tema, visto que diversos estudos tendem a propor soluções, torna-se ainda mais vital estabelecer relações entre os resultados deste tipo de estudos (que se utilizam de mais de um método) e os impactos socioeconômicos, reais ou potenciais da presença do lixo marinho em praias. Apenas dessa forma, a gestão adequada focará na solução do problema em sua fonte, tendo o potencial de reduzir os investimentos em soluções de curto prazo.

2.2 Os impactos ambientais e socioeconômicos do lixo marinho e a gestão transfronteiriça

Nas últimas duas décadas houve um aumento significativo no número de estudos sobre lixo marinho e seus resultados demostram que o acúmulo de lixo em praias é um problema crescente, em nível mundial, causando contaminação e gerando impactos estéticos às praias (Hardesty *et al.*, 2015; Somerville *et al.*, 2003). Também são comumente mencionados os riscos de introdução de espécies invasoras (Barnes, 2002), a ingestão e estrangulamento em animais (Thompson *et al.*, 2009) e a pesca fantasma (Moore, 2008), todos causando perdas para a biodiversidade e perdas econômicas para a pesca (Gregory, 2009). A segurança e a saúde humana também são ameaçadas pela presença de vidros quebrados, lixos hospitalares e seringas (Sheavly e Register, 2007), além de perdas econômicas com limpeza de praias (Potts e Hastings, 2011).

Apesar da diversidade de impactos, os que mais têm sido explorados por estudos são os impactos à fauna, especialmente a carismática. Um estudo referencial sobre o tema é o trabalho desenvolvido por Laist (1997), o qual apontou que indivíduos de pelo menos 135 espécies marinhas, incluindo uma porcentagem significativa de tartarugas marinhas, mamíferos marinhos e aves marinhas já foram alvos de enroscamento em lixo marinho. O autor destaca ainda que estes números seriam, provavelmente, subestimados uma vez que os estudos que avaliam estes tipos de impacto se baseiam, em sua grande maioria, em estudos realizados em terra, com animais que sobrevivem à ingestão, emalhe ou ao enredamento, ou ainda são animais que foram impactados próximos à costa. Como provavelmente apenas uma pequena parcela dos animais impactados é estudada, especialmente pelas dificuldades logísticas em realizar estudos dessa natureza, o autor aponta que a extensão dos impactos em níveis populacionais é desconhecida. Em estudo mais recente Gregory (2009) afirma que os impactos são maiores e que o número de espécies atingidas chega a mais de 260. Gall e Thompson (2015) em uma extensa revisão bibliográfica atualizada estabelecem que há um número ainda maior, com registros de 693 espécies marinhas sendo afetadas pela presença de lixo marinho. Os principais impactos resultam em limitação de movimentos e alimentação, redução da capacidade reprodutiva, lacerações, úlceras e em última instância morte (Juying *et al.*, 2016; Secretariat of the Convention on Biological Diversity, 2016; UNEP, 2016).

Muitos dos impactos observados nos mares e oceanos estão associados a mudanças em produtos utilizados em atividades marinhas, como por exemplo, a troca das malhas de fibras naturais por linhas de nylon, por ser um produto mais durável e flutuante (GESAMP, 2015; Gregory, 2009). Esta troca começou a ocorrer por volta dos anos 1950, fazendo com que os impactos dessa natureza começassem a surgir, mais intensamente, nos oceanos. E as propriedades desejáveis na utilização do material plástico – como durabilidade, flutuação, variedade de aplicações na produção – são também aquelas responsáveis pelos problemas criados para o ambiente marinho (Gregory, 2009). Essa mudança de padrão de consumo, não veio acompanhada de estratégias de sensibilização, intensificando o problema.

Estas mudanças nos padrões de consumo são ainda mais visíveis nas atividades desenvolvidas em terra, gerando mudanças nos resíduos que chegam a mares e oceanos. E este aumento dos impactos vem acompanhando o aumento do consumo de itens plásticos descartáveis (PlasticsEurope, 2015). Estas mudanças e seus impactos ficam evidentes quando estudos interanuais são desenvolvidos. Um exemplo são os resultados observados por Willoughby *et al.* (1997) ao estudar o lixo marinho nas praias da Indonésia. Em amostragens realizadas em 1985 não havia garrafas plásticas nas praias, tanto que esta categoria de lixo não precisou ser incluída no trabalho daquele ano. Contudo, nas coletas realizadas em 1995, mais de 1600 garrafas plásticas foram encontradas. Esta diferença tão evidente foi atribuída ao aumento do mercado consumidor de água engarrafada no país. No Brasil, alguns autores observaram que as garrafas PET representavam uma grande proporção de lixo plástico encontrado na Baía de Guanabara/RJ em 1999 (Neto e Fonseca, 2011). Ao longo da pesquisa, entre 1999 e

2008, observaram diminuição proporcional destes itens, porém sendo observado também aumento constante na presença de sacolas plásticas. Os autores concluem que as mudanças na composição do lixo marinho refletem primeiramente o incentivo à reciclagem, reduzindo a quantidade de garrafas no ambiente, e também as mudanças nos padrões de consumo com o aumento da utilização de sacolas plásticas. Evidencia-se, assim, que mudanças nos hábitos de consumo repercutem em mudanças nos tipos de impactos ambientais, econômicos e sociais observados.

Entre os impactos ambientais observados nas praias, que repercutem em impactos econômicos e sociais, a degradação estética é especialmente preocupante (Derraik, 2002). Esta perda da qualidade estética e recreacional é medida pela redução do interesse de turistas frequentando uma dada localidade, uma vez que a quantidade de lixo observada exerce papel fundamental no momento da escolha de praia para recreação (Santos *et al.*, 2005; Tudor e Williams, 2008). Ballance *et al.* (2000) observaram que as perdas econômicas podem ser extremas caso altos níveis de poluição por lixo marinho ocorressem, uma vez que 97% dos turistas não voltariam às praias de Cape Peninsula, África do Sul. A importância econômica da presença do lixo marinho foi destacada ainda por Leggett *et al.* (2014) que observaram que a redução em 50% na quantidade encontrada nas praias de Orange County, na Califórnia, poderia representar um aumento de 67 milhões de dólares em benefícios para os moradores, em um período de apenas três meses. Dessa forma, é imperativo entender a percepção dos usuários de praia a respeito do lixo marinho para se mensurar as potenciais perdas econômicas associadas à sua presença.

Ainda, Potts e Hastings (2011) apontam o fato de que é muito provável que a presença do lixo marinho reduza a resiliência destes ecossistemas, o que pode gerar outras perdas, ainda não mensuradas. Por isso, dentre os serviços ecossistêmicos afetados por atividades humanas impactantes – como a disposição do lixo no ambiente marinho – os serviços culturais, especialmente os serviços de recreação e beleza cênica, são extremamente prejudicados (Naturvårdsverket, 2009). A presença dos resíduos sólidos em praias impacta turistas e veranistas e gera reflexos sobre as autoridades públicas locais que se obrigam a realizar limpezas de praia para continuar a atrair visitantes (Walker *et al.*, 2006). Entretanto, estes gestores das praias também carecem de diretrizes fornecidas por estudos científicos de qualidade que auxiliem na adoção de medidas para a mitigação ou prevenção da geração de lixo marinho, sejam elas ações de governança ou campanhas para mudança comportamental (Potts e Hastings, 2011).

Como observado, a pressão humana sobre os recursos costeiros impacta não apenas a fauna *per se* mas também compromete a qualidade de serviços ecossistêmicos cruciais para o bem-estar das comunidades costeiras e da economia (MEA, 2005). É, nesse sentido, paradoxal observar que os serviços ecossistêmicos se convertem em benefícios que as populações humanas têm e que derivam, direta ou indiretamente, dos diferentes habitats, funções sistêmicas e biológicas ou processos dos ecossistemas (Costanza *et al.*, 1997), enquanto a pressão exercida pelas mesmas populações sobre os ecossistemas gera perdas, ou até o desaparecimento, de determinados serviços ecossistêmicos. Estes serviços ecossistêmicos podem ser agrupados em quatro tipos: de Provisão, de Suporte, de Regulação e Culturais (Naturvårdsverket, 2009)

Há que se destacar que essas perdas associadas ao lixo marinho ocorrem especialmente nas praias que são um dos principais fornecedores de serviços ecossistêmicos de recreação, culturais e estéticos (MEA, 2005). Essas perdas de serviços ecossistêmicos têm um caráter mundial, mas também um caráter local significativo. Igualmente, o lixo marinho tem um caráter local, pois a sua geração está diretamente associada ao comportamento individual (Slavin *et al.*, 2012). Este caráter local é refletido, por exemplo, na composição do lixo encontrado em ambientes praiais e ao se comparar estudos de diferentes regiões ficam evidentes essas peculiaridades regionais. Em praias turísticas, observa-se que a proporção de lixo de origem turística é sazonal, como estudado por Walker (2006) na praia de Black Rock Beach no Canadá. Em Oman, realizou-se observação similar e o lixo de usuário de praias representou 70% dos itens e apenas 25% foi atribuído àqueles originados de pesca (Claereboudt, 2004). Diferentemente dos dois trabalhos anteriores, Ferrari (2009) observou em sua pesquisa[1] realizada no litoral paranaense a dominância de itens associados à pesca, chegando a 67% atribuído a essa fonte, enquanto aqueles de origem doméstica somaram 16% e apenas 9% foram atribuídos a usuários da praia. Finalmente, em um trabalho na costa do Chile, os autores observaram que não havia lixo atribuído a turistas, sendo a maioria

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[1] Na pesquisa conduzida por Ferrari (2009) a maior parte das amostras (68%) não pode ser atribuída a uma fonte provável. As porcentagens são referentes aos itens em que foi possível atribuir uma fonte provável. Essa observação é muito comum em estudos sobre lixo marinho pelo alto nível de fragmentação dos itens coletados ou ainda pela ação do intemperismo.

atribuída a resíduos de origem doméstica (79%) e o restante atribuído à pesca e aquicultura (21%) (Thiel *et al.*, 2013). Estes exemplos demonstram que as diferenças de composição do lixo marinho têm relação com as formas de utilização das praias e geram reflexos nos impactos sociais e econômicos observados em cada local (para uma revisão compreensiva observar Gregory, 2009).

De acordo com Mouat (2010), estes impactos associados às formas de uso das praias acabam gerando a redução nas oportunidades recreativas, perda de valor estético e perda de valores de não-uso[2] (Cheshire *et al.*, 2009). Estas perdas são muitas vezes mitigadas por meio de limpeza de praias que, por sua vez, gera impactos econômicos. Como já mencionado, a limpeza de praia é necessária pois a presença do lixo marinho torna os ambientes praiais menos atrativos aos usuários de praia (Golik, 1997). Por exemplo, os municípios do Reino Unido gastam, aproximadamente, 18 milhões de euros anualmente com a remoção de lixo de praias (Mouat *et al.*, 2010), o que representou, entre 2000 e 2010, um aumento de 37% destes custos.

Apesar de se saber dessas perdas e dos potenciais efeitos econômicos que o lixo marinho pode ter sobre comunidades costeiras, a quantidade de lixo encontrado em uma praia que efetivamente faria um frequentador parar de visitá-la é extremamente subjetivo e dependente de preferências pessoais, do propósito das atividades que serão desenvolvidas e do nível de lixo encontrado em áreas próximas (Mouat *et al.*, 2010). É comum observar que a literatura voltada à análise de percepções de usuários de praias use diversos critérios para separar grupos de interesse para estudos, como forma de identificar essas preferências pessoais. Há alguns estudos que segregam os grupos *a posteriori*, com base nos resultados obtidos do trabalho em campo, por exemplo, dividindo-os com base em características socioeconômicas como renda, idade, escolaridade ou gênero (Slavin *et al.*, 2012) ou em grupos de opiniões divergentes (Roca e Villares, 2008). Entretanto, o processo mais comum de separação de grupos de usuários é *a priori*. Ou seja, geralmente baseia-se em características previamente conhecidas para separá-los como, por exemplo, (i) origem: locais/residentes e estrangeiros/visitantes (Cervantes e Espejel, 2008; Marin *et al.*, 2009); (ii) de acordo com a atividade recreativa que desenvolve: campistas, turistas, pescadores recreativos,

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[2] Valor de não-uso refere-se aos benefícios gerados por se saber que um ecossistema em particular está sendo mantido. Três categorias de valores de não-uso são valor de existência, de legado e altruístico (Mouat,2011)

caminhantes ou outros (Whiting, 1998); banhistas e surfistas (Silva e Ferreira, 2014); (iii) atividade econômica ou setor da sociedade a qual faz parte: autoridade local, comunidade, associação entre outros (Roca *et al.*, 2008); ou ainda (iv) se proprietário ou não de segunda residência (não em ambiente costeiro; Huhtala e Lankia, 2012). A identificação e separação de grupos deve ser feita alinhada aos objetivos de pesquisa (Williams e Micallef, 2009). Independentemente se *a priori* ou *a posteriori,* o objetivo dessas diferenciações é identificar as influências de padrões, subjetivos e intrínsecos a cada grupo, sobre as suas preferências e percepções ambientais (Botero *et al.*, 2013). Por exemplo, Huhtala e Lankia (2012) identificaram que proprietários de segunda residência valorizam a existência de praias lacustres e que a sua ausência representaria uma redução de 40% no valor de recreação da visita. A seleção desse grupo foi feita, pois além de mais de 60% da população ter acesso a segundas residências, essa segregação se alinhava ao objetivo daquela pesquisa (Huhtala e Lankia, 2012). Nessa mesma linha, a separação desse grupo faz sentido no litoral do Paraná também, pois existe um grande número de proprietários de segundas residências nessa região (Monteiro, 2013). Na realidade, este é um grupo pouco estudado no Brasil, especialmente em relação à percepção relativa a perda de qualidade das praias, ainda que essa perda de qualidade ambiental possa representar o declínio do valor das propriedades (Long e Hoogendoorn, 2013) e também gerar efeitos econômicos negativos para as comunidades locais (Jang *et al.*, 2014). Em 1988, estimou-se que em Nova Jersey, nos Estados Unidos, perdeu-se entre 379 milhões e 3,6 bilhões de dólares com turismo e outras receitas em decorrência do lixo marinho trazido para as praias (Ofiara e Brown, 1999).

Mas os impactos econômicos do lixo marinho não se limitam a diminuição de turistas, há ainda o aumento dos riscos associados à saúde e à navegação, à ocorrência de incidentes com engate em petrechos de pesca abandonados, colisões com lixo marinho flutuante e ainda riscos oferecidos a mergulhadores (Ofiara, 2001). Esta variedade de impactos torna a realização da medição de todos os custos econômicos relacionados ao lixo marinho extremamente complexa (Mouat *et al.*, 2010). A dificuldade de adoção de ferramentas econômicas é ainda ampliada pelo fato de seus impactos não serem gerados pelos poluidores[3] (por exemplo, a indústria de polímeros e o setor do varejo), mas pelas

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[3] Há poucas informações quantitativas sobre a relação entre impactos e níveis de lixo (Ballance *et al.*, 2000). Neste caso, o que o autor aponta como "poluidor" é, por exemplo, o produtor do plástico. Logo, alguns

“atividades econômicas” costeiras como a pesca, aquicultura, o turismo e mais especialmente pelas comunidades costeiras (Newman *et al.*, 2015). Dessa forma, os instrumentos adotados as vezes não atingem o problema na sua fonte, focando apenas nos usuários finais dos recursos (Birdir *et al.*, 2013) fazendo com que essas também acabem figurando como medidas paliativas.

Mesmo assim é essencial buscar transmitir de forma eficiente os fatos sobre os impactos do resíduos ao meio marinho, para diferentes audiências, especialmente aos tomadores de decisão, visto que o campo de estudos sobre lixo marinho afeta muitas pessoas (Jang *et al.*, 2014; Kirkley e McConnell, 1997). As barreiras existentes entre ciência e tomadores de decisão baseiam-se especialmente em diferenças culturais, nas barreiras institucionais, na inacessibilidade de dados científicos para gestores, na manutenção de um modelo clássico de troca de conhecimento onde a academia gera e os tomadores de decisão recebem conhecimentos e ainda nas diferentes percepções pessoais de cada indivíduo sobre temas ambientais (Leviston e Walker, 2012). De acordo com TEEB (2010), a valoração econômica tem a capacidade de comunicar o valor de ecossistemas e da biodiversidade, bem como os fluxos de seus serviços e bens ambientais, na linguagem do modelo mundial dominante: a econômica.

Observa-se que o lixo marinho reduz os benefícios econômicos derivados das atividades marinhas e costeiras, aumentando os custos associados a elas (Ofiara e Brown, 1999). Por isso, preocupa o fato de que ainda existam regiões costeiras onde as autoridades locais considerem o fundo marinho, ou até mesmo as praias, como sendo o “destino final” do resíduo sólido que chega aos mares (Gregory, 2009). Especialmente, pelo fato de que alguns destes destinos finais, não necessariamente, estão dentro dos territórios do mesmo país ou região que é a fonte desse resíduo. Porém, essa relação entre fonte e sumidouro é delicada, especialmente quando se trata das responsabilidades da gestão e dos custos envolvidos com a solução do problema. Um exemplo é a pesquisa de Yoon *et al.* (2010) que simularam a dispersão de lixo marinho no mar do Japão. Os autores observaram que o lixo gerado na costa do Japão permanece nas praias do país. Porém o lixo gerado em grandes cidades de outros países, que circundam o Mar do Japão, acaba sendo exportado para a costa japonesa. Esses resultados assinalam a impossibilidade de

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instrumentos podem reduzir o lixo marinho, quando direcionados aos usuários de praia, mas não estão reduzindo o impacto do poluidor em sua fonte.

confinar o lixo marinho dentro de fronteiras territoriais (Cheshire *et al.*, 2009) e a necessidade da adoção de um enfoque regional, transfronteiriço e ecossistêmico (Lane *et al.*, 2007; McIlgorm *et al.*, 2008). Nesse sentido a Estratégia de Honolulu enfoca nos resíduos gerados, não apenas no mar, mas também em terra.

A Estratégia de Honolulu foi desenvolvida com o apoio de diversos setores da sociedade e foi aprovada durante a 5ª Conferência Internacional sobre lixo marinho. Ela é uma diretriz que não suprime e nem substitui as obrigações e atividades de autoridades, empresas e sociedade, mas visa ser um facilitador para o enfrentamento do problema do lixo marinho (Kershaw *et al.*, 2011). Ela cria diretrizes para a prevenção e gestão do lixo marinho através de 19 estratégias divididas em três objetivos principais, todos centrados na redução da quantidade e dos impactos do lixo marinho em diferentes escalas. A adoção desta estratégia ainda está em seu início, porém tem o potencial de reduzir os impactos ecológicos, econômicos e à saúde humana, do lixo marinho em nível global. Ela ainda tenta avançar no sentido da mitigação regional e transfronteiriça, isto é, busca abranger os impactos do lixo marinho sobre regiões que não são necessariamente as responsáveis por sua geração, mas estão arcando com os custos de sua limpeza, ou mesmo sentindo as perdas econômicas associadas a presença do lixo marinho.

Ainda no sentido de adoção do enfoque transfronteiriço (*transboundary*), pode-se destacar a atuação do Programa de Mares Regionais da UNEP (Cheshire *et al.*, 2009; Kershaw *et al.*, 2011; UNEP, 2005). Existem 19 iniciativas de integração regional sendo desenvolvidas mundialmente para o enfrentamento dos impactos do lixo marinho. Especialmente a abordagem regional da gestão de resíduos sólidos, em terra, tem o potencial de reduzir a quantidade de resíduos sólidos encontrados no ambiente marinho, uma vez que reduz a geração diretamente na fonte.

No Brasil, os resíduos sólidos em terra são um desafio crescente para a administração local devido aos altos índices de crescimento populacional nas zonas costeiras e aos baixos investimentos na destinação adequada de resíduos (Gollo *et al.*, 2010). Quanto ao lixo marinho e sua gestão, ambos não são diretamente reconhecidos pela legislação (Oliveira *et al.*, 2011). Há apenas algumas convenções internacionais, apoiadas por esparsas leis generalistas relativas ao meio ambiente, que preveem fiscalização e punição pela poluição do meio marinho. Dessa forma, embora um dos princípios do direito ambiental seja o do poluidor-pagador, o qual prevê a imputação de responsabilidade do dano ambiental ao poluidor (Colombo, 2006), não existem fortes suportes legais para sua aplicação em nível nacional. Nesse cenário, dois instrumentos da recente Política Nacional de Resíduos Sólidos (Brasil, 2010) surgem como possível caminho para a adoção de uma abordagem integrada e, ainda que de forma limitada, transfronteiriça. Apesar de suas aplicações não serem direcionadas ao lixo marinho e agirem sobre a geração de resíduos em terra, os planos microrregionais e a logística reversa poderão trazer grandes reflexos para as quantidades de resíduo entrando no ambiente marinho.

O primeiro instrumento é o que prevê a descentralização de ações de gestão dos resíduos, a qual estimula a formação de consórcios municipais e também de planos microrregionais de gestão de resíduos sólidos (Brasil, 2010). Esta abordagem microrregional é a essência da abordagem sistêmica e transfronteiriça, visto que não substitui, nem exime, a responsabilidade municipal sobre a gestão do resíduo, mas prevê a integração entre os municípios envolvidos para o enfrentamento de um problema que ultrapassa as barreiras geopolíticas municipais. Apesar de possuir um caráter mais estratégico, tem o potencial de auxiliar que munícipios ou regiões que não destinam adequadamente seus resíduos, por limitações orçamentárias ou técnica, consigam fazê-lo.

Já a logística reversa segue o princípio do poluidor-pagador e prevê que os fabricantes, importadores, distribuidores e comerciantes de produtos devem planejar sistemas para o retorno dos produtos (e em algumas situações suas embalagens) após o uso pelo consumidor (Brasil, 2010). Apesar de serem previstos apenas seis grupos de produtos pela Política Nacional de Resíduos Sólidos (PNRS), há a previsão de que outros produtos e embalagens possam ser alvo da logística reversa, dependendo da viabilidade técnica e econômica para sua execução. Dentre estes, inserem-se produtos que tenham embalagens plásticas, metálicas ou de vidro e que possuam significativo grau e extensão de impacto à saúde pública e ao meio ambiente (Brasil, 2010). Dessa forma, abre-se a possibilidade de que uma grande parcela do lixo marinho, em especial os plásticos, sejam recuperados através da logística reversa. Nesse cenário, a geração de dados sobre as extensões dos impactos do lixo marinho para embasar a tomada de decisão sobre a aplicação da logística reversa torna-se ainda mais importante.

Com a implementação de ambas as iniciativas, espera-se que uma cultura de responsabilidade integrada possa surgir, especialmente em municípios costeiros, em relação ao resíduo sólido, podendo ser refletida na gestão do lixo marinho. Até o momento, as iniciativas para implantação da Política Nacional são discretas e, em sua grande maioria, focam na adequação do descarte (Oliveira e Turra, 2015). No Estado do Paraná vem sendo planejada a adoção de planos microrregionais para a gestão dos resíduos sólidos municipais. O plano microrregional para a Bacia Hidrográfica Litorânea foi elaborado e concluído em 2013, porém passados quatro anos, sua implementação ainda não foi realizada. Alguns municípios já desenvolveram seus planos municipais integrados de resíduos sólidos, como Pontal do Paraná, mas sua total implantação também não aconteceu.

A adoção de estratégias de regionalização, também para o lixo marinho, figura como o avanço necessário para a gestão integrada de seus impactos, independente das escalas trabalhadas. Alguns estudos realizados recentemente no Brasil apontam que há espaços para melhorias na integração de políticas públicas relacionadas ao tema (Franz, 2011; Oliveira e Turra, 2015). Essa integração permitiria a redução na fonte geradora do lixo marinho e reduziria a presença destes itens nas praias. Porém, há a necessidade de reconhecimento sobre a existência dos impactos do lixo marinho pela legislação brasileira, ainda que isso não garanta a implantação de uma gestão adequada.

3. Justificativa

O lixo marinho é um problema global que gera impactos ambientais, sociais e econômicos. Primeiramente, a realização desse trabalho se justifica pela necessidade de trazer novas informações sobre a composição do lixo marinho e da sua dispersão em áreas estuarinas. As informações sobre o lixo marinho nesses ambientes são escassas. Soma-se a isso a necessidade de se testar novas abordagens que evidenciem os processos de dispersão do lixo marinho, pois os métodos existentes apresentam limitações na determinação dos caminhos percorridos pelos resíduos, especialmente nesses ambientes. Os métodos atuais focam nas atividades geradoras dos resíduos, sem buscar o reconhecimento de suas fontes geográficas. Os resultados têm aplicabilidade na gestão, afinal não apenas os municípios, mas também as regiões costeiras onde dinâmicas de exportação de lixo marinho estejam acontecendo, devem se responsabilizar e adotar estratégias de gestão transfronteiriça, considerando a estratégia de Honolulu.

Há poucos estudos que associam métodos diversos para compreender a dispersão do lixo marinho em pequenas escalas e, nesse sentido, esse trabalho é inovador e busca contribuir na redução dessa lacuna de conhecimento. Ainda, a influência de alguns fatores oceanográficos e meteorológicos sobre a dispersão do lixo marinho são pouco conhecidos. Abordar esses fatores de forma individualizada, buscando compreender seus efeitos, e não meramente abordado os resultados de maneira sazonal é também pioneiro e necessário. Com isso testar a influência desses fatores sobre a quantidade e qualidade do lixo marinho é essencial para futuras iniciativas de gestão. Considerando que o lixo marinho é um problema mundial, mas que deve ser gerido localmente, é fundamental que sejam reconhecidas suas fontes e seus sumidouros, para que sejam adotadas as melhores medidas de gestão, reduzindo sua geração e mitigando seus impactos.

Finalmente, há a necessidade de gerar informações científicas sobre a dimensão social dos impactos do lixo marinho incluindo os efeitos econômicos da presença do lixo marinho em praias turísticas. Especialmente nessa interface entre complexo estuarino e praias oceânicas, onde os estudos são ainda mais escassos. Por fim, os resultados dessa pesquisa têm o potencial de embasar a adoção de estratégias de monitoramento, coleta e limpeza mais adequadas em longo prazo.

4. Objetivos de pesquisa

Objetivo Geral: Analisar a distribuição e os fluxos espaço-temporais do lixo marinho nas praias do litoral do Paraná e seus impactos socioeconômicos

Objetivo específico 1: Investigar a movimentação e a trajetória de lixo marinho pelo Complexo Estuarino de Paranaguá e a relação fonte e sumidouro destes itens no gradiente estuarino.

Objetivo específico 2: Analisar o efeito de processos meteorológicos e oceanográficos sobre a quantidade e a qualidade de lixo marinho em praias arenosas no gradiente estuarino.

Objetivo específico 3: Entender a percepção e a reação dos usuários da praia em relação à presença de lixo marinho e os consequentes efeitos econômicos.

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5. Transboundary movement of marine litter in an estuarine gradient: evaluating sources and sinks using hydrodynamic modelling and ground truthing estimates

O movimento transfronteiriço do lixo marinho em um gradiente estuarino: avaliando fontes e sumidouros com o uso de modelos hidrodinâmicos e amostragens *in situ*

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Keywords: *marine debris, marine litter, modeling, transboundary, estuarine complex*

Palavras chave: *lixo marinho, modelos hidrodinâmicos, transfronteiriço, complexo estuarino*

Transboundary movement of marine litter in an estuarine gradient: evaluating sources and sinks using hydrodynamic modelling and ground truthing estimates

Abstract

Marine debris' transboundary nature and new strategies to identify sources and sinks in coastal areas were investigated along the Paranaguá estuarine gradient (southern Brazil), through integration of hydrodynamic modelling, ground truthing estimates and regressive vector analysis. The simulated release of virtual particles in different parts of the inner estuary suggests a residence time shorter than 5 days before being exported through the estuary mouth (intermediate compartment) to the open ocean. Stranded litter supported this pathway, with beaches in the internal compartment presenting proportionally more items from domestic sources, while fragmented items with unknown sources were proportionally more abundant in the oceanic beaches. Regressive vector analysis reinforced the inner estuarine origin of the stranded litter in both estuarine and oceanic beaches. These results support the applicability of simple hydrodynamic models to address marine debris' transboundary issues in the land-sea transition zone, thus supporting an ecosystem transboundary (and not territorial) management approach.

Keywords: *marine debris, marine litter, modeling, transboundary, estuarine complex*

Highlights

- Temporary permanence inside the Complex is followed by exiting to oceanic beaches;
- Ocean acts as buffer for marine debris from the PEC but not a source to PEC;
- Domestic sourced items had a proportionally higher presence in the internal sector;
- Unknown sourced/plastic fragments were found in higher proportion in external beaches;
- Modelling contributes to the understanding of marine debris transboundary dynamics

1. *Introduction*

Marine debris are persistent solid waste that enters the marine environment generated by land- or marine-based activities (Coe and Rogers, 1997) and it is estimated that 80% of marine debris comes from land-based activities (Windom, 1992). Marine debris can be categorized into different material classes, including cloth, rubber, paper, processed timber, glass and ceramic, metal and plastics (Cheshire *et al.*, 2009). Several studies indicate that most marine debris (50 – 90%) is composed by plastics (Barnes *et al.*, 2009; Gall and Thompson, 2015; Thompson *et al.*, 2004) and it is estimated that between 4.8 to 12.7 metric tons of plastic debris enter the oceans annually (Jambeck *et al.*, 2015). Since 46% of the plastic produced shows floatability in its original form (Li *et al.*, 2016; Stevenson, 2011), they are able to disperse and generate impacts in areas distant from sources (Carson *et al.*, 2013; Duhec *et al.*, 2015; Maximenko *et al.*, 2012). Marine debris pollution is thus a global problem and there is a plethora of literature describing its negative effects on biota, society and local and national economies (Coe and Rogers, 1997; GESAMP, 2015; Gregory, 2009; Jang *et al.*, 2014; Juying *et al.*, 2016; Mouat *et al.*, 2010; Potts and Hastings, 2011; Thompson *et al.*, 2009; UNEP, 2016). Despite its global ubiquity, marine debris' adverse effects are a concrete and visible problem at the local level, requiring engagement of local stakeholders to reduce its input and to remove it from the environment (Liu *et al.*, 2013). In some cases, sinks of marine debris, *i.e.* beaches, are out of the geopolitical limits of the generator locations (Nixon and Barnea, 2010), situation where a transboundary co-operation among neighbouring municipalities, states or nations is required. There are notable efforts in monitoring regional seas (Cheshire *et al.*, 2009; Galgani *et al.*, 2010; Schulz *et al.*, 2013), which support the adoption of a transboundary approach to marine debris. However, comprehension of aspects that reinforce the need of a transboundary approach (and not a territorial one) to marine debris are somehow understudied, especially at the local level. Investigating the relationship between sources and sinks, establishing the debris pathways and environmental conditions that define its trajectory are examples of gaps to be fulfilled (Ryan *et al.*, 2009).

It is common for scientific studies to claim enforcement of annex V, from the MARPOL agreement, as a solution to prevent these "orphan" marine debris to reach seas and oceans (Duhec *et al.*, 2015; Lane *et al.*, 2007; UNEP, 1990). Relying exclusively on adoption of this agreement will only deal with ocean-based marine debris loads and some important transboundary aspects remain unmanaged. On other hand, fully adopting transboundary approaches would imply new and a frequently unknown ecosystem based co-operation efforts of international or neighbouring sub-national jurisdictions (Sandwith *et al.*, 2001).

One effort intended to disseminate the transboundary approach is the Honolulu Strategy (NOAA and UNEP, 2011). The Honolulu Strategy emerged as a transboundary framework that deals with prevention of introduction of litter into the sea. Its three goals are focused on reducing both the amount and impacts of ocean and land-based sources of litter and diminishing accumulated marine debris in the environment. It focuses not only in shorelines but also in benthic habitats and pelagic waters (NOAA and UNEP, 2011) and thus incorporates the transboundary approach (Agardy *et al.*, 2011). However, there is a core limitation to its full adoption, which is the lack of a widely-recognized framework that powerfully links litter to their sources (Tudor and Williams, 2004). This uncertainty undermines the recognition that marine debris may be a transboundary issue in certain regions. Consequently, marine debris may be treated as a low priority issue by decision makers, especially from locations that are sources, but not sinks. This scenario reinforces that proper establishment of the most probable origin of beached marine debris is crucial.

Marine debris monitoring programs are essential to identify sources, but they are costly (Earll *et al.*, 2000; McIlgorm *et al.*, 2008) and sometimes are not effective in their purpose (Tudor and Williams, 2004). Most worldwide methods used to establish an item's source fall into one of the following strategies: assigning items to a unique source (Earll *et al.*, 2000); using indicator items (Ribic, 1998; Silva-Iñiguez and Fischer, 2003), and cross tabulating data in association with multivariate analysis or complex matrixes (Tudor *et al.*, 2002; Tudor and Williams, 2004; Whiting, 1998). Each of these methods present limitations and the development of complimentary strategies to improve confidence on litter sources and sinks is a clear demand (Veiga *et al.*, 2016). For instance, the usage of hydrodynamic models is an useful technique (Critchell *et al.*, 2015; Duhec *et al.*, 2015; Kataoka *et al.*, 2013) that has also the potential to improve communication with society and decision makers. However, there exists a clear gap in its application in small-scale settings (Critchell *et al.*, 2015), especially to support the transboundary management of marine litter (UNEP, 2016). Such approaches have also the potential to improve analyses about abundance and quality of marine debris in a comprehensively manner, considering local settings (Veiga *et al.*, 2016). Marine debris' abundance is a function of proximity to urban centres (Leite *et al.*, 2014), population behaviour (Slavin *et al.*, 2012) and medium or large-scale oceanographic conditions (Duhec *et al.*, 2015; Lebreton *et al.*, 2012).

In fact, meteorological and oceanographic conditions, such as prevailing wind, tide currents and frontal systems (Liu *et al.*, 2013; Walker *et al.*, 2006) can be integrated under a model approach to contribute to identification of sources, pathways and sinks of litter in coastal and oceanic environments. Marine debris pathways and fates have being studied by the usage of global mapping, data from surface drifters and numerical models (Carson *et al.*, 2013; Kataoka *et al.*, 2013; Maes and Blanke, 2015; Maximenko *et al.*, 2012). For instance, Kako *et al.* (2011) found that there exists a good reliability in forecasting amounts of marine debris that could lead to a reduced or optimized cost of cleaning. Also, crossing data obtained *in situ* with modelling has already been done on a global scale to evaluate the potential of plastic ingestion by sea turtles (Schuyler *et al.*, 2016), estimating amount of debris in oceans (Lebreton *et al.*, 2012) and addressing amounts of organic debris outflowing from embayment areas (Kataoka *et al.*, 2013). However, the global scales and resolutions used in most of those models, especially applied to plastic debris movement (*e.g.*, Lebreton's 2012 study has an average grid cell spacing of about 7 km), are not adequate enough for predicting accumulation areas at a more local scale (Critchell and Lambrechts, 2016).

Local or small scales are especially relevant in understanding the early steps of litter input into the ocean, since they represent places where most of the management measures and *in situ* marine debris' sampling take place. In this context, estuaries – in a worldwide perspective – become potentially excellent study areas to address the export and transboundary behaviour of marine litter due to the potential of marine debris generation, availability of information and sampling facilitation. In fact, estuaries and other regions where information about physical processes (winds, tidal dynamics, nearshore currents and wave patterns) is available, allows simulation of their interactions through oceanographic modelling. An example, is a study that estimated accurately the inflow of natural debris into Tokyo Bay by using simulations and results of *in situ* collection (Kataoka *et al.*, 2013). The same logic may be applicable for other bays and estuarine regions where anthropogenic marine debris is observed. As observed by Kataoka *et al.* (2013), comparing results of simulations with ground truthing in such environmental setting may increase certainty about marine debris fluxes and origins in estuarine regions.

Estuarine regions and their neighbourhoods generally house high populated urban areas, harbour facilities and are an asset for leisure activities (Brown *et al.*, 1991). In some cases, the circulation pattern of these areas is well known (Camargo and Harari, 2003). However, such data is not used for supporting management strategies, especially for the monitoring and control of marine debris (Mayerle *et al.*, 2015). It is a fact that those environments remain understudied in relation to marine debris, especially in Latin America (Ivar do Sul and Costa, 2007). Nevertheless, some studies enlighten the dynamics of marine debris in estuaries. For instance, it is known that riverine inflows, tides, winds and currents play a significant role for litter spreading in estuarine regions (Brown *et al.*, 1991; Browne *et al.*, 2010; Gallagher *et al.*, 2016). Also, salinity fronts, estuarine fronts and estuarine maximum turbidity zones influence debris distribution (Acha *et al.*, 2003; Brown *et al.*, 1991; Galgani *et al.*, 2010; Largier, 1993; Possatto *et al.*, 2015). Nevertheless, within a given estuary, differences are observed not only along the estuarine gradient (Acha *et al.*, 2003; Possatto *et al.*, 2015) but also between margins according to its degrees of pressure and level of urbanization (Procopiak *et al.*, 2007; Tudor and Williams, 2001).

Some examples of those effects are the findings of Acha *et al.* (2003) that demonstrated Rio de la Plata salinity fronts working as a barrier to both benthic and marine debris. Similarly, but at a smaller scale, Possatto *et al.* (2015) observed that the estuarine maximum turbidity zones (EMTZ) potentially reduces the sediment transportation and inferred that benthic marine debris tend to accumulate in areas with low circulation and high sediment accumulation (Galgani *et al.*, 2010). Previous studies also indicate that during high riverine flows, accumulation tend to occur seaward (Brown *et al.*, 1991). These illustrate the varied influences of factors over marine debris distribution and exemplify that identification of sources is a less straightforward task in estuarine environments. Consequently, it reinforces those utilising complimentary methods for sourcing, which can congregate several of those aspects, *i.e.* hydrodynamic modelling, may be beneficial for advancing in the field.

The present study carried out a strategy to address the transboundary nature of marine litter in an estuarine gradient combining the results of a hydrodynamic model DELFT-3D applied to floating marine debris associated with marine debris collected *in situ*. The study was conducted in a Natural World Heritage Listed Site, Paranaguá Estuarine Complex, Brazil, and considered small temporal (days) and geographical (10s of km) scales. The study considered three steps. A simplified modelling of dispersion from probable sources was conducted to identify general marine debris movements and to identify sampling sites to characterize debris and confirm sources (ground truthing). Then, a single but synoptic *in situ* sampling was undertaken to characterize marine debris. Six sites were sampled along the estuarine gradient and most probable sources of actual items were identified (more information about each beach, is given below, in section 3.2). This data was also used to corroborate modelling results through comparisons. Finally, five-day regressive vectors were calculated based on the environmental conditions observed during the period prior to the *in situ* collection for each of six sampling points. These regressive vectors were used to reinforce the geographical origins of the items found *in situ*. The hypothesis tested was that items observed in the oceanic sector of the Paranaguá Estuarine Complex were possibly generated or released in the inner part of the estuary (Hypothesis I); items found at the inner estuarine sector might have been generated or released in the oceanic sector (Hypothesis II); and ground truthing estimates of marine debris corroborate results obtained through computational simulations (Hypothesis III).

2. *Study area*

Paranaguá Estuarine Complex (PEC) is located in the northern coast of Paraná, Brazil (25º30'S e 48º30'W) and it is part of a large subtropical estuarine system, which includes Iguapê-Cananéia Bay (Lana *et al.*, 2001). The PEC comprises two major waterbodies along north-south and east-west alignments. The southernmost axis is about 40 km long and 7 km wide encompassing Paranaguá and Antonina Bays (Castella *et al.*, 2006). The PEC is connected with the open ocean through three tidal channels (Lana *et al.*, 2001) and the present study focuses on the southern outlet. The study area is divided into three different sectors (Figure 1). The internal sector is located close to the innermost part of the mixture zone of PEC (Noernberg *et al.*, 2006). This sector is close to the main human occupation zone (*i.e.*, with a high potential to generate marine litter). The median sector is close to the outermost area of the same mixture zone and the external sector was established in open-ocean beaches. The formation of a shoal (Galheta shoal), in addition to the presence of Mel Island, reduces the wave energy entering the PEC (Lamour *et al.*, 2006). Mel Island houses two protected areas and is one of the most important tourist places of the state. PEC houses a significant part of Atlantic Rainforest and is recognized as a Natural World Heritage Site (Unesco, 1999). Site selection also aimed at guaranteeing that tide-dominated, tide-dominated influence by outlet and wave-dominated shorelines were sampled (Lamour *et al.*, 2006; Rosa and Borzone, 2008)

The PEC is part of Lagamar Mosaic Network, which connects 34 Terrestrial and Aquatic/Marine Protected Areas (Brasil, 2006). The second biggest Brazilian harbour is located in one of the five municipalities inside the PEC, Paranaguá. Paranaguá is the biggest urban centre in Paraná`s coastal zone, whose development is mainly driven by the presence of the harbour, and houses a population of 140,469 inhabitants (IBGE, 2014; Silva *et al.*, 2015). Different from Paranaguá, municipalities downstream in the PEC outlet, *e.g.* Pontal do Paraná, are dependent on sun and bathing tourism. As a consequence, beaches are an important asset for such municipalities. Exploratory studies observed that estuarine and open ocean beaches in the PEC's outlet area are polluted by both land and marine-generated debris (Krelling and Chierigatti, 2014; Possatto *et al.*, 2015). Generation of land-based debris are potentially associated to the inner part of the PEC (Procopiak *et al.*, 2007).

The PEC is considered a tide-dominated estuary (Marone and Jamiyanna, 1997) with dominance of asymmetrical semi-diurnal tidal cycles, with amplitudes at the outlets just below 2 m. Tidal currents tend to follow the dredged-in navigation channel (Noernberg *et al.*, 2007), and ebb tidal currents can be up to 48% stronger than flooding during spring tides (Mantovanelli *et al.*, 2004). Precise estimates about freshwater inflow are not available, but Marone *et al.* (2005) estimated a mean value of 200 $m^3.s^{-1}$ for the E-W axis, using a box-model approach. This value, however, is diluted over a 330 km^2 surface area and a hydrological system with 1.12 $rivers.km^{-2}$ (Noernberg *et al.*, 2006). The resulting typical salinity gradient is from 12 – 29 (austral summer) to 20 – 34 (austral winter). Furthermore, the export nature of this estuarine system is also exemplified by the geomorphological structures at its outlets. At the southern outlet, the focus of this study, Angulo (1999) described a large ebb-tidal delta. This delta mainly protects the inner sectors of the estuary from incoming wave energy, with small waves (0.5 m high) and low periods (3 to 7 s; Lana *et al.*, 2001), features that impact mainly general turbulence and sediment deposition (Noernberg *et al.*, 2007).

The socioecological scenario exhibited by PEC represents an adequate study area to address the relationship between sources and sinks of floating marine debris in a transboundary gradient from estuarine to open-ocean beaches. There is a gap of knowledge regarding the application of modelling in smaller scales settings. Given the local scientific information available on the estuarine functioning and the availability of a validated hydrodynamic model, the use of modelling techniques coupled with *in situ* data will be potentialized.

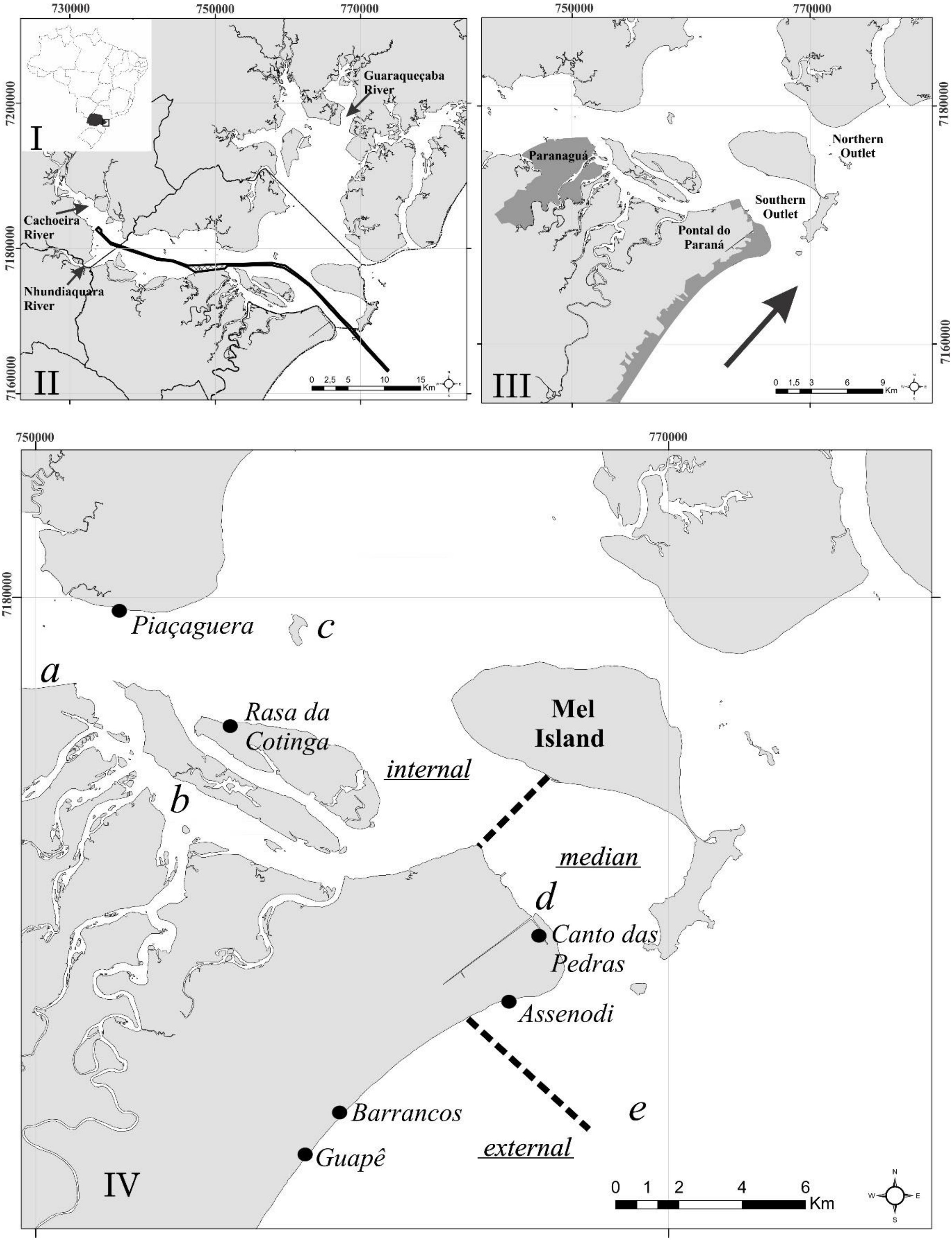

Figure 1 – Location of Paraná state in Brazil (I). Map indicating the Galheta navigable channel (Black line crossing the aquatic area across the East-West axis) and main freshwater contributors of the region Nhundiaquara, Cachoeira and Guaraqueçaba rivers (II). Main PEC's urban areas (dark grey), including the location of the cities of Paranaguá and Pontal do Paraná; geographical location of Mel Island, southern and northern PEC's outlets. The arrow represents the general current direction (SW-NE), according to Noernberg *et al.* (2007), in the external sector (III). The division of the study area into three sectors (IV; black dotted lines): inner sector (internal), median sector (median) and external part of the estuary (external). Marine debris was collected in two beaches in each sector: Internal: Piaçaguera and Rasa da Cotinga; Median: Canto das Pedras and Assenodi; External: Barrancos and Guapê. The geographical location of drifters' initial points (in italics) are: a. Harbour of Paranaguá, b. Itiberê River, c. Cobras Island mooring area (PEC inner mooring area), d. National Department Against Drought (DNOS) channel and e. External mooring area.

3. *Material and methods*

3.1 Dispersion from potential sources and identification of potential sinks– the Delft3D model

The dispersion from potential sources and identification of potential sinks was evaluated using the Delft3D model. Delft3D resolves the Reynolds-averaged Navier-Stokes and continuity equations for incompressible fluids in shallow waters, considering the Boussinesq approximation (Lesser *et al.*, 2004). The model is forced mainly using the high-passed frequency filtered tidal oscillations in the oceanic open boundary, and daily freshwater discharge rates from nine main drainage basins. It was validated along the E-W axis of the Paranaguá Estuarine Complex for tidal propagation, current velocities and the along-channel salinity gradient (Souza, 2015).

Unfortunately, a lack of available data for the N-S axis of this system made it impossible to validate the model for the whole domain. The employed time step is 0.5 minute. It has a variable for horizontal resolution with increased refinement at constrictions sections of the estuary. On the vertical, the model has 14 sigma layers and higher definition at both the surface and bottom. Waves can be accounted by online coupling to an inner shelf domain, validated at an offshore oceanographic buoy regarding wave characteristics (Figure 2; Souza, 2015).

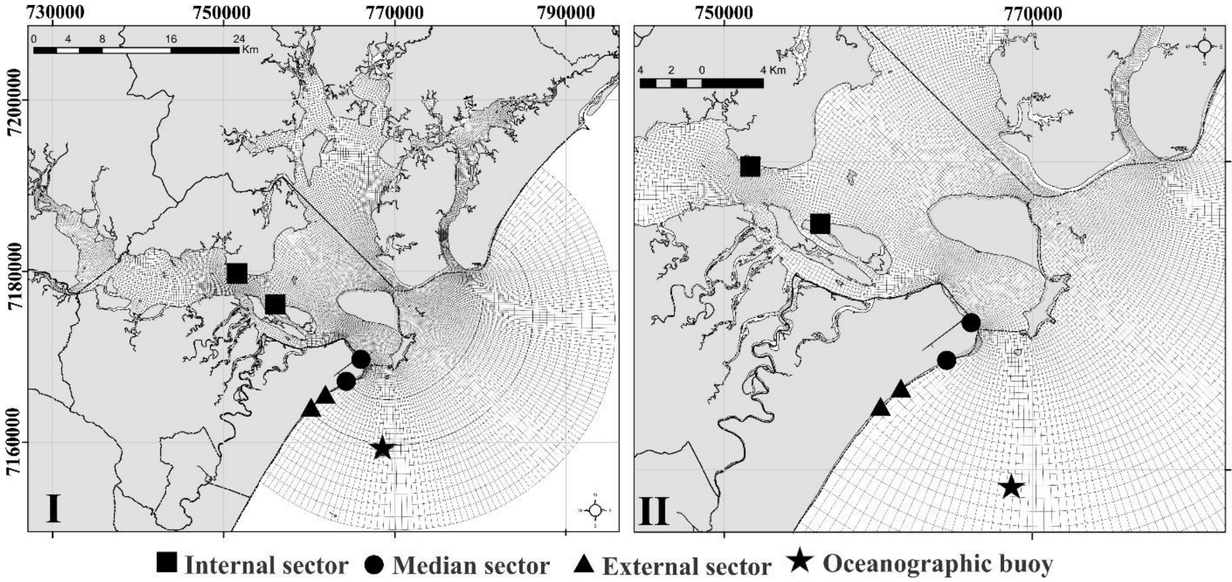

Figure 2 – Model domain. (I) Representation of the whole domain of the model, including its internal, median and external areas of the PEC (symbols). (II) Zooming in to the model's domain to show in detail the study area and demonstrate differences in grid cells sizes. Cells sizes vary from lower resolutions in the outer part (~1km) to cells of higher resolutions (tens of metres) in some internal areas of the PEC.

Prior to model simulation, a spin-up of two months was carried out to ensure a stable salinity gradient along the estuary. The run lasted 30 days and simulated tidal frequency and mean river discharges (as reported by Marone *et al.*, 2005). The aim of this simulation was to determine the overall dispersion patterns inside the estuary, when mean estuarine conditions were considered. Since wave action is limited inside the estuary and believed not to affect the hydrodynamic pattern inside this system (Noernberg *et al.*, 2007), including waves would represent an unnecessary and time-consuming process at this early stage. Winds, on the other hand, can greatly affect surface dispersion patterns. Unfortunately, no studies in the region are available regarding the overall wind patterns, and accounting for a full spectre of wind conditions is beyond the scope of this approach. Nevertheless, the overall hydrodynamics pattern will respond mainly to tides and, secondly, to freshwater inflow (Mantovanelli *et al.*, 2004; Marone *et al.*, 2005). In this sense, the selected 30 days allow for two complete fortnightly tidal cycles to be represented, while the mean freshwater inflow ensured a stable and representative salinity gradient and the corresponding baroclinic circulation.

For the purpose of this work, a simplified approach to marine floating debris was adopted. Debris was represented as virtual drifters (floating items) and was transported along the surface layer. In this model, the surface layer represents the first 5% of the total water column. It is important to stress that this approach neglects any chemical transformation that debris experience once in the water column. Since item degradation can affect not only the material composition but also its position on the water column (Vermeiren *et al.*, 2016), a complex ecological model would be necessary. But, as previously stated, this initial approach aims to only describe the general pathways in which the debris might propagate along the estuary.

Five areas, considered to be the most probable origin for marine litter, as sewage (including related solid wastes), domestic and harbour inputs, were selected as source points for these drifters. The following sites, (i) Harbour area; (ii) mooring area inside the estuary; (iii) the outer open-ocean mooring area, aimed at evaluating the possibility that ships anchored in offshore and inshore areas could be sources of marine debris to the estuarine gradient; In turn, sites at (iv) the mouth of Itiberê River; and (v) the point in front of the channel of the National Department Against Drought (DNOS channel) had the objective of observing possible sewage-related and domestic items that enter river and watersheds of the region, consequently reaching the estuary and accumulating in adjacent areas (Figure 1).

At each release point, one drifter was released every four minutes, until 200 drifters were virtually released. The total period summed up approximately 13 hours in order to ensure that drifters were released under the whole spectrum of tidal cycle conditions. Once released, the drifters remained active for the whole period. When several drifters’ pathways from the hydrodynamic model were close to the coastline (limit of the model), the area was considered as a potential sink for marine debris accumulation. This approach allowed the whole tidal energy spectrum to influence the drifters, and the main transport pathways along the estuary to be identified. This paper focuses on a short time scale and a limited geographical area, so simulating longer periods (*i.e.* months or years) would not fit the processes under analysis. By knowing where drifters converge, especially when close to shore, resources could be better focused during the ground truthing stage. Based on results of this first round, some sand beaches were considered potential sampling areas where drifter trajectory suggested a possible marine-debris-accumulation site.

3.2 Ground truthing - Marine debris sampling and categorizing

The aim of ground truthing was to acquire qualitative information about abundance, composition and most probable source of beached marine debris. From the potential sampling areas inside PEC, six beaches (two beaches per sector) were considered as suitable sampling sites to allow synoptic collection of marine debris (Figure 1), *i.e.* the site is a sand beach, accessible by boat or car, (at least) fifty-metre long and marine debris was observed during the first site exploration. Distance between beaches within sectors was of the order of thousands of metres and GPS coordinates were recorded for using as a baseline for future studies in the PEC, as *via* application of regressive litter vectors (see section 3.3).

Inner beaches were located close to the innermost part of the mixture zone of PEC and close to the city of Paranaguá. Piaçaguera and Rasa da Cotinga are estuarine beaches, with approximately 10 metres wide and both are only accessible by boat. Both are located in the municipality of Paranaguá. Piaçaguera is in front of the Paranaguá harbour, in the northern margin of the PEC (Figure 3). There is a traditional community living close to the sampling site and the area is also visited by a few families which possess second-homes used for weekends and vacations periods. Rasa da Cotinga is an isolated beach, in the southern margin of PEC and only sporadic users are observed mainly for sport-fishing activities (Figure 3). Intermediate beaches were close to the outermost area of the same zone and are located in Pontal do Paraná. Canto das Pedras and Assenodi are approximately 70 metres wide, in the balneary of Pontal do Sul, in Pontal do Paraná (Figure 3). Both are accessible by car and they are common destinations for tourists during summer periods and weekends. Compared to the internal sector, these beaches are more exposed to the action of waves due to its geographical location, which is southward to the Galheta shoal (Lamour *et al.*, 2006). Canto das Pedras experiences a greater density of users during summer periods if compared to Assendi, mainly due to availability of amenities for tourists, such as, restaurants with restrooms and parking areas. The external sector's beaches were selected in open-ocean beaches, without the direct protection of the Galheta Shoal. Barrancos and Guapê are approximately 100 metres wide and accessible by car. Barrancos houses a traditional fishermen community (Figure 3) and, during summer, experiences an increased number of tourists. Guapê is beside one of those balnearies (Shangri-lá) which concentrates a great number of users during summer periods (Figure 3). Consequently, the area experiences a higher pressure of beach goers. During the ground truthing sampling, beach users were virtually absent in all sampling sites, since ground truthing was conducted in Autumn.

In each beach, three five-metre-wide transects were randomly chosen within a fifty-metre-long shore site (Dixon and Dixon, 1981; Lippiatt *et al.*, 2013; Velander and Mocogni, 1999) for collection of marine debris. The adoption of this width followed two methodological aspects: a preliminary study of beaches on the region indicated that at least 80% of the litter categories – which were encountered in 50 metre beach strips of all beaches sampled in that study – were detected within fifteen-metre beach stretch; and the need to insure statistical random replicates for each beach (n=3), since some beaches were narrower than 60 metres.

It is known that the intertidal zone comprises a small proportion of the total amount of marine debris found on a beach (Tudor and Williams, 2001). However, as the aim of this study was to sample only freshly or recently arrived items, which were beached in the last tidal cycle, just the intertidal zone was sampled. It comprised the area that extends from the highest drift line (landward) to the actual waterline (Moreira *et al.*, 2016).

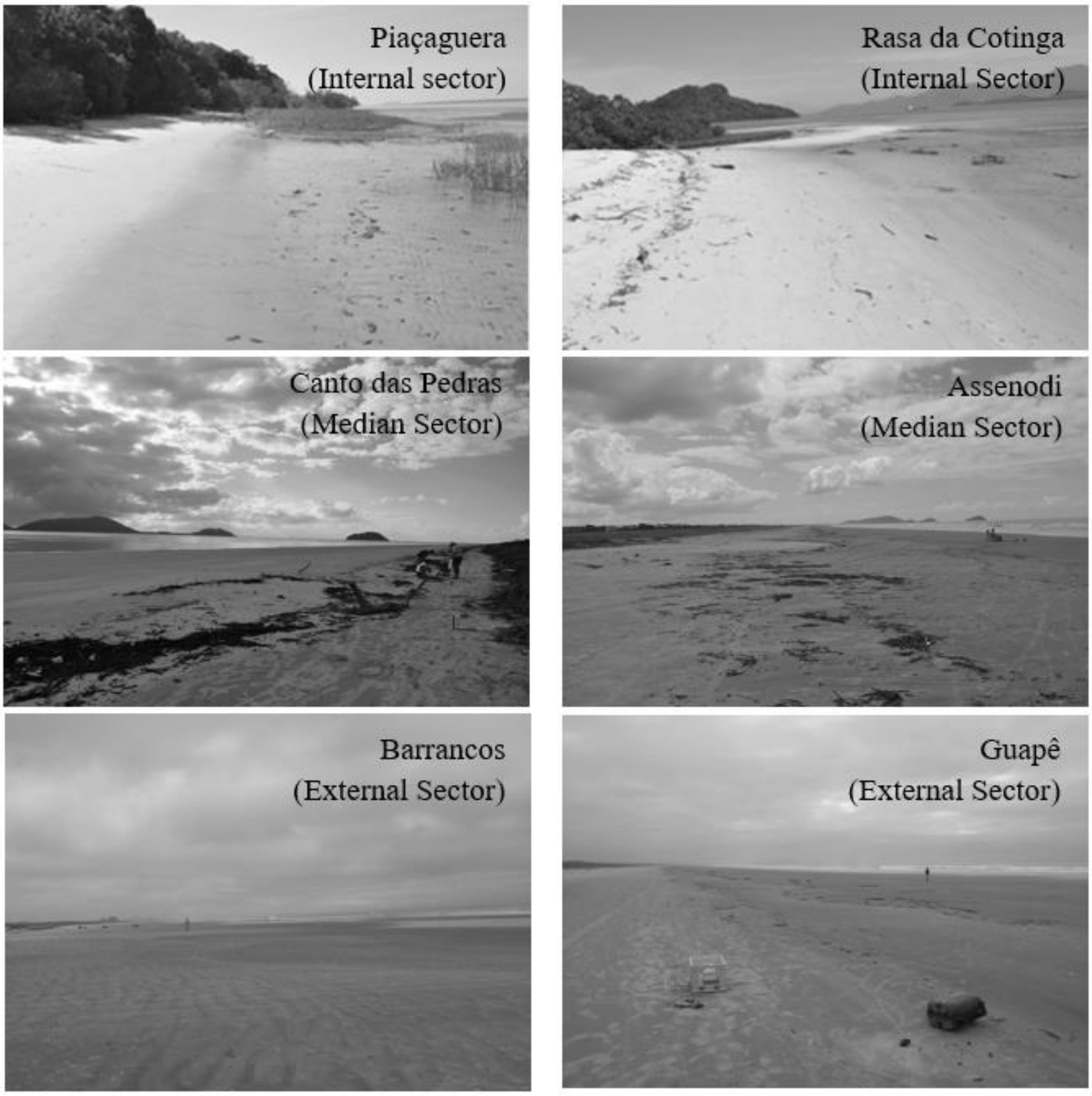

Figure 3 – Sampling sites. Marine debris was collected in two beaches in each estuarine sector: Internal: Piaçaguera and Rasa da Cotinga; Median: Canto das Pedras and Assenodi; External: Barrancos and Guapê.

All anthropogenic marine debris greater than 2.5 cm was collected, cleaned and stored. They were than characterized regarding their composition, litter item type and the most probable source. A system comprising a two-level hierarchy (Cheshire *et al.*, 2009) was used. Firstly, items were categorized by material composition, considering nine categories: Plastic, Processed Wood, Glass, Styrofoam, Metal, Clothing, Paper, Rubber and "Other". Secondly, they were classified by litter item type, which considered an adapted medium resolution survey that recognizes *circa* 77 item types (Cheshire *et al.*, 2009). For a complete list of types, refer to ANNEX I.

Items identification was augmented with information about the most probable sources of marine debris. Among several methodologies (Tudor and Williams, 2004), here the items were "attributed by litter type" (Earll *et al.*, 2000) according to the following sources: fisheries, domestic, sewage-related, beach users, shipping/harbour and unknown. For attributing an item to a source, an elimination process was considered, similarly to the method proposed by Tudor and Williams (2004). The eliminating process considered indicatives that an item was likely originated by a certain source, for instance, a plastic bottle. The content of the bottle and the information of labels, if present and readable, determined the most probable source. If the bottle was found with oil or traces of oil (for engines) inside, which is a common practice of fishermen of the region, it was likely to have been used by fishing boats. Therefore, it was attributed to a "fisheries source". If it was a bottle of cooking oil, it was likely to have been used for domestic purposes and it was attributed to "domestic". If there was a label indicating international origin, it was attributed to “ships or harbour”. If inside the bottle there were items associated to beach users, for example napkins, cigarette butts or ice cream sticks, it was attributed to “beach users”. It is also a common practice inserting these items inside bottles since there is a lack of bins at the beaches. Otherwise the bottle was considered a non-sourced item. Items were not weighted due to bias caused by wet items (Lippiatt *et al.*, 2013) or sand and fouling which were not visually detectable.

As the study aim was to test if simulations can determine the geographical origin and pathways of a pool of marine debris found in a certain beach, for a specific moment, the seasonal patterns were disregarded. A punctual, but synoptic, campaign was conducted in April, 1st 2015. Repetitions were not done because day-to-day variation is more frequently observed in those environments (Moreira *et al.*, 2016) and samples would not be objective replicates. This strategy is based in previous studies which adopted not only punctual sampling but also used singular items (n=2) for determining item sources (Maes and Blanke, 2015). Results of the statistical data obtained through fieldwork were compared to the graphical results of specific simulation run of the prior days of the campaign *in situ* (further explanation in section 3.3).

Statistical analyses of composition, litter items types and most probable source were performed using Permutational multivariate analysis of variance (PERMANOVA), considering a single fixed factor (estuarine sector), a random factor (beach) and three replicates (three transects). Composition analysis considered nine levels (Plastic, Processed Wood, Glass, Styrofoam, metal, clothing, paper, rubber and “other”); while litter items types analysis considered 56 levels (the number of different observed litter items) and most probable sources six levels (fisheries, domestic, sewage-related, beach users, shipping/harbour and unknown). When PERMANOVA indicated significant differences, *post hoc* pair-wise tests were performed. Three independent non-metric multidimensional scaling (nMDS) ordinations were done based on Euclidean Distance regarding each variable tested (composition, litter items types and most probable sources; Clarke and Gorley, 2006). For both PERMANOVA and nMDS, the set of data was standardized prior to conducting analysis (Zar, 2010). The contribution of these different litter levels to overall dissimilarity among beaches and within sectors were analysed with a Similarity Percentages (SIMPER) routine (Clarke and Gorley, 2006). Raw data was used for conducting SIMPER analysis. SIMPER results also support the interpretation of nMDS regarding similarities and dissimilarities within sectors and among beaches.

3.3 Target simulation and regressive vector analysis

After collection of *in situ* marine debris, a regressive vector analysis was performed (Figure 4). This simulation ran for 35 days, from March 1st to April 4th, 2015. It included daily river discharge data obtained from the Regional Water Agency (Instituto das Águas do Paraná, 2015) for the Cachoeira, Nhundiaquara and Guaraqueçaba Rivers; high-frequency tidal elevations derived from tidal harmonics; wind fields; and wave fields (Souza, 2015). Wind speed and direction was obtained from a meteorological station located at Mel Island, provided by the National Institute of Meteorology (INMET, 2015), and wave data was extracted from a buoy located at the inner shelf, in front of the estuary’s inlets (Souza, 2015; Figure 2). The inclusion of wind and wave data was necessary at this step, since those forcing are possibly relevant for the open-ocean area, including wave generated along-shore drift. As opposed to the analysis of dispersion from potential sources and identification of potential sinks done previously, this approach aimed to reproduce the expected circulation fields and then support a better estimation of the debris transport pathways through the regressive vector analyses.

The initial time for the analysis was considered the date of *in situ* debris collection. From this point, a backward five-day period was used for estimation of debris origin. The five-day window was based on the water renewal time for the PEC (Marone *et al.*, 1995). For this backward displacement, the initial position of debris was considered at the model cell closest to the geographical coordinate of the sampling site, as well as all valid cells around it. This definition enabled the inclusion of some variability in the results, considering that the velocity fields are deterministic. At this point of origin, current speed and the inverse of current direction were used to calculate the displacement of particles for the duration of a result record (30 minutes). If, after this period, the drifter position had moved to another cell, the new set of current speed and direction was used to calculate the new displacement. In case it remained in the same cell, drifter displacement was calculated with the new set of data for the next time step. This was repeated for every result time step during the simulated period.

It is important to stress that the regressive vector approach provided a general idea of possible floating debris origin. In this sense, these results should be interpreted as a possible generation gradient, and debris could be originated within these areas. In the natural environment, debris pathway may exhibit some chaotic displacement, which cannot be determined with this methodology. Nevertheless, the averaged-out path will filter most irregularities, and the end destination remains somewhat unchanged. All situations analyzed here are dependent on oceanographic and meteorological conditions, which, consisted of smaller transboundary scales when compared to other studies (Duhec *et al.*, 2015; Law *et al.*, 2010; Lebreton *et al.*, 2012; Mansui *et al.*, 2015; Maximenko *et al.*, 2012; Neumann *et al.*, 2014).

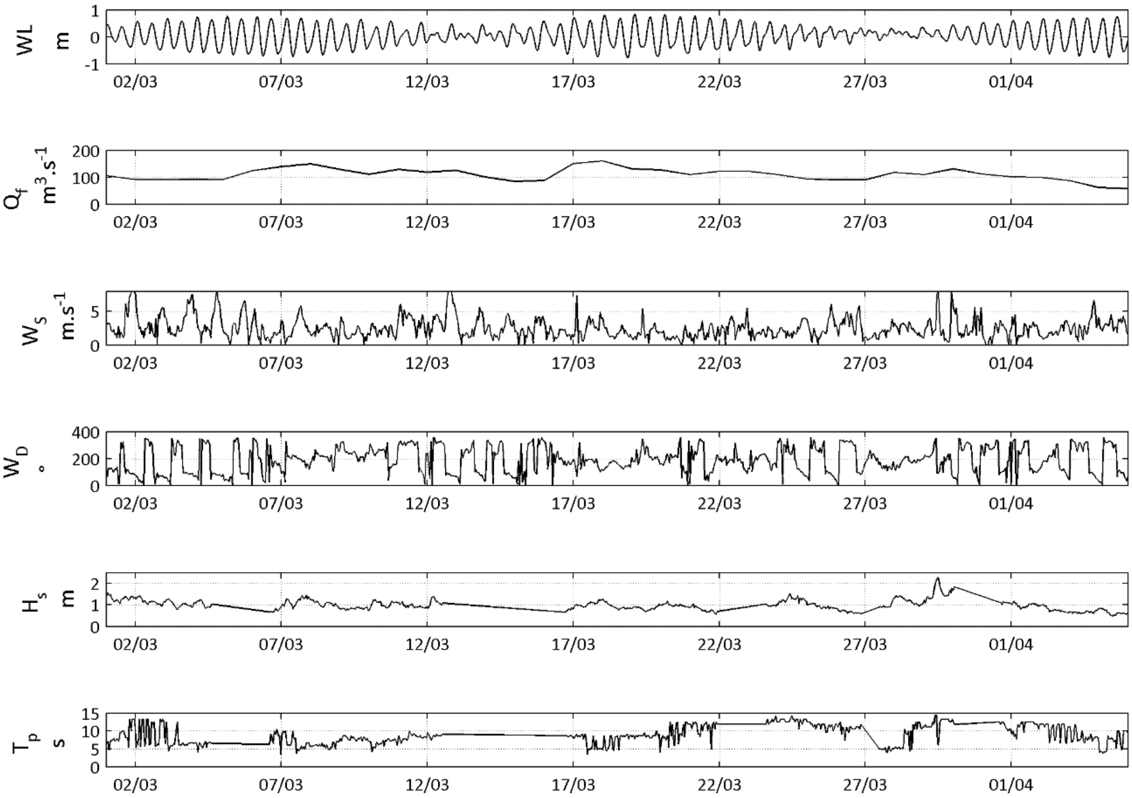

Figure 4 - Boundary conditions for the regressive vector simulation, between the period March, 1st and April 4th. From top to bottom, water level (metres), total freshwater inflow ($m^3.s^{-1}$), wind speed ($m.s^{-1}$), wind direction (grades), significant wave height (metres) and peak wave period (seconds).

3.4 Hypotheses testing

Hypothesis I states that items observed in the oceanic sector of the Paranaguá Estuarine Complex were possibly generated or released in the inner part of the estuary and Hypothesis II that items found at the inner estuarine sector might have been generated or released in the oceanic sector. Both hypotheses were tested through observation of the simulated trajectories and endpoint locations of drifters virtually released both in the inner and outer part of the estuarine complex. Hypothesis I could be considered corroborated if endpoints of the drifters released in the inner part of the gradient were mostly observed in the external area of the gradient. Hypothesis II could be considered corroborated if endpoints of the drifters released in the outer part of the gradient were mostly observed in the internal area of the gradient. For these tests, ‘virtual releases’ of the first round were used. Results of regressive vectors supported the analysis and discussion of the results for these two hypotheses, as well (Table 1). Hypothesis III states that ground truthing estimates of marine debris would corroborate results obtained through computational simulations. Hypothesis III was tested by comparing the thirty and five-day virtual releases’ graphical results (sink-based perspective) to the statistical outcomes from the *in-situ* sampling (source-based perspective). This hypothesis corroboration was dependent of the results of hypotheses I and II analysis. In a ‘First case’, if both hypotheses I and II were corroborated, it would be expected that the marine debris composition, types and sources were homogeneous along the estuarine gradient. Consequently, hypothesis III could be considered corroborated if neither graphical segregation in nMDS nor differences regarding principal contributors for similarities and dissimilarities (SIMPERS) were observed for sectors or beaches. In a ‘Second case’, if one of the hypotheses or both were not corroborated, then it would be expected that marine debris composition, types and sources were heterogeneous along the estuarine gradient. Consequently, the hypothesis III could be considered corroborated if graphical segregation in nMDS or differences regarding principal contributors for similarities and dissimilarities (SIMPERS) were observed for sectors or beaches. Indications of probable geographical origins of items found on those sinks (beaches) were postulated with respect to the local PEC geography. Comparisons about similarities, differences and limitations of the methods were pointed out.

Table 1 – Summary table of simulations. All simulation runs performed for the study are summarized informing: the purpose of the run; number of drifters launched; time simulated; the mode of the run (Forward/Backward in time) and drivers included in the specific run.

Simulation run	*purpose*	*number of drifters launched*	*time*	*mode of run*	*forcing for the model*
Simplified run	Determining general circulation patterns of surface drifters from different source points.	1000 (200 per releasing point)	30 days	Forward	Tidal frequency Mean river discharges
Regressive vectors based in target simulations	Establishing possible geographical range of origins for items found at sampled beaches, based on the hydrodynamic fields from a 35-day target simulation	from 1-5 (model cell and valid cells around it)	5 days	Backward	Daily river discharge High frequency tidal elevations Wind and waves fields for the period

4. *Results*

4.1 Dispersion from potential sources and identification of potential sinks– the Delft3D model

A common pattern was observed among the three internal releasing points (Paranaguá Harbour, Itiberê River and Cobras mooring area). These drifters’ trajectories pointed out the existence of a temporary permanence of not more than five days inside the estuarine complex, followed by an exit to the open ocean (Figure 5). Drifters virtually released in Itiberê river mouth and Paranaguá harbour exited to the open ocean almost exclusively through the southern outlet. Differently, Cobras mooring area exported the simulated particles by both northern and southern outlets. All drifters released inside PEC exited to the open-ocean. Nevertheless, when drifters were in the open ocean, a general northerly transport pattern was observed, when items were further away from the PEC’s outlets (Figure 5). The northerly transportation pattern in the outer part of the estuary was observed for the drifters from both internal and external releasing points. The outer mooring area seems to be especially influenced, showing a drifting pattern directly north. Drifters from this point did not approached the shore in the situations of tides and riverine discharges simulated in this study.

Drifters from both release points at the outer parts of the study site, DNOS Channel and external mooring area, showed trajectories limited to the southern outlet external area and open-ocean (Figure 5) indicating that in absence of severe meteorological situations, drifters tend to remain in the open ocean and not enter the PEC. Similar to those previous trajectories of the internal points, drifters of the DNOS Channel showed a first southern movement and then, similarly to the outer mooring area drifted away from the estuarine influence area moving to the open ocean in a northward pattern. Nevertheless, even without inclusion of waves and wind information in this model run, it was noticeable that trajectories of most drifters tend to approach the areas of the southern outlet of the PEC (Figure 5), being potentially stranded at the external sector, especially under the influence of specific oceanographical and meteorological events.

The trajectory of items from inner points overlapped the areas reached by the trajectories originated from the outer points. However, this happened only in the southern outlet area and in the outer part of the complex. Therefore, not only items originating from the innermost part of the estuary, but also from the outlet area and the outer part, have the potential of reaching open ocean beaches, depending on environmental conditions. The other way around, *i.e.*, items originating outside the estuarine complex were not able to reach inner estuarine areas. Only items originated in the interior of PEC seem to possibly reach inner beaches. These results indicate that hypothesis I was corroborated, but hypothesis II was refused. Consequently the ‘Second case’ was considered for testing hypothesis III (recall section 3.4, for hypotheses testing).

The innermost part of the PEC is a probable main litter source for the region, since after 30 days all drifters’ trajectories ended up in the open-ocean (Figure 5). Despite the fact that 40% of drifters were virtually released already in outer areas (southern outlet and open-ocean), it was noticeable that there existed a pattern of exporting items from the PEC’s innermost part under the meteorological conditions used for these runs. Beaches located in the southern portion of the PEC’s outlet area (Canto das Pedras, Assenodi, Barrancos and Guapê) are potential sinks for marine debris originated in four out of five releasing points.

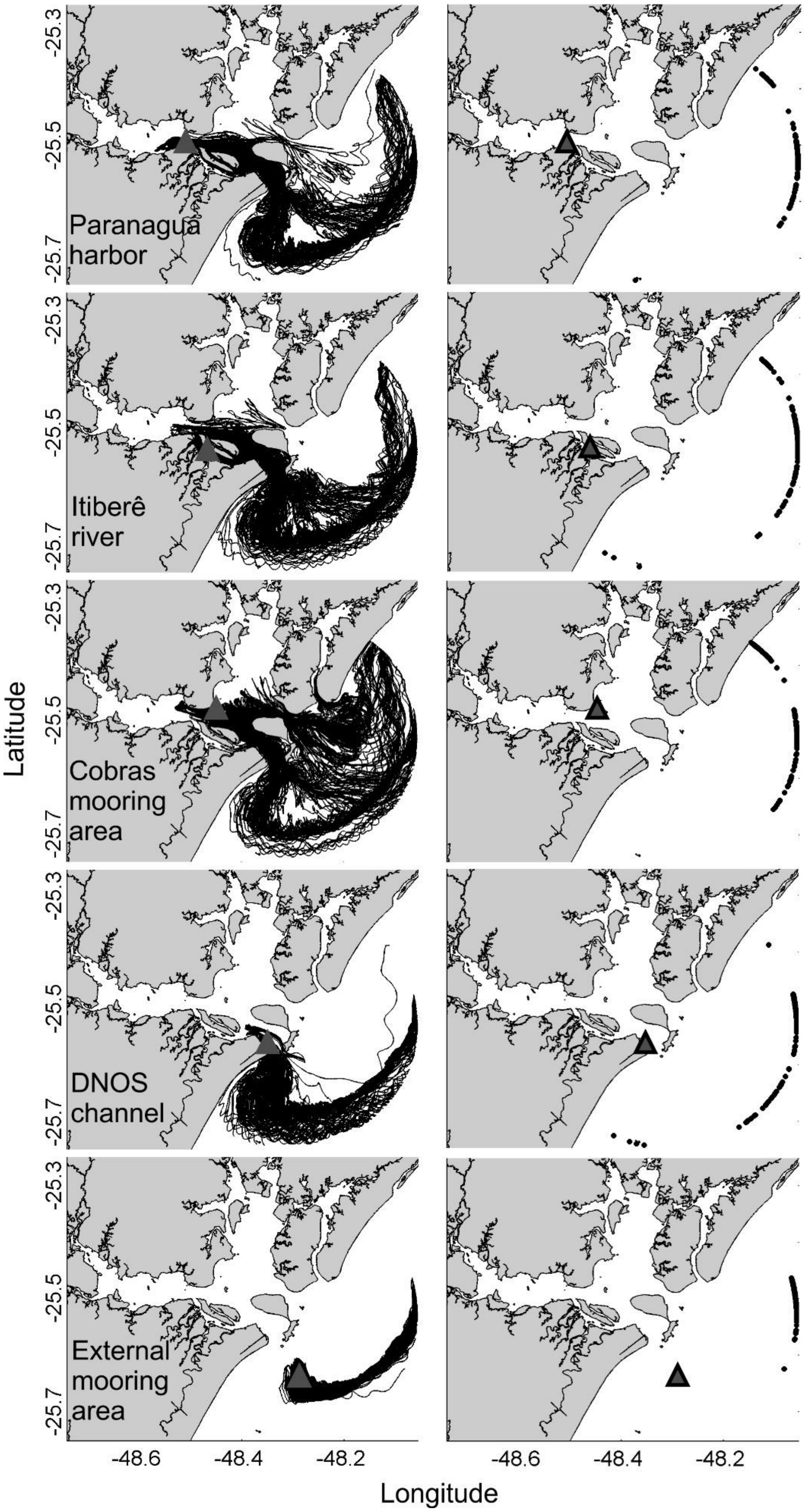

Figure 5 – Dispersion of drifters from five releasing points along the estuarine gradient. Black lines represent the trajectory of 200 drifters for each releasing point (left column), during 30 days. Black dots represent the end points of the trajectory of the same 200 drifters for each releasing point, after 30 days (right column). Releasing points are Paranaguá Harbour, Itiberê River, Cobras mooring area, National Department Against Drought (DNOS) Channel and external mooring area, represented by each grey triangle. In each releasing point, a drifter was virtually released each four minute, until drifters summed up 200 for each point along approximately 13 hours, which is a complete tidal cycle for the region.

4.2 Ground truthing - Marine debris sampling and categorizing

4.2.1 Composition

Nine hundred and twenty-four items of marine debris were recorded from all six beaches comprising 751 plastic items (81.3%), 77 Styrofoam/foam (8.33%), 25 rubber (2.7%), 24 processed wood (2.6%), 10 Glass (1.1%), eight metal (0.9%), three clothing (0.3%), one paper (0.1%) and 25 items of "other items" (2.7%; Table 2). PERMANOVA did not detect significant differences regarding marine debris composition neither among sectors (pseudo-F=2.436 and p=0.0675) nor between beaches within sectors (pseudo-F=1.2511 and p=0.1753). Even though PERMANOVA detected a marginal significance, pair-wise tests failed to detect differences among sectors (Internal *vs.* Median: p=0.3321; Internal *vs.* External: p=0.3377 and Median *vs.* External: p=0.3332).

A graphical segregation between external and internal sectors' samples regarding composition was observed at the nMDS (Stress=0.04; Figure 6). The external sectors showed the highest similarities within samples of the same beach, Barrancos (91.52%) and Guapê (77.57%), being significantly influenced by the presence of plastics (Figure 6). Such a result supports the existence of a gradient differentiating internal and external beaches and sectors, with a mixed characteristic in the median sector. One sample in each sector showed discrepancies. In Piaçaguera, in the internal sector, amount of glass and 'other' compositions may be responsible for such pattern, while a great number of pieces of wood may be responsible for Canto das Pedras difference and two pieces of clothing in Barrancos, in the external sector. Nevertheless, a graphical segregation is observable for the estuarine gradient.

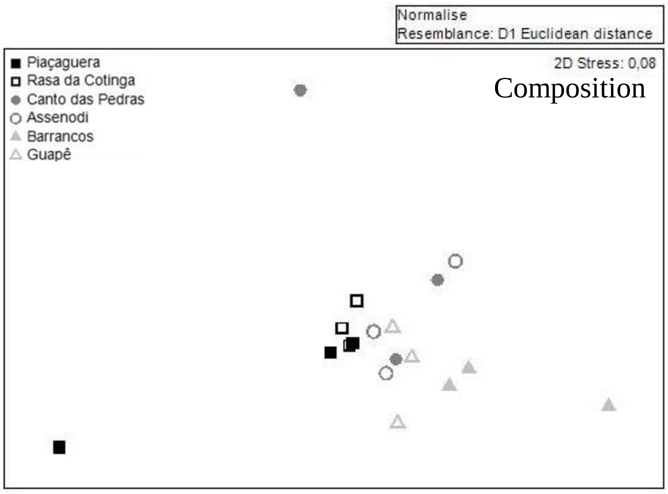

Figure 6 – nMDS grouping of samples, regarding composition per beaches within sectors. Beaches of the internal (squares), median (circles) and external (triangles) sectors are indicated.

Variability among beaches was extremely significant, offsetting differences between sectors when performing PERMANOVA. Even though, SIMPER indicated a contribution of plastic above 80% to the similarities between beaches within each sector. The second most important contribution was foam items for the external (5.85%) and the median (9.64%) sectors, while for the internal, metal components (7.46%) were the second highest contributors. Plastics were also the most important contributor for dissimilarities when overall comparisons were conducted among sectors (>65%) and between beaches (>57%). The only exception was the comparison within beaches from the internal sector, Rasa da Cotinga and Piaçaguera, where plastics showed a lower contribution (33.02%) for dissimilarities while "other items" (22.3%) and glass and ceramic (17.8%) had a proportionally higher contribution for their dissimilarity. Such differences regarding dissimilarities, indicate that beaches of the internal sector are different influenced by marine debris composition if compared to the other beaches of the gradient.

4.2.2 Marine debris litter items

Differences regarding marine debris items were observed for beaches within sector (pseudo-*F*=1.3882; p=0.002) but not for sectors (pseudo-*F*=1.4312; p=0.069), according to PERMANOVA. However, *post hoc* Pair-wise tests failed to detect significant differences for litter items of marine debris for beaches within sectors (Piaçaguera *vs.* Rasa da Cotinga p=0.2029; Canto das Pedras *vs.* Assenodi p=0.7966; Barranco *vs.* Guapê p=0.0974).

The nMDS using the litter items types reinforced the segregation of the internal sector's beaches (Rasa da Cotinga and Piaçaguera) from other beaches, especially Barrancos (Stress=0.13; Figure 7). A clear graphical segregation among sectors is observed also for marine debris items types. Even though some discrepancy was observed in a sample from Canto das Pedras due to an outlying number of caps and lids, and in another from Piaçaguera, due a higher quantity of fragments of glass and ceramic, the graphical differentiation is observable. SIMPER results supported such segregation since dissimilarities when comparing the internal sector to median (79.9%) or to external (85.5%), were higher than differences between the median and external sectors (55.8%).

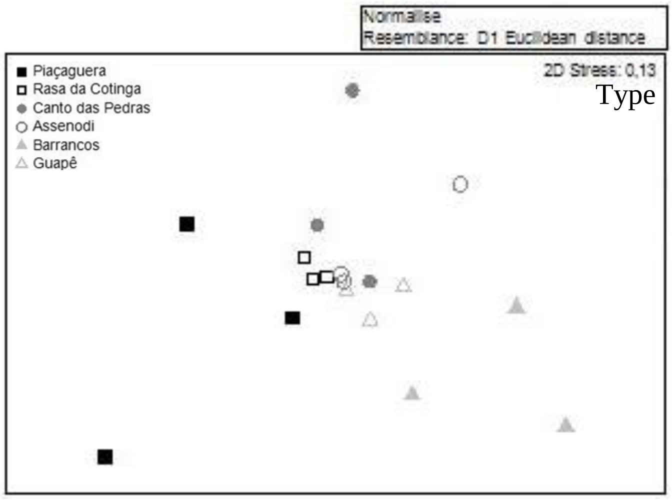

Figure 7 – nMDS grouping of samples, regarding litter item types per beaches within sectors. Beaches of the internal (squares), median (circles) and external (triangles) sectors are indicated.

SIMPER analysis showed that fragments of plastic contributed significantly to the similarity of all sectors being proportionally more representative to the external (55.24%) and median (44.36%) sectors. For the internal sector the contribution of fragmented plastic items (29.83%) is smaller since food wrapping (30.40%) overcame the percentage contribution. On the other hand, food containers and wrappings contribute in a smaller proportion for the external (12.26%) and median (3.8%) sectors. Considering raw data, it is also observed that fragmented or weathered plastics were mostly found in the external sector, summing up 249 items (71.96%; Table 2). The median sector, which is in the middle of the graphical gradient, is dominated by plastic fragments (44.3%), bottle caps (14.2%) and Styrofoam fragments (12.8%). Results indicate that marine debris types influence differently the similarities within and dissimilarities among sectors.

Table 2 – Most common marine debris litter items. Absolute number of items of each most common litter items (per beach within each sector). These items contribution is above 2.5% of the overall number of items. The total number of items of each composition (inside parenthesis, besides composition).

	Internal sector		***Median sector***		***External sector***		***Total***
Beach name	*Piaçaguera*	*Rasa da Cotinga*	*Canto das Pedras*	*Assenodi*	*Guapê*	*Barrancos*	
Plastic (751)							**679**
Bottle caps & lids	3	0	25	12	13	4	57
Food containers (boxes, wrapping...)	8	4	9	2	16	34	73
Cigarettes butts/filter	1	1	9	5	3	4	23
Monofilament line	1	0	3	7	6	10	27
Rope	0	0	2	2	5	11	20
Lollipop stick	0	0	4	7	6	16	33
Plastic fragment	6	8	43	50	70	179	356
Seals	0	0	7	2	1	7	17
Styrofoam fragment	1	0	19	20	12	21	73
Glass & ceramic (10)							**17**
Glass/ceramic fragments	17	0	0	0	0	0	17
Other (25)							**36**
Sanitary (nappies, cotton buds...)	1	1	5	10	5	14	36
Other compositions: Styrofoam (77), Rubber (25), Wood (24), Metal (8), Clothing (3) and paper (1)							**192**
Other types	30	18	36	18	35	55	192
TOTAL	**68**	**32**	**162**	**135**	**172**	**355**	**924**

4.2.3 Most Probable Sources

When testing most probable source of the items, PERMANOVA did not detected differences between sectors (pseudo-*F*= 1.9605; p =0.1963) but detected for the interaction between beach and sector (pseudo-*F*=2.5177; p=0.009). The *post hoc* Pair-wise tests failed to detect significant differences between beaches within sectors (Piaçaguera *vs* Rasa da Cotinga: p=0.2029; Canto das Pedras *vs*. Assenodi p=0.7966; Barrancos *vs*. Guapê p=0.0974). A great variance among beaches may have offset variation among sectors.

As regards most probable sources (Stress=0.06, Figure 8) considering nMDS, a similar gradient was also observable with samples from the internal sector at one extreme, especially from Rasa da Cotinga, and samples from the external sector on the other, especially Barrancos (Figure 8). The presence of “Harbour” items differentiated one sample of Barrancos and two samples of Rasa da Cotinga, in relation to the rest of samples. Also, an outlying number of domestic items segregated one sample from Barrancos from the other samples of the same beach. Nevertheless, differentiation is clearly observed along the estuarine gradient. Such a pattern is also supported by SIMPER results that indicate the highest dissimilarity regarding the most probable source was observed between external and internal sectors (>70%). When the level analysed is “beach” the dissimilarity is high when comparing Barrancos to Piaçaguera (71.34%) and Barrancos to Rasa da Cotinga (84.12%).

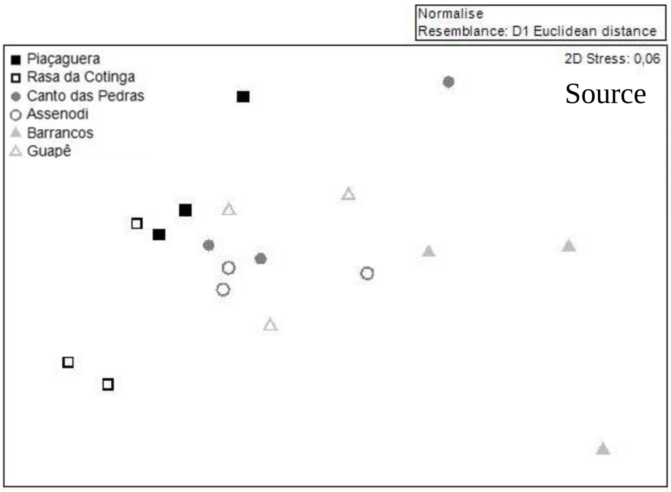

Figure 8 – nMDS grouping of samples, regarding most probable sources. Beaches of the internal (squares), median (circles) and external (triangles) sectors are indicated.

SIMPER indicated that undefined sources were the most relevant contributor for similarities within external (64.68%) and median (59.43%) sectors. Domestic sources are low contributors to the similarities within both median (10.22%) and external (6.85%) sectors. Differently, the relevance of undefined sources' items (32.94%) is proportionally smaller for the internal sector. Likewise, the second and the third contributors for the internal sector similarity – beach users (32.56%) and domestic sources (25.74%) – presented similar proportions to the first.

Those proportions were corroborated when raw absolute numbers of items found within each sector were analysed (Figure 9). Items without a single determined source were the most common (515 items), representing 55.73% of all items analysed. Most of those items (289; 56.12%) were found at the beaches from the external sector. The median sector housed 191 items (37.09%), while only 35 items (6.79%) with unidentified source were observed in the internal sector (Figures 8). Despite low absolute values (3), items from harbour and ships were mostly observed in the internal sector (>66%) while sewage related items where mostly observed in the external sector (>69%; Figure 8). A differentiation between sectors, especially internal and external, is observed regarding most probable sources.

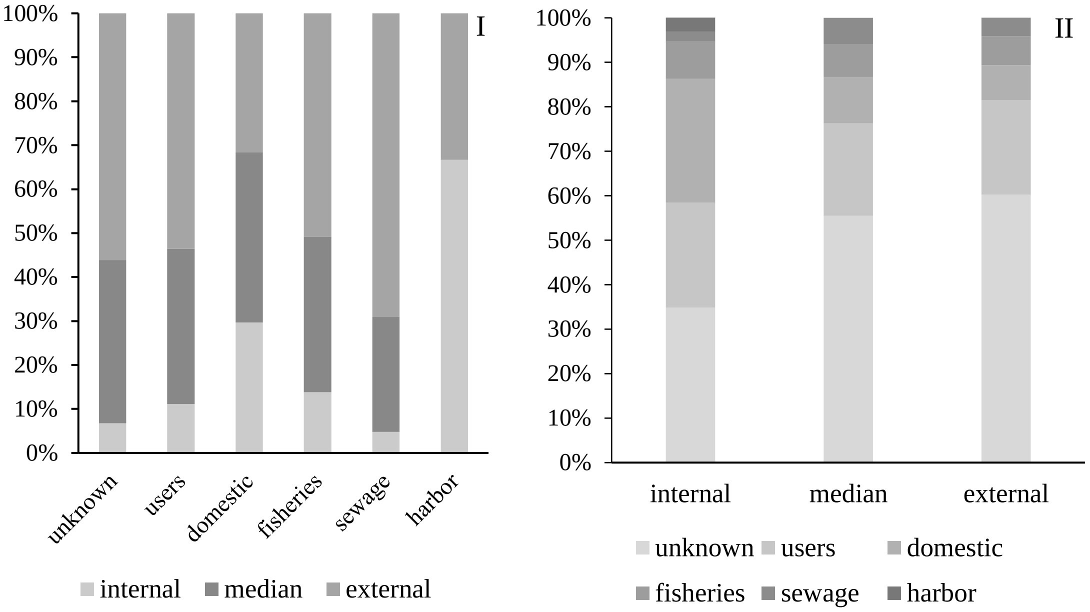

Figure 9 - Proportion of marine debris according to most probable source (% of number of items). *I* – proportion of items (in % of items within each most probable origin) from each source divided per sector, where 100% represents the proportional sum of all items of certain most probable source. Absolute number of items according to most probable sources: unknown (515); beach users (198); domestic (101); fisheries (65); sewage related items (42); harbour (3). *II* - proportion of contribution of each most probable source (in % of items) within sector, where 100% represents the sum of all items found in a certain sector. Absolute number of items found in each sector: external (490), median (334) and internal (100).

4.3 Regressive vectors

Regressive vector calculations considered a previous period of five days and indicated that marine debris were probably originated within a range that reaches the inner parts of the PEC for all sampled beaches (Figure 10). To all sampling sites it is indicated inner parts of the estuarine gradient, *i.e.* generation of these items may also have occurred at any point along the described trajectory. Items found in Piaçaguera and Rasa da Cotinga have their geographical range of potential sources, which includes Paranaguá and Antonina Bays, located in the innermost part of the PEC (Figure 10). Both fluxes seem to follow the Galheta's navigable channel, which influences circulation patterns in this area of the PEC (Noernberg *et al.*, 2007). For those two points, there is a higher probability that items come from urban areas, from PEC's E-W axis, such as, Paranaguá and potentially Antonina.

Canto das Pedras, one of the intermediate sector beaches, showed a different pattern and marine debris sources were limited to the northern part of the PEC's E-W axis, in Paranaguá Bay (Figure 10). These results differ slightly from previous ones, since the range of sources to this beach is limited to Paranaguá municipality. Not only Assenodi, but also Barrancos and Guapê's regressive vectors showed that marine debris items were likely to have originated from the innermost part of the PEC (Figure 10). These results differ from those of Piaçaguera and Rasa da Cotinga, because the regressive vectors indicated a tendency to be influenced by the southern part of the PEC's E-W axis, which is not directly influenced by Antonina city. Such results reinforce the prediction of Hypothesis I and support the assumption that PEC exports marine debris for the whole gradient, including open ocean beaches in the southern outlet.

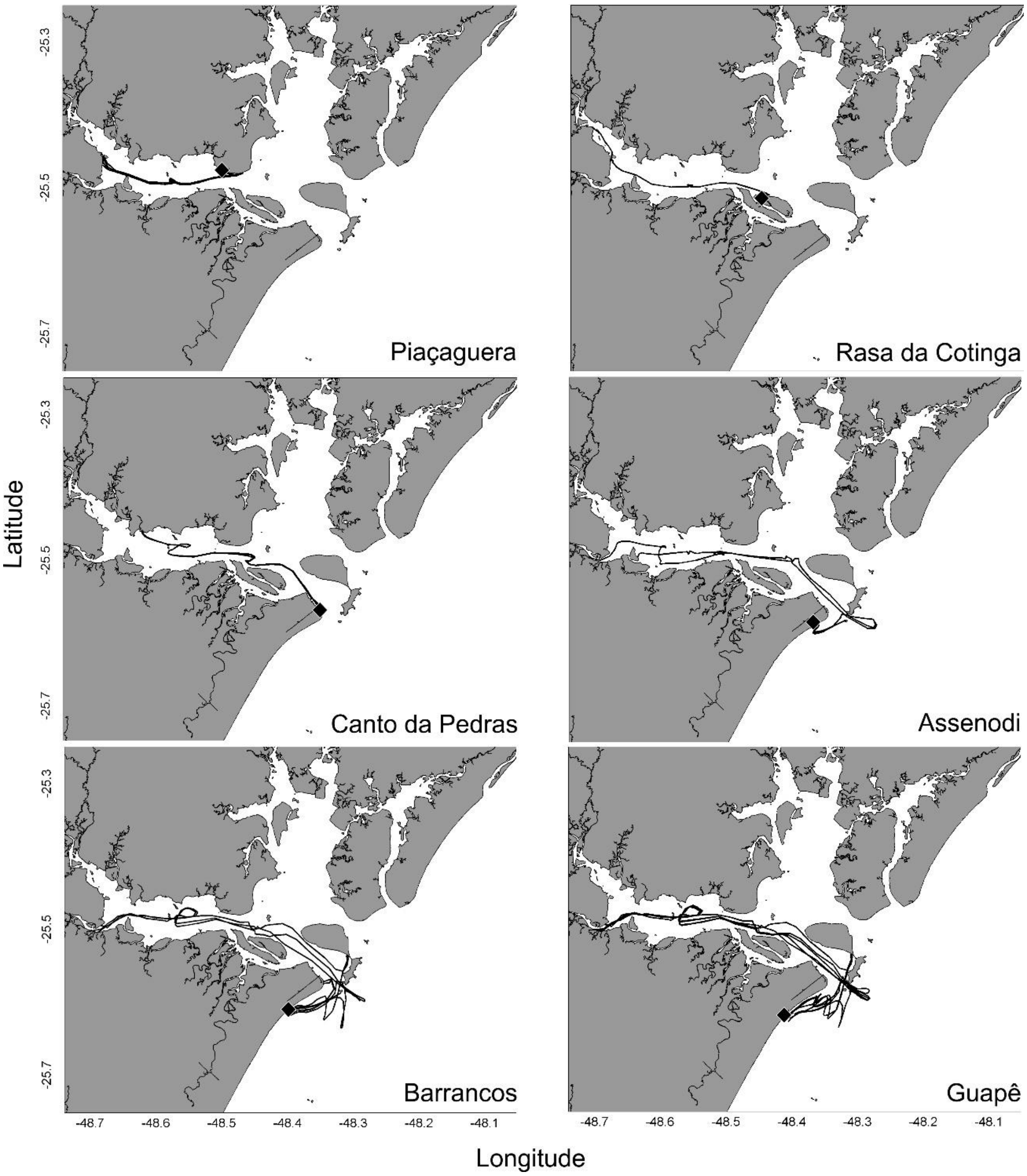

Figure 10- Trajectories of the marine debris' regressive vectors found in each beach, indicating the geographical range of potential sources of marine debris for a five-day prior found in each sampled beach. There were two beaches in each sector: internal: 1. Piaçaguera, 2. Rasa da Cotinga; median: 3. Canto das Pedras, 4. Assenodi; external: 5. Barrancos and 6. Guapê.

5. *Discussion*

There is a widely known dominance of plastics in the marine environment (Gregory, 2009; Jambeck *et al.*, 2015; Widmer and Hennemann, 2010) and this general pattern is also observed in the PEC. The most common items of marine debris found in PEC are comparable to that observed in the 15 European Countries under the OSPAR convention (Schulz *et al.*, 2013). Five litter items were among the most commonly found in both studies: caps/lids, fishing lines, sewage related items, lollipop sticks and ropes. Considering these findings, the PEC is similar to other numerous estuarine and coastal environments, reinforcing the view that marine debris is an omnipresent concern (Acha *et al.*, 2003; Gallagher *et al.*, 2016; Tudor and Williams, 2001; Vermeiren *et al.*, 2016). Knowing these characteristics of the composition of marine debris is important but understanding the processes of transportation of these items, especially along an estuarine gradient, is urgently needed. There are few studies focusing on such aspects, especially in small-scale settings (Acha *et al.*, 2003; Critchell and Lambrechts, 2016; Kataoka *et al.*, 2013; Mansui *et al.*, 2015).

Usage of modelling for marine debris tracking is becoming popular among researchers that investigate processes of transportation of marine debris, however most are focused on regional seas, large ecosystems or even entire oceans (Carson *et al.*, 2013; Duhec *et al.*, 2015; Lebreton *et al.*, 2012; Maximenko *et al.*, 2012; Mestres *et al.*, 2010). Studies dedicated to the usage of modelling at smaller scales, where most management strategies may be implemented, are rare. However, investigating litter dispersion only through fieldwork, even in smaller scales, seem to be extremely time consuming, especially due to several environmental influences that must be taken into account (Critchell and Lambrechts, 2016; GESAMP, 2015; UNEP, 2016). For instance, some environmental conditions that may influence dispersion are: capability of retention of marine debris due to the type of vegetation (Ivar do Sul *et al.*, 2014), changes in wind directions (Walker *et al.*, 2006), currents (Critchell *et al.*, 2015), topography (Vermeiren *et al.*, 2016) and freshwater inputs through riverine discharges (Kataoka *et al.*, 2013; Moore *et al.*, 2011). Consequently, there is a clear demand for effectively finding methods that can analyse such a plethora of effects, but are less time consuming and less costly. The present study analysed the usage of simulation runs associated to collection *in situ* to enlighten some aspects of transportation along estuarine gradients.

For the present, two runs were performed to understand marine debris circulation along the PEC's gradient. In both simulations – considering only tides and riverine discharges or all actual environmental conditions (waves, winds, riverine discharges and tides) – modelling suggested debris exiting from the internal PEC's to the open-ocean. Result suggests that the ocean is acting as a buffer zone (sink) and once marine debris reaches the external sector they are not transported to the inner area of the PEC anymore. This marine debris flux is in accordance to the dynamic characterization of the PEC (Noernberg *et al.*, 2006) and it follows, in a general manner, the Galheta's navigable channel (Noernberg *et al.*, 2007). Using this modelling approach clarified such pattern, but it also explained the movements of marine debris when they had exited PEC.

Virtual release simulations effectively determined a first southerly movement followed by a northward drifting of the PEC's marine debris. Even though the present study was applied specifically to floating marine debris, in the surface of the water column, the results suggests that transportation of marine debris follows also the natural sedimentary transport of the region, which occurs from SW to NE (Lamour *et al.*, 2006; Noernberg *et al.*, 2007). Though it was not under the remit of the present study, it is also possible to deduce that the previous findings of greater abundance of items in beaches above the northern PEC's outlet by Ferrari (2009) are possibly potentialized by exiting of the PEC's marine debris. Therefore, downstream beaches from another municipality (Guaraqueçaba) of PEC might be impacted by marine debris from its innermost areas. This pattern is related to local dynamics of PEC's outlet, which is mainly ruled by tidal currents (Noernberg *et al.,* 2007) that commonly work in perpendicular direction and outward from the coast (Lamour *et al.*, 2006). This transportation of marine debris in such direction may be potentialized when longshore currents occur, especially during events of high wave energy (mainly from the Southeast). Since these currents are normally associated to occurrence of frontal systems that arrive from South (Mayerle *et al.*, 2015; Noernberg *et al.*, 2007), complementary studies must be conducted to comprehend the influence of such oceanographical meteorological events over marine debris abundance.

Data obtained during the ground truthing campaign, also support some patterns suggested by modelling. It can be postulated that inner beaches of the PEC might be a temporary sink, before marine debris reaches the long-term sink. It may be a valid pattern for the region because a lower presence/influence of fragmented and weathered items was observed in the internal sector. Such result suggests that more items of the external sector have faced a degradation process, which is typical in sandy beaches environments (Corcoran *et al.*, 2009), while a smaller proportion in the internal sector have gone through it. Such an assumption is also supported by the fact that fragmented items were less important for determining within similarity for the internal sector, but they were relevant for external and median sectors. Nevertheless, to fully understand retention periods and other factors influencing dispersion, further investigation must be conducted. For that, other characteristics of the marine debris must be taken into account, such as, buoyancy, size, composition and biofouling levels (Ivar do Sul and Costa, 2013; Lebreton *et al.*, 2012; Vermeiren *et al.*, 2016). Also, the influence of different environmental conditions for the whole estuarine gradient, which were not under the scope of this study, must be further tested, *i.e.* riverine discharges oscillations, estuarine maximum turbidity zone, estuarine fronts and plumes (Acha *et al.*, 2003; Brown *et al.*, 1991; Galgani *et al.*, 2010; Largier, 1993; Possatto *et al.*, 2015).

Still regarding data from ground truthing, if analysing solely the statistical results and even considering its limitations, there are some remarkable bonuses. PERMANOVA and SIMPER indicated that the internal sector houses low-buoyance items, such as, glass fragments, which were only present in the internal sector. It indicated that the sector has smaller proportions of fragmented or weathered items and it is more influenced by food wrappings and by domestic debris. The analysis also indicated that the external sector is dominated by fragmented and weathered plastic items (highly buoyant), showing the highest proportion of unknown sources. Noteworthy, those items found in the external sector are not necessarily directly derived from the internal area of the estuarine complex. Weathered items might have been originated from other regions, explaining the higher frequency of fragments in that sector. These results, are in accordance with previous literatures (Leite *et al.*, 2014; Neves *et al.*, 2011; Williams *et al.*, 2003) and they could, by themselves, indicate differences along the estuary and some limited inferences would be made.

However, the establishment of the dynamics of marine debris was only possible by associating modelling. Some specific facts can be used to exemplify such contribution to interpretation. For instance, finding more sewage related items in the external area could lead to a misinterpretation without the complimentary information provided by modelling runs. Another example, according to Leite *et al.* (2014), it was expected that beaches close to the source, in this case urban centres in the inner part of the PEC, would be more polluted then beaches from other areas. However, beaches closer to Paranaguá city showed 10 times less debris then the ones in the outer part. This result could lead one to question if the ocean could be the source and the estuary the sink. Only through the analysis of regressive vectors it was made clear the inexistence of an ocean-estuary flux. Consequently, it is possible to state that modelling is a supportive tool. Even considering its inherent limitations, such as, complex factors that may limit modelling applications, it supported the filling of gaps of information, which would not be filled through other feasible efforts, such as, extra fieldwork or different statistical analysis over the set of data. Also, it indicated patterns within sectors that statistical analysis did not, *i.e.* pair-wise tests failed to detect differences among sectors which were probably affected by extreme variations among beaches. Such concealing of differences through statistics would have represented a failure to explain the assemblage of items found in each beach, if modelling was not conducted.

Another key finding through the usage of modelling was that the biggest city of the region (Paranaguá) and the internal mooring area are located in the middle of the exiting trajectory of the marine debris from the PEC's internal area to all the rest of the downstream gradient. It is possible to deduce that the city, with its intrinsic problems (Silva *et al.*, 2015), and its harbour play a potential role as geographical origins to a significant part of marine debris of the region.

Downstream cities, *i.e.* Pontal do Paraná, are sinks of marine debris coming potentially, from three municipalities (Paranaguá, Antonina and Morretes) from the inner part of the PEC.

In the same way, future scenarios may be predicted based on present findings for the region, whose economy is driven by harbouring and tourist services (IPARDES, 2013). Considering that the level of urbanization and the industrial activities are significant influences in marine debris abundance in estuarine environments (Tudor and Williams, 2001) and that the inner areas of the PEC were already identified as potential significant sources of pollution for the PEC (Procopiak *et al.*, 2007), it is presumable that downstream beaches will suffer an increase of impacts by marine debris in the next years. Consequently, the marine debris originated along the whole gradient may reach tourist beaches and possible losses to local economies may become reality. On top of that, Pontal do Paraná has the greatest populational growth rate of the region (IPARDES, 2013) and marine debris is a growing threat (GESAMP, 2015). Such scenario poses practical implications to present and future coastal managers, claiming for adequate and integrated waste management strategies for the whole PEC, combined with education, pollution prevention assessments and comprehensive scientific research (Morrison, 1999).

Considering that municipalities that are not necessarily responsible for marine debris generation are paying the costs of cleaning beaches, marine debris is recognized as a “major transboundary” concern for municipalities in the PEC. Adopting a transboundary approach appears as the most adequate management strategy to deal with the marine debris along the PEC gradient (CEP, 2009; GEF, 2013; Morrison, 1999).

Finally, all the results reinforce the viewpoint that associating simulation and regressive vectors, on top of fieldwork, increases certainty regarding small-scale geographical sources of marine debris (Kataoka *et al.*, 2013). Considering only fieldwork and statistical analysis, data obtained would not inform the totality of processes involved with the assemblage of marine debris found at a certain beach. In fact, to aggregate such a plethora of processes through fieldwork would be an extreme complex and time consuming effort that might become practically unfeasible in real time. But modelling is the tool that can aggregate several oceanographic variables such as wind, current, tide, river flow and other aspects that affect marine debris assemblage. It represents reduction in time consumed and empowers analysis of distribution of marine debris. It also combines the factors that determine the amount, type, and distribution of beached marine debris (Araújo and Costa, 2006). For estuarine complexes regions, especially in Brazil and specifically in the PEC, this integration of analysis including litter items is innovative and, at our knowledge, there is no comparable data regarding such information for marine debris. These results will form a baseline for the PEC’s region. This can encourage an effective transboundary marine debris management and increase knowledge about effective fluxes from continental sources and the marine environment. The omnipresence of marine debris in estuarine, marine and oceanic environments may be an opportunity to apply modelling and generate comparable worldwide data.

6. *Conclusions*

It can be concluded that items observed in the oceanic sector of the Paranaguá Estuarine Complex were potentially generated or released in the inner part of the estuary. Simulation indicated an exiting of marine debris, represented by drifters, after a temporary period inside the estuarine complex. An overlap of trajectories in front of open-ocean beaches suggests that the ocean acts as a buffer for debris of the PEC. Also, items may be beached, especially along the southern outlet beaches, depending on oceanographic and meteorological conditions. Regressive vectors reinforce such a conclusion, since they indicate that the geographical origin of items may be in the inner part of the PEC for all beaches of the estuarine gradient. Hypothesis I was then corroborated. Contrarily, hypothesis II was not corroborated since items found at the inner estuarine sector seem to be exclusively generated or released in the estuarine sector, and not released or generated in the oceanic sector and a higher proportion of fragmented or weathered items was observed in open-ocean beaches. Considering that, it was expected that composition, types and most probable sources would be heterogeneous along the estuarine gradient, but plastic dominated all sectors. However, differences for item types and sources were observed not only graphically but also for similarities and dissimilarities, especially among internal and external sectors. Fragmented plastics and unsourced items were more commonly found in the external sector while food wrappings and domestic items were more representative for the internal sector. Considering that, it is possible to conclude that ground truthing estimates corroborated the existence of differences among sectors as suggested through computational simulations and hypothesis III was corroborated. Adopting both source-based and sink-based complimentary methods increased certainty of marine debris sourcing in estuarine gradients, even when *post hoc* statistical test fail to detect differences. For the present study, it indicated that marine debris is a transboundary problem for the estuarine gradients, such as PEC. Understanding environmental factors influencing marine debris distribution is essential to adopt adequate management strategies.

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6. Influence of oceanographic and meteorological events on the quantity and quality of marine debris along an estuarine gradient

Influência de eventos oceanográficos e meteorológicos sobre a quantidade e a qualidade do lixo marinho ao longo de um gradiente estuarino

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Keywords: *marine debris, oceanographical conditions, meteorological events, temporal analysis, estuary*

Palavras chave: *lixo marinho, condições oceanográficas, eventos meteorológicos, análise temporal, estuário*

Influence of oceanographic and meteorological events on the quantity and quality of marine debris along an estuarine gradient

Abstract

Understanding the dynamics of litter in marine ecosystems and the influence of environmental variability on its distribution pattern represents one of the challenges to risk analysis and definition of management strategies. The influence of three meteorological/oceanographic conditions – frontal systems (FS), high riverine discharges (HRD) and regular weather conditions (RWC) – over the quantity and quality (composition and most probable source) of marine debris was assessed in sand beaches along three sectors (internal, I; median, M; and external, E) of an estuarine gradient. The highest overall abundance and richness of types were observed in HRD (I and E). The lowest overall abundance and richness of types were observed in RWC in most of the sectors (I and M), differently, the external sector showed lowest abundance in FS. Greatest numbers of "domestic" and "sewage related debris" were observed under the influence of HRD for the internal and external sectors (I>E>M). "Domestic" and "sewage related" items showed homogeneous distribution under RWC through the gradient. Greatest numbers of "fisheries" items were observed in HRD in most of the gradient (I and E). A gradient for "fisheries" sourced items was observed along the estuary during RWC (I<M<E), but for "unknown" sourced items, there was no indication of a single condition with smaller quantities (E>I=M). Results suggest that adopting oceanographical and meteorological conditions for analysis have the potential to detect temporal variations.

Keywords: *marine debris, oceanographical conditions, meteorological events, temporal analysis, estuary*

Highlights

- Riverine discharge is determinant in increasing debris overall abundance and Richness;
- Regular weather condition determined lower overall abundance and richness for tide-dominated and outlet environments;
- Frontal system influenced open-ocean beaches' lower abundance;
- Domestic, sewage related and fisheries items increased in abundance under high riverine discharges;
- Interaction of sectors and conditions was significant for the estuarine complex

1. Introduction

Marine debris is any persistent solid waste (generally inert), generated by land or marine-based activities, that enters the marine environment (Coe and Rogers, 1997). Since the first studies in the early seventies (Carpenter and Smith, 1972), persistent pollution by debris threats occur in marine environments in an increasing manner (GESAMP, 2015). Recent studies estimated that up to 12.7 million of tons of plastic waste (only) may be already in oceans (Jambeck *et al.*, 2015) and that a minimum of 5.25 trillion plastic items enters the ocean each year (Eriksen *et al.*, 2014). It is known that plastic marine debris are ubiquitous (Thompson *et al.*, 2004), representing approximatelly 50-80% of the shoreline debris (Barnes *et al.*, 2009). Such pollution pattern is mainly an outcome of large scale application of plastics and their flexibility and durability, characteristics that generate several problems to the marine environment (Gregory, 2009).

Negative effects of marine debris are extensively described in literature for marine biota, such as entanglement, ingestion and suffocation of marine fauna, hitch-hiking of invasive species and ghost fishing (Gall and Thompson, 2015; Secretariat of the Convention on Biological Diversity, 2016; UNEP, 2016). There are evidence that several marine taxa, from diverse trophic levels, have already ingested plastic particles and, especially, microplastics (plastic particles smaller than 5 mm; GESAMP, 2015; UNEP, 2016). Direct impacts to humans are also described, such as threats to human health and safety (Sheavly and Register, 2007) and loss of beach attractiveness (Leggett *et al.*, 2014).

Even though it is recognized that marine debris is a global problem, there is limited knowledge about their trajectories and especially the effects of oceanographical and meteorological conditions over their displacement (Ryan *et al.*, 2009). Especially in coastal environments, such as estuaries, these conditions are understudied (Ivar do Sul and Costa, 2007; Kataoka *et al.*, 2013). There is evidence that marine debris in these special environments may respond differently to oceanographic and meteorological conditions, if compared to other oceanic environments (Krelling, *chapter 5*).

Not only regional and global scale conditions, but also local small-scale processes are determinants for the quantities and quality of marine debris (Corcoran *et al.*, 2009). There are several hydrological and geographical aspects influencing marine debris (Vermeiren *et al.*, 2016), but there are also cultural aspects, such as, proximity to the source (Leite *et al.*, 2014), main uses of the beach (Thiel *et al.*, 2013) and user behaviour (Slavin *et al.*, 2012). Such complexity makes difficult to determine an unique model for the influence of each factor over marine debris (Smith and Markic, 2013). However some general oceanographic and meteorological conditions are commonly cited to potentially increase quantities of marine debris, such as, the input of rivers or waterways (Araújo and Costa, 2006; Moore *et al.*, 2011; Rech *et al.*, 2014; Williams and Simmons, 1997) and the prevailing wind direction in association with beach direction (Fleet *et al.*, 2009; Possatto *et al.*, 2015; Walker *et al.*, 2006). These two factors are also related as indirect results of storms events, which intensify the action of winds and waves, increasing run-off (Smith and Markic, 2013), which ultimately leads to an increase in marine debris (Moore *et al.*, 2011).

Even though these conditions are indicated as playing an important role in marine debris composition, most studies that analyse temporal variations use comparisons among broad seasons (Ali and Shams, 2015; Morishige *et al.*, 2007; Possatto *et al.*, 2015; Rosevelt *et al.*, 2013; UNEP, 2016). Sampling is mostly conducted considering periods greater than one month (Smith and Markic, 2013). Such approaches conceals, for instance, daily or weekly variances of determinant factors (UNEP, 2016), such as riverine inputs or wind influences. Moreover, the outcomes of some of these studies suggest that focusing on meteorological and oceanographical events, rather than seasons, may be more effective to determine inflow of items (Kataoka *et al.*, 2013). For example, previous studies observed that winds can influence the quantities of macro debris in scales smaller than a month (Kako *et al.*, 2010). Similarly, Vermeiren *et al.* (2016) affirmed that small scale temporal variations can distort seasonal patterns and variations may be observed within one day, especially in estuarine environments. Indeed, it is also suggested that studies estimating beach litter quantities might have under-estimated litter loads in one order of magnitude due to increased sampling interval (Smith and Markic, 2013), *i.e.* considering an inadequate temporal scale. It is possible, than, that some studies may have not detected seasonal differences especially due to such kind of limitation associated to the intrinsic short-term variances in litter input in sand beaches (Vermeiren *et al.*, 2016). For instance, in a study about benthic marine debris in the Paranaguá Estuarine Complex (PEC), Brazil, no differences were found regarding temporal variations by the authors, which mentioned that local processes contributing towards marine debris accumulation are less clear (Possatto *et al.*, 2015). It is probable, then, that short-term variances of conditions, which are observed within seasons, were offset. Another example in the same region is the study of Moreira *et al.* (2016), which found that variations in stranded microplastics for the same area may occur in small-scales, within a day. Despite of differences of environments and sampling strategies, these results demonstrate that the seasonal approach might not be efficient for detecting some temporal variation patterns, especially in environments were winds and river inflows vary in short period.

Therefore, comprehending the effect of each meteorological and oceanographic factors, even within broad seasons, over local sources is essential for establishing marine debris accumulation patterns and temporal variances. Increasing knowledge about those influences may also lead to a greater accuracy in establishing relationships between sources and sinks (Veiga *et al.*, 2016). Considering that freshwater riverine discharges and winds play an important role in input and distribution of marine debris in estuarine environments (Kataoka *et al.*, 2013; Rech *et al.*, 2014), the present study focuses in specific events, investigating the influence of both conditions along an estuarine gradient.

Indeed, estuaries appear as an ideal area for evaluating such influences since they have known dominant wind directions, water fluxes (Browne *et al.*, 2010) and are relatively easy to access. As well, estuarine environments are transitional areas between watersheds to open ocean areas. Since most of the litter which enter the marine environment is land-generated, they are important early pathways of marine debris (UNEP, 2016; Vermeiren *et al.*, 2016).

The study was conducted in an Estuarine Complex in southern Brazil, the Paranaguá Estuarine Complex (PEC). The PEC was chosen due to its subtropical location, where rain is distributed along the whole year, with absence of a dry season (Cfa; Maack, 1968). There is a tendency of concentrating rainfalls, with consequent increased mean riverine discharges, during southern hemisphere summer periods (December–March; Mantovanelli, 1999). In addition, the region is dominated by the action of Frontal System (FS; Quadros *et al.*, 2007), which presents greater frequency during winter periods (June – September; Rodrigues *et al.*, 2004). This characteristic is also an asset to understand the influence of those events over marine debris composition.

In the PEC's E-W axis, there is an estuarine gradient composed by three different zones regarding its dynamic's characteristics [inner zone (Antonina and Paranaguá Bays) , mixture zone and the outer zone (outlet and open-ocean areas), Figure 1], forming different sectors along the land-sea axis (Noernberg *et al.*, 2006). Previous studies found evidences of differences in marine debris quantities and quality if comparing the mixture zone to the outlet and the open-ocean areas (Krelling, *chapter 5*; Figure 1). Consequently, for the present study focus was given to these two zones: mixture zone and open-ocean.

Finally, the biggest urban centre of all Paraná's coast is located right in the upper stream of this gradient, while the municipality in the downstream depends on tourism and is affected by the presence of marine debris coming from inner areas of the PEC (Krelling, *chapter 5 and 7*). Along the gradient there are sand beaches with different characteristics. In the internal sector, they are tide-dominated beaches, while in the median and external sector they are wave-dominated, with differences regarding their dynamics (see description below, in methods section).

Considering all these aspects, PEC is an ideal area to evaluate if oceanographic and meteorological conditions will differently influence quantities and quality of marine debris. The overall abundance, the richness of types (number of types) and the abundance of some key items' qualities regarding sources (domestic, sewage related, fisheries and unknown) of marine debris, along the estuarine gradient, were investigated. Considering the proximity to a known terrestrial source and that High Riverine Discharges (HRD) would affect differently the sectors along the estuary, it is expected that more items, especially those attributed to land-based sources (*e.g.*, domestic/sewage related items), would be found in the inner sector if compared to the other sectors, creating an estuarine gradient of such debris (internal>median>external; hypothesis I). Also, there is evidence that the ocean is acting as a buffer in the PEC's outlet for debris generated in its inner parts (Krelling, *chapter 5*). Consequently, it is expected that more degraded items, whose sources are not identifiable, will be found floating in the coastal waters together with fisheries items. Items accumulated in this area may be potentially beached under specific meteorological and oceanographical conditions. One of these conditions that may bring items to the coast is intense southerly winds associated to Frontal Systems (FS) and thus a proportional increase in the number of ocean-generated items (fisheries or unsourced items), during FS, is expected. It is also expected that FS have different effects on the overall abundance of marine debris along the estuarine gradient (internal<median<external; hypothesis II). Finally, in the absence of those situations, which is the Regular Weather Condition (RWC), will be a moment were riverine discharges and off-shore winds will contribute less to marine debris. Consequently, it is expected that the smallest overall abundance and richness of types would be observed, under this condition, all along the gradient. As closeness to the source determines the quantities of beached items, it is expected that external beaches will have the smallest number of domestic and sewage related items and the internal sector will present the smallest quantities of fisheries and unknown sourced items (hypothesis III).

2. Material and methods

2.1 Location and local setting

Paraná`s coast is characterized by short extension (~98 km), occurrence of bays and existence of several ecosystems, such as, mangrove forests, intertidal flats and sand beaches (Figure 1; Castella *et al.*, 2006; Lamour *et al.*, 2006; Lana *et al.*, 2001) and in essence, the region depends on tourism, harbouring activities and fisheries (Estades, 2003). The Paranaguá Estuarine Complex (PEC) houses the most populated city of the coast, Paranaguá, with approximately 140,000 inhabitants (IBGE, 2014). The city houses the second largest Brazilian harbour, which plays an important role for the economy, representing 3.93% of the GDP of Paraná (IPARDES, 2013). Krelling (*chapter 5*) based on hydrodynamic modelling, proposed that there is an exit of marine debris from the PEC’s innermost part to the adjacent beaches. Within this context, the city may play an important role as source of land-generated marine debris, such as domestic and sewage related items. Consequently, other smaller cities along the PEC’s gradient that depend almost exclusively on tourism, such as, Pontal do Paraná, are potential sinks of the marine debris coming from its inner parts (Krelling, *chapter 5*). In these cities that depend on ‘sun-and-bath’ tourism, for the most part, houses are properties considered to be “second homes” (Monteiro, 2013). The seasonal attraction of visitors during summer periods also represents a significant input of beach litter. There is evidence that beach users are responsible for an increase of three times the amount of litter found in local beaches (Krelling *et al.*, 2014). During these periods, increased riverine discharges are common due to increased rainfall (Mantovanelli, 2004). The setting is completed by the peculiar ecological importance of the PEC, which has been recognized as a core area of a Biosphere Reserve (Unesco, 2002) and a World Heritage Listed Site (Unesco, 1999).

This intricate scenario suggests that many sources and sinks may be differently distributed along the PEC’s gradient. Under this scenario, the sampling rationale of the study considered a hierarchical design (Estuarine Sector and Beach) based on different dynamics of the sectors along the PEC's gradient and their differential exposure to oceanographic and meteorological conditions evaluated (Figure 1).

The coast of Paraná is divided into three main seascapes according to its dynamics: estuarine, estuarine outlets and open-ocean coasts (Angulo and Araújo, 1996). The sectors of this study (internal, median and external) were allocated along the E-W axis of the southern outlet of the PEC and its adjacent area and each sector represented one of these coastal seascapes. Indeed, the hydrodynamical characteristics of PEC (Figure 1) and results from previous studies (Krelling, *chapter 5*) were especially considered for sampling site selection. Nine sand beaches along the mixture zone (internal) and in the outer zones of PEC (median and external; Figure 1) came under the remit of the present study. Three beaches were sampled in each sector with the maximum distance between beaches being of the order of hundreds of metres (<1000m). Distance between sectors was in the order of thousands of metres (~5km). GPS Coordinates were recorded to ensure that sampling occurred in the same area for all the campaigns.

2.2 Sampling sectors and sites

The internal sector is located inside the mixture zone of PEC, in Mel Island, municipality of Paranaguá. The beaches of this sector were located on an "estuarine coast", which meant that they are mostly influenced by tidal variations (Angulo and Araújo, 1996). This tide-dominated environment houses low energy estuarine beaches (Rosa and Borzone, 2008) characterized by low amplitude waves (<0.25m) with short periods (<5s; Jackson *et al.*, 2002). The beaches sampled in this area, Ponta Oeste, Gonzaga and Cedro, are approximately twenty-metres wide, characterized by a low presence of users even during high tourist season. They face South/Southwest directions and they are reached only by boat, being located inside a natural protected area (Estado do Paraná, 2009). Beaches in the intermediate and external sectors are positioned out of this tide-dominated environment.

The intermediate sector is dynamically characterized as an "outlet coast" with sand beaches that are morphologically similar to open-ocean beaches, however with a more complex dynamic, since they are dominated by not only the action of waves and along-shore currents, but also by tidal currents (Angulo and Araújo, 1996). In the present setting, the formation of the Galheta Shoal in the outlet of the PEC moderates the action of waves over the beaches of the sector (Martins *et al.*, 2004). Canto das Pedras, CEM and Coruja are approximately sixty-meter wide beaches, composed by sparse vegetation landward with Northeast/East directions. This sector, especially Canto das Pedras beach, is a recreational site during summer, which attracts a significant quantity of beach users.

The external sector is composed of open-ocean beaches, which are not directly affected by estuarine outlets (Martins *et al.*, 2004). The beaches of the sector mainly face East/Southeast, suffering direct action of South/Southerly winds. Due to the absence of natural barriers they suffer direct action of oceanic waves and along-shore currents (Quadros *et al.*, 2007). Barrancos, Barrancos Sul and Guapê are approximately hundred-metre wide beaches, composed by sparse vegetation landward. Barrancos houses a traditional fishermen community and, during summer, tourists are present in the region. Beaches from both median and external sectors are in the municipality of Pontal do Paraná and are accessible by car.

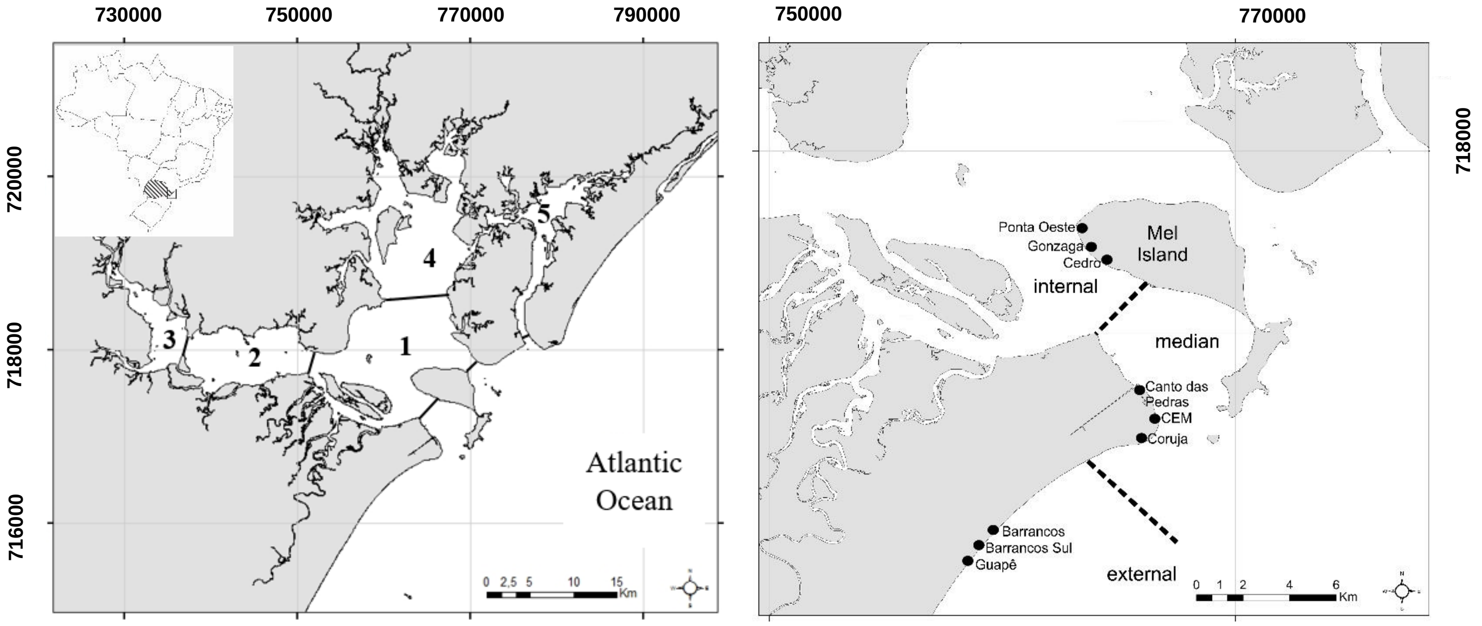

Figure 1. Sectors of Paranaguá Estuarine Complex and zooming in to the study area. Location of Paraná State within Brazil (top left). The PEC is divided in 1-Mixture Zone; 2 – Paranaguá Bay; 3 – Antonina Bay; 4 – Laranjeiras and 5 – Pinheiros (left; adapted from Noernberg *et al.* (2006)). Estuarine sectors and beaches where marine debris was collected: Internal sector - Ponta Oeste, Gonzaga and Cedro; Median sector - Canto das Pedras, CEM and Coruja and External sector: Barrancos, Barrancos Sul and Guapê (right).

2.2 Marine debris collection and categorization

Marine debris items were collected in nine beaches, nested in sectors, to acquire quantitative (abundance of items and richness of types) and qualitative (composition, type of item and most probable source) data. In order to sample simultaneously and synoptically several beaches, it was necessary to have more than one fieldwork team. Four replicates of five-meter width transects were obtained at each beach in order to collect litter from the low tide shoreline to the highest strandline (Lippiatt *et al.*, 2013). Adopting such an approach, the aim was to collect only freshly inputted litter, disregarding items accumulated on the backshore derived from previous events or from long-term accumulations. Variation in transect length was not important, since data was analysed considering total number of items in the intertidal area. All marine debris greater than 2.5 cm were collected and characterized, and a special category, tar balls, was included as they represent marine debris that are poorly researched in Latin America (Ivar do Sul and Costa, 2007; Warnock *et al.*, 2015). Also, there is a historical concern with marine debris originated by international ships in the PEC, which may include tar balls, that still remains only anecdotal (Possatto *et al.*, 2015). Considering that these items were already observed during fieldwork in the region, testing their contribution to marine litter assemblages along the estuarine gradient may aggregate the present analysis. As they appear in varied sizes (Owens *et al.*, 2002), all visible items were collected including those smaller than 2.5 cm.

Items were then manually collected and stored in plastic bags during fieldwork. Samples were washed using a 5mm sieving net, dried and finally categorized. Items were quantitatively scrutinized considering abundance of items and richness of types. Item were qualitatively categorized according to three aspects: Composition, type of item and most probable source. Regarding composition and type of item, the classification followed a two levels hierarchy (Cheshire *et al.*, 2009): items were categorized firstly according to its composition, following nine classes (plastic, foamed plastic, glass, metal, processed wood, clothing and textile, rubber, paper and other) and then were classified by item type considering a medium resolution survey, which adopted *circa* 84 items types (Cheshire *et al.*, 2009; Miljo, 2010; Schulz *et al.*, 2013). The last qualitative categorization regarded the most probable sources and it was conducted through "attribution by litter type" (Earll *et al.*, 2000), what means that a certain item is attributed to only one most probable source. Six most probable sources were adopted for the present: Domestic, Unknown (unsourced items), Ships and Harbour, Fisheries, Sewage related items and Beach users. Items were attributed to a most probable source after an elimination process, similar to the one proposed by Tudor and Williams (2004) and Krelling (*chapter 5*). The eliminating process considered evidence that a single item was likely to originate in a source so that informed assumptions can be made (Williams *et al.*, 2003). Using a plastic bottle as an example, the content inside the bottle and presence of labelling/brands can be used to determine its most probable source. If the content shows evidences of engine oil, it is likely to have been used in fishing activities (boats) and therefore, associated to a "fisheries source". If there were evidences of it being a cooking oil bottle (branding or residues), it was attributed to a most probable "domestic source". In case there was labelling indicating international source, the most probable source was "ships or harbour". If inside the bottle, items associated to beach users were observed (like cigarette butts and ice cream sticks), then the most probable "beach users" source was considered. Otherwise the bottle was considered a non-sourced item.

2.3 Selection of sampling days

Sampling design involved a temporal variation and considered nine campaigns. Regarding temporal variation, three categorical situations were established for sampling: (i) high riverine discharges situations (HRD); (ii) frontal systems (FS); and (iii) absence of frontal systems or significant riverine discharges, named "Regular Weather Conditions" (RWC). It was established that the collection should be executed in a period no greater than four days after the event evaluated. This period was determined according to the findings of Marone *et al.* (1995), which established a water renewal time of approximately 3.5 days for the PEC. Results of Krelling (*chapter 5*) reinforced the adoption of such period, since simulations indicated a period of approximately 4 days for a floating item to travel from the innermost area of the PEC until the southern outlet. Within this period the chance that a marine debris item, which was in the PEC when the meteorological oceanographical event occurred, has already exited the PEC to the open-ocean is reduced. Such an approach aimed to guarantee that samples were taken still under the influence of the event investigated within the PEC gradient.

For HRD, data was collected on the following days when values were near or above the mean values of the rainy season. The use of mean values of the rainy season as a proxy was based in the fact that it is the period in which high rivers' discharges are observed more frequently (Mantovanelli, 1999). Thus, sampling during periods with similar values of discharges may represent effectively a greater inflow of freshwater in the PEC. According to Mantovanelli (1999), Nhundiaquara River's discharge mean values during rainy season are 46,46 m^3/s. Because there are no real-time data available regarding discharges, rainfall was used as a daily proxy for establishing campaigns. Such an approach was adopted also based on local studies that found a positive correlation between rainfall values and riverine discharges values for rivers of the PEC, including Nhundiaquara (Oliveira, 1999). Discharge values and fluxes to the Nhundiaquara River were confirmed afterwards when data became available, to ensure that the sample effectively represented a high discharge situation.

FS situations were categorized by a shift to southerly winds that lasted for, at least, 24 hours (Rodrigues *et al.*, 2004). The same authors found a mean (±s.e.) wind speed of 7.76 (±0.88) knots in FS arrival days. For the present study, FS was categorized by the presence of a minimum of 6 knot wind gusts. Fieldwork was conducted also within a four-day period, considering the same aspects described above. RWC was characterized by absence of frontal systems (not southerly winds for 24h during the previous 4 days) in addition to low riverine discharge values, which would be ideally close to minimum values – below 10 m^3/s – for the Nhundiaquara River. This was the only river with information for the whole study period (Figure 2).

Rainfall forecasts were daily consulted from the Meteorological System of Paraná (SIMEPAR) website for planning fieldwork, especially regarding HRD. Daily mean river discharges were obtained *a posteriori* from the State Agency of Water Management (Instituto das Águas do Paraná). Wind direction and intensity were obtained in real time from an automatic station of National Institute of Meteorology (INMET) located in Mel Island and from the station of SIMEPAR in Paranaguá. In addition, tidal elevation was obtained from the Brazilian NAVY in order to prioritize sampling during low tides, since greater exposed beach areas are observed during these periods.

HRD sampling occurred in 26/10/15, 11/01/16 and 17/02/16. The first sample of this condition, in October, also showed southerly winds in the previous days. The randomness of working in natural environments does not allow for the total exclusion of other environmental variables. However, since the period showed significant riverine discharges, the sample was considered representative of the HRD condition (Figures 2 and 3). FS situations were sampled on 20/08/2015, 13/09/2015 and 07/10/2015. All sampling periods showed at least 24 hours of southerly winds (between 145° and 225°) and wind gusts of 6 knots (Figure 3).

RWC sampling occurred on 05/04/16, 20/04/16 and 06/07/16 (Figure 3). There was a malfunctioning of the INMET station's equipment during the second sampling period. Data of wind velocity and direction for this specific sampling were obtained from a different SIMEPAR station in the same municipality, Paranaguá. A comparison of data from the stations considering a period when both stations were active – from April, 14th (00:00:00 UTC) to 16th (19:00:00 UTC) – indicated a significant relationship for wind velocity ($n=67$; $p<0.001$; $R^2=0.55$) and for wind direction ($n=67$; $p<0.001$; $R^2=0.27$). Consequently, data of SIMEPAR was used for characterizing this sample. No anomalies in wind directions and intensities that could represent a Frontal System were observed during the days that the station was not working.

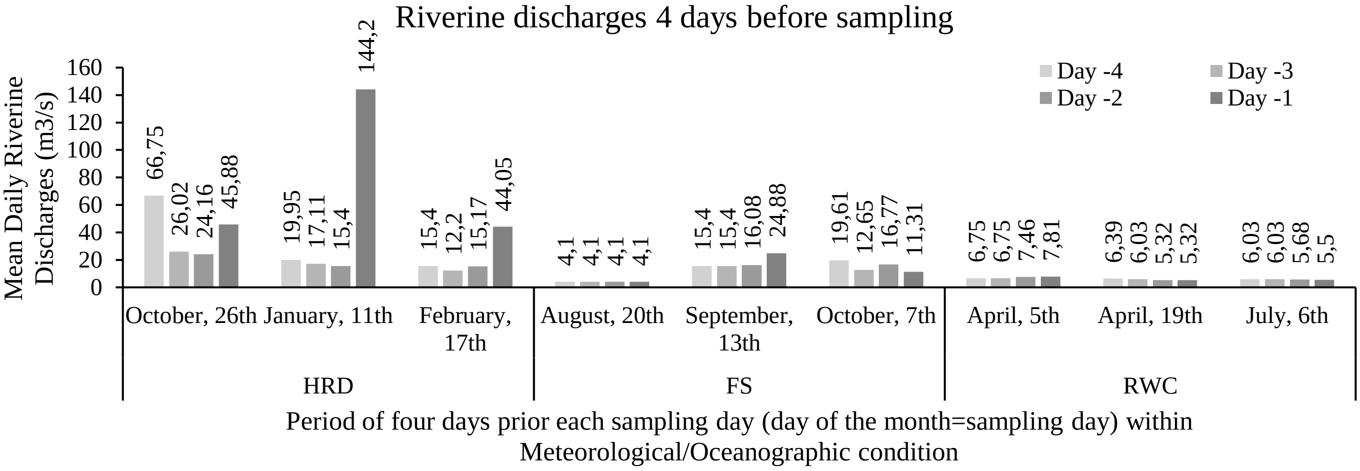

Figure 2. Riverine discharges of Nhundiaquara River in the previous days of sampling within each environmental condition: High Riverine Discharge (HRD); Frontal System (FS) and Regular Weather Conditions (RWC). The day of sampling is indicated (x axis) and the mean daily riverine discharges (m^3/s) are presented for the four days previously of the sampling (y axis). The Riverine discharge of the sampling day is not included in the bars, where “day -1” = the day before the sampling, “day -2” = two days before and so on.

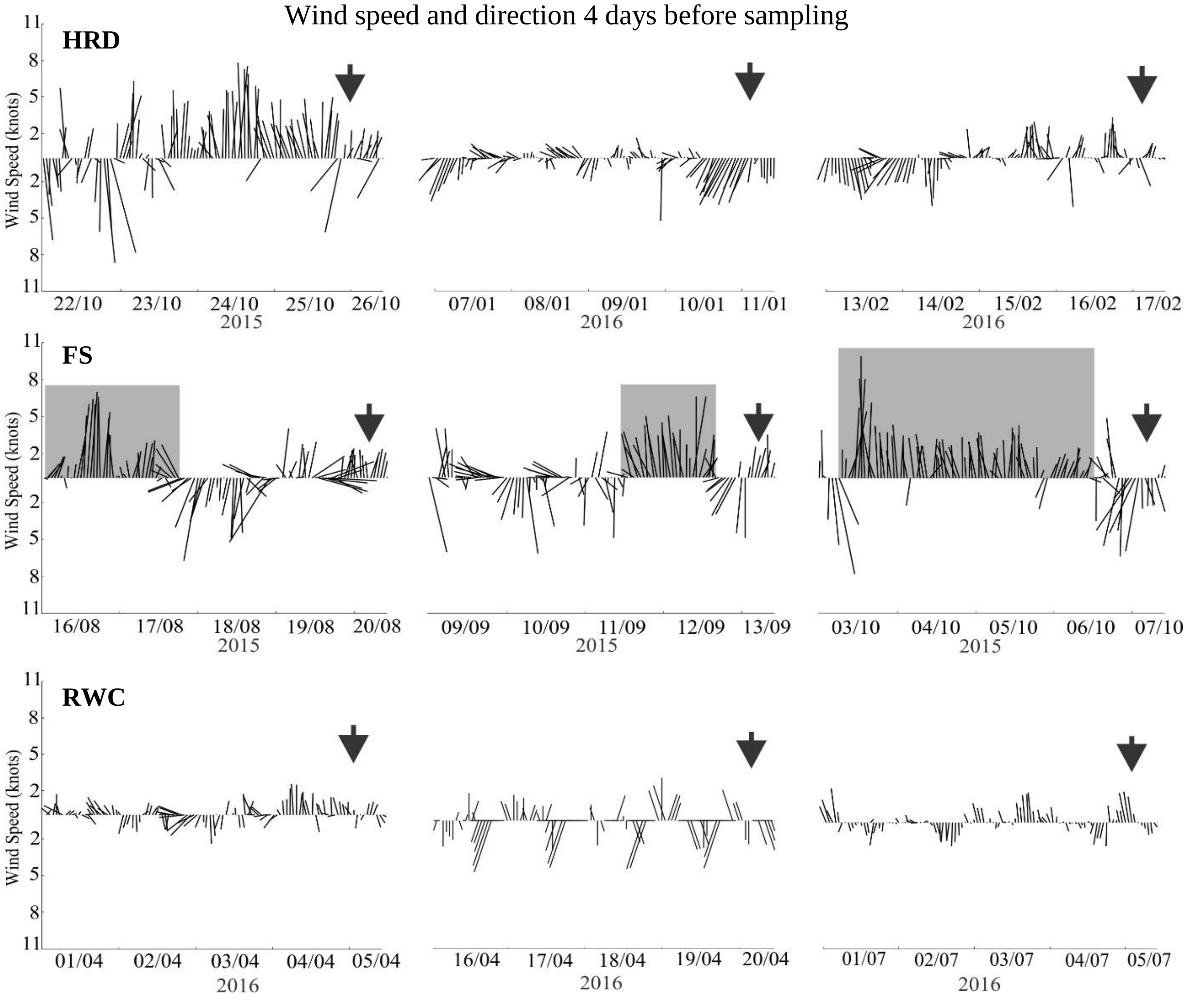

Figure 3. Wind direction in the previous days of sampling for situations (from the top to the bottom): High Riverine Discharge (HRD); Frontal System (FS) and Regular Weather Conditions (RWC). Wind direction is represented by the direction of the vector (grades) and size of vector indicates velocity (knots). Arrows indicate the day of sampling. Grey boxes indicate the period when more than 24 hours of southerly wind was observed during FS.

2.4 Statistical analysis

Data was analysed by combining univariate and multivariate procedures considering a mixed model with three factors: Meteorological/oceanographical “Condition” (three levels, fixed factor, crossed with “Sector”: HRD, FS and RWC), “Sector” (three levels, fixed factor: Internal, Median and External sectors) and “Beach” (three levels, random factor, nested in “Sector”). The null hypotheses predicted no effect of these variables over the overall abundance of items, richness of types, composition and most probable sources among and within conditions and sectors.

For evaluating univariate variables (overall abundance of items, richness of types and number of items per most probable source: domestic; sewage related; fisheries and unknown), an Analysis of Variance (ANOVA) was used. *Post hoc* Student-Newman-Keouls (SNK) tests were performed when ANOVA indicated significant results. Data were transformed according to the best fit transformation to stabilize heterogeneous variances. Fourth root transformation was used for overall abundance of items and most probable source (sewage related items, fisheries and unknown sourced items); while log(x+1) transformation was used for domestic items. Normality was tested by a Shapiro-Wilk normality test and Homogeneity of variances was evaluated by Cochran Tests. Nevertheless, when no transformation was able to remove heterogeneity of variances, ANOVA was conducted since it is a robust test for large and balanced data sets (Underwood, 1997). Such an approach was adopted for marine debris studies by Widmer and Hennemann (2010) and results were interpreted with caution in order to avoid a type I statistical error.

First ANOVA tests were conducted to test if riverine discharges generate an increasing in the overall abundance of items and in the number of types (richness of types) of marine debris. Another set of ANOVA procedures were then developed to test if the number of items attributed to land-based sources (domestic/sewage related items) decreased through the estuarine gradient during HRD.

Hypothesis I could be considered corroborated if: (i) a clear discrimination of higher quantities of items and greater richness of types could be observed, during high riverine discharge (HRD in comparison to the other situations) situations and (ii) if internal beaches presented higher quantities of domestic and sewage related items, followed by the intermediate and the external sectors during HRD.

Another set of ANOVA procedures were developed to test if during frontal systems (FS), an increase in the number of ocean-generated items (fisheries or unsourced items) was observed. It was also tested if the number of items attributed to these sources decreased along the gradient from the outermost part to the innermost, during FS. Hypothesis II could be considered corroborated if (i) a clear discrimination among conditions could be observed where FS showed the highest quantities of fisheries and unsourced items and (ii) that external beaches presented higher quantities of fisheries and unknown sourced items, if compared to the intermediate and the internal sectors, during FS.

Finally, the results of the general ANOVA of the first set of data (overall abundance and richness of types), were used for testing if in absence of these two oceanographical and meteorological patterns (RWC) there was a smaller overall abundance of marine debris and richness of types of items in all beaches. Complimentarily, results of the specific ANOVA's above (domestic; sewage related; fisheries and unsourced items), were also used for testing if the smallest number of domestic and sewage related items was observed in external beaches and the smallest number of oceanic-generated (fisheries and unsourced items) items were observed in internal beaches. Then, hypothesis III could be corroborated if: (i) a clear discrimination could be observed, due to smaller overall abundance and richness of types in Regular Weather Condition (RWC) situation in comparison to the other conditions. Also, (ii) if the external sector showed a clear discrimination from the other sectors, presenting the lowest quantities of domestic and sewage related items and (iii) if the internal sector showed a clear discrimination from the other sectors, presenting the lowest quantities of fisheries and unknown sourced items, if compared to the other sectors, under RWC.

Permutational multivariate analysis of variance (PERMANOVA) was performed to analyse a composition matrix of multivariate variables (number of items per composition and per most probable sources). Pair-wise *post hoc* tests were performed to detect significant interactions. Raw untransformed data was used for conducting Similarity Percentages (SIMPER) routines, based in Euclidean Distance, to analyse overall similarities and dissimilarities regarding composition and number of most probable sources among the interaction of sectors and meteorological and oceanographic conditions. Ordination with a non-metric multidimensional analysis (nMDS) based on Euclidean Distance regarding composition and number of most probable sources was used to support result interpretation (Clarke and Gorley, 2006). The data set was standardized prior to conducting analysis for both PERMANOVA and nMDS (Zar, 2010).

3. Results

3.1 General Compositional Pattern of marine debris

A total amount of 12,048 items was collected and categorized. There was an overall dominance of plastic 74.8% followed by foamed plastic (8.7%), wood (3.6%), rubber (1.9%), glass and ceramic (0.8%), metal (0.7%), clothing and textile (0.4%) and paper (0.3%). "Other compositions", which included the tar balls, represented 8.8% (ANNEX II).

In respect to the most common item types, outstanding were the number of plastic fragments (2,512) and Styrofoam (996), representing 20.8% and 8.3% of all items found, respectively. Out of the top 10 types of debris, 80% was plastic, being food wrappings (988; 8.2%), fishing lines/monofilaments (962; 8%) and caps or lids (809; 6.7%) being the most common. Also, a significant number of tar balls (825) was found, which represented 6.8% of the items recorded. Other wrappings (585; 4.9%), fragments of manufactured wood (405; 3.4%), cigarette butts (386; 3.2%) and sewage related items (313; 2.6%) – including cotton buds – completed the list of the ten-most-common types of items.

With respect to the most probable sources, 5,620 items were categorized as unsourced items (ANNEX III). These items were extremely fragmented or weathered, or even there was no evidence that could support an assumption as to the most probable single source. Unsourced items were the most frequent origin, representing 46.6% of the total amount, followed by beach users (1,996; 16.6%); domestic (1,915; 15.9%); fisheries (1,364; 11.3%); ships and harbour (866; 7.2%) and sewage related items (287; 2.4%).

3.2 Univariate analysis of overall abundance, richness of types and most probable origin

ANOVA indicated that the interaction between condition and sector was significant and the variations between sectors were not significant. A great variance between beaches was observed for all univariate analysis, especially in the median sector (Table 1; Figure 4). Beaches behave differently to meteorological/oceanographical conditions, indicating a transitional area in the median sector of the gradient. Consequently, comparisons will be focused mainly on the internal and external sector.

First, ANOVA detected the interaction of condition and sector influenced overall abundance of total items, richness of types and the abundance of all specific sources evaluated: “domestic”, “sewage related sources”, “fisheries” and “unknown” (Table 1; figure 4) (Table 1; Figure 4). When comparing conditions, SNK tests indicated that HRD showed the higher overall abundance and greater richness of types (internal and external sectors). No difference was detected between HRD and FS in the median sector for both richness of types and overall abundance. Nevertheless, HRD and FS were higher than RWC for both considering all sectors together (Table 2; Figure 4).

During HRD, it was not observed the formation of a decreasing gradient (I>M>E) regarding “domestic” and “sewage related”. Internal sector showed greatest abundance of “domestic” items, but it was followed by external and then the median sectors (I>E>M). Such gradient was not observed for “sewage related” items (Table 3) as well.

SNK results also indicated that a greater number of “fisheries” and “sewage related” occurred during HRD, and not during FS as hypothesised, especially for internal and external sectors. Such increase was not observed under FS. In the median sector, statistical testing failed to detect differences among all conditions and a homogeneity was observed between conditions (Table 2; Figure 4).

Consequently, the gradient predicted in hypothesis II for “fisheries” and “unknown” sourced items (E>M>I), was not observed for both, during a FS conditions (Table 3; Figure 4). Under this condition, all sectors, showed similar quantities of “fisheries” items. While, for “unknown” sourced items, only a difference between internal and external sector was observed (I>E).

SNK detected that during the RWC situation the lowest overall abundance of items and richness of types were observed, but only in the internal and median sectors, if compared to the other conditions. The external sector showed different patterns for both aspects. In the external sector, the lowest overall abundance was observed in FS. And testing failed to detected differences between FS and RWC, but indicated that HRD showed the greatest overall abundance for the sector, for the condition. Consequently, RWC did not show the lowest values for neither overall abundance nor richness of types (Table 2; Figure 4).

The differences predicted for “Domestic” and “Sewage Related” items in hypothesis III were not observed. It was expected that external sector showed the smallest quantities under RWC conditions, if compared to other sectors, however a homogeneity of those items was observed along the whole gradient (Table 3; Figure 4).

However, the differences predicted for “Fisheries” and “Unknown” sourced items indicated different patterns. The internal sector showed the smallest quantities of “fisheries” items. Moreover, the gradient predicted for the FS condition, in hypothesis II, was observed during RWC for “Fisheries” items (Table 3; Figure 4). However, for “unknown” sources testing failed to detected differences between internal and median sectors, but indicated that the external showed the greatest numbers for this source under this condition.

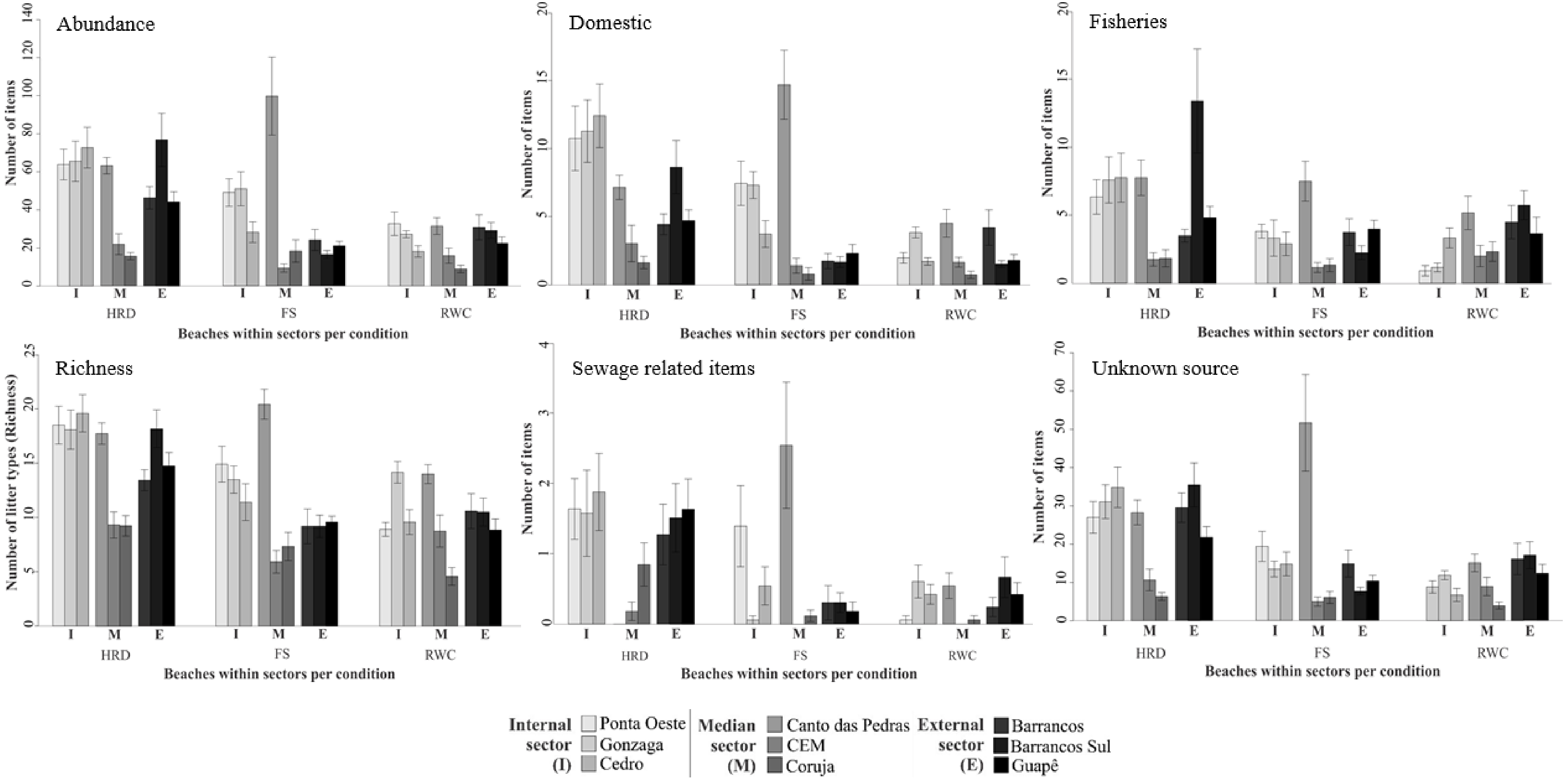

Figure 4. Overall abundance of items, richness of types and abundance per most probable sources. Number of items is presented for overall abundance of items, richness of types and overall abundance of most probable sources, which includes: Domestic; Sewage Related Items; Fisheries and Unknown source. Data is presented by beach (legend) aggregated per sector: Internal (I); Median (M) and External (E) within the environmental condition tested in the study: High Riverine Discharge (HRD); Frontal System (FS) and Regular Weather Condition (RWC).

Table 1. Results of a mixed model ANOVA of three factors for differences among Oceanographic/Meteorological Condition (Condition, C: High Riverine Discharge, HRD; Frontal System, FS; and Regular Weather Condition, RWC); Estuarine Sector (S) and Beach (B) regarding: overall abundance, richness of types of marine debris types and overall abundance of specific items (domestic, sewage related, fisheries and unknown sourced). For overall abundance of items, no transformation removed heterogeneity of variances; Cochran's test C = 0.23 (p-value = 0.0001), however data were used under a fourth root transformation, since it achieved normality (W = 0.99315, p-value = 0.1463). For richness of types, untransformed data was used, since no transformation could achieve normality (W = 0.98271, p-value = 0.00061); Cochran's test C = 0.16 (p-value = 0.2698). For domestic sources, data were log transformed log (x + 1)., no transformation could achieve normality (W = 0. 96474, p-value <0.001); Cochran's test C = 0.20 (p-value = 0.0074). For sewage related, fisheries and unknown sourced items, data was fourth root transformed; no transformation could achieve normality (sewage related: W = 0.671, p-value <0.001; fisheries items: W = 0.85, p-value <0.001; unknown sourced items: W = 0.96, p-value <0.001); Cochran-tests (sewage related: C = 0.17; p-value = 0.088; fisheries items: C = 0.166; p-value = 0.2; unknown sourced items: C = 0.17; p-value = 0.088). df = Degrees of freedom, Mean Sq = Mean Square.

Variable/Source of variation	*df*	*Mean Sq*	*F-value*	*p*
Overall abundance				
Condition = C	2	61.56	35.96	<0.001
Sector = S	2	31.86	0.95	0.430
C X S	4	0.89	51.27	<0.001
Beach (C X S)	6	33.45	195.42	<0.001
Residual	309	0.17		
Richness of types				
Condition = C	2	872.24	409.38	< 0.001
Sector = S	2	361.94	0.88	0.461
C X S	4	100.98	47.39	0.010
Beach (C X S)	6	410.53	192.68	< 0.001
Residual	309	21.31		
Domestic items				
Condition = C	2	165.49	326.25	<0.001
Sector = S	2	120.20	12.92	0.342
C X S	4	27.89	54.99	<0.001
Beach (C X S)	6	93.06	183.47	<0.001
Residual	309	0.51		
Sewage related items				
Condition = C	2	183.01	66.01	0.002
Sector = S	2	154.12	0.58	0.588
C X S	4	0.78	28.26	0.025
Beach (C X S)	6	263.99	95.21	<0.001
Residual	309	0.28		
Fisheries items				
Condition = C	2	42.80	157.52	<0.001
Sector = S	2	17.33	0.80	0.491
C X S	4	10.00	36.80	0.006
Beach (C X S)	6	21.56	79.35	<0.001
Residual	309	0.27		
Unknown sourced items				
Condition = C	2	56.09	344.18	<0.001
Sector = S	2	14.92	0.58	0.586
C X S	4	0.84	51.34	0.001
Beach (C X S)	6	25.48	156.37	<0.001
Residual	309	0.16		

Table 2. Summary table of *post hoc* SNK tests. Differences per sector of the estuarine gradient: internal (I); median (M) and external (E) for overall abundance of items, richness of types and abundance of most probable source (domestic, sewage related, fisheries and unknown sourced items). According to each Oceanographic/Meteorological Condition: High Riverine Discharge (HRD); Frontal System (FS) and Regular Weather Conditions (RWC). Symbols represent significance of differences (α): ">>>" 0.0001; ">>" 0.01; ">" represents 0.05" and "~" not significant

Sector	**Overall abundance**	**Richness of types**	**Abundance of most probable sources**			
			Domestic	***Sewage***	***Fisheries***	***Unknown***
Internal	HRD>>>FS FS>>>RWC HRD>>>RWC	HRD>>>FS FS>>RWC HRD>>>RWC	HRD>>>FS FS>>>RWC HRD>>>RWC	HRD>>>FS HRD>>>RWC FS~RWC	HRD>>>FS FS>>RWC HRD>>>RWC	HRD>>>FS FS>>>RWC HRD>>>RWC
Median	HRD~FS FS>>RWC HRD>>>RWC	HRD~FS FS>>RWC HRD>>>RWC	HRD~FS FS>RWC HRD>>RWC	~	~	HRD~FS FS>RWC HRD>>RWC
External	HRD>>>RWC RWC>FS HRD>>>FS	HRD>>>FS HRD>>>RWC FS~RWC	HRD>>>FS HRD>>>RWC FS~RWC	HRD>FS HRD~RWC FS~RWC	HRD>>>FS HRD>>RWC FS~RWC	HRD>>>FS HRD>>>RWC FS~RWC

Table 3. Summary table of *post hoc* SNK tests. Differences per Oceanographic/Meteorological Condition: High Riverine Discharge (HRD); Frontal System (FS) and Regular Weather Conditions (RWC), among sectors of the estuarine gradient: internal (I); median (M) and external (E). Data regard Overall abundance of items, Richness of types and abundance of most probable source (domestic, sewage related, fisheries and unknown sourced items). Symbols represent significance of differences (α): ">>>" 0.0001; ">>" 0.01; ">" represents 0.05" and "~" not significant)

Condition	**Overall abundance**	**Richness of types**	**Most Probable Sources**			
			Domestic	***Sewage Related***	***Fisheries***	***Unknown***
HRD	I>E>>>M	I>>>E>>>M	I>>>E>>>M	I>>>M I>>>E E~M	I>>>M E>>>M I~E	I>>>M E>>>M I~E
FS	I>>>M>E	I>M>E	I>>>M>>E	~	~	I>E
RWC	I>>M E>>>M I~E	~	~	~	E>>M>I	E>>I E>>M I~M

3.3 Permutational Analysis

3.3.1 Composition

PERMANOVA detected significant differences for beaches and the interaction between sectors and conditions, for composition (Table 4). Like ANOVA, great variability among beaches within sectors and conditions offset differences between sectors. Consequently, sectors were only differed within each condition for composition. Focus is given in comparing Internal and External sectors, supported by SIMPER from sectors.

Table 4. Results from PERMANOVA analysis for differences among Oceanographic and Meteorological Condition (Condition; C); Estuarine Sector (S) and Beach (B) regarding composition of items (Composition) and most probable sources (Source). Degrees of freedom (df), Mean Squares (MS), Pseudo-F (F) and p-value.

	df	*MS*	*Pseudo-F*	*p-value*
Composition				
Condition = C	2	63.79	7.786	<0.001
Sector = S	2	71.08	1.381	0.233
CxS	4	29.51	3.602	<0.001
Beach (C X S)	6	51.48	6.283	<0.001
Res	308	8.19		
Total	322			
	df	*MS*	*Pseudo-F*	*p-value*
Source				
Condition = C	2	82.23	19.101	<0.001
Sector = S	2	54.50	1.422	0.280
CxS	4	25.75	59.821	<0.001
Beach (C X S)	6	38.27	89.008	<0.001
Res	308	4.30		
Total	322			

When comparing conditions per sectors, pair-wise tests detected a greater number for the HRD situation in most of the sectors. Per sector, it was possible to observe that there existed a gradient in the internal sector HRD>FS>RWC. For the median sector, tests indicated that RWC showed lower numbers than the other conditions. Also, tests were only capable to indicate greater numbers for HRD compared to the other conditions in the external sector (Table 5).

SIMPER indicated that composition’s influence varied per sector. Similarities in the internal sector was influenced by “other” and “glass and ceramic”, in the median sector by “wood” and “foamed plastics” and in the external by “foamed plastics” and “metal” (Table 6).

When comparing sectors within conditions, variances among beaches made difficult the detection of variations among sectors (Table 7). Even though, the pair-wise test detected marginal differences for composition between Internal and External sectors. Those differences occurred under FS and RWC, which were mostly related to greater abundance of “other” and “glass and ceramic” compositions in the internal sector.

nMDS results for composition (Stress=0.14) indicated a higher cohesion of RWC samples and samples under this condition were graphically aggregated. Only four outlying samples were observed for this situation, which relate to Canto das Pedras, in the median sector (Figure 5). A different pattern of grouping was also observed for HRD samples in relation to the other conditions. Regarding sectors, median and external sectors showed a similarity in grouping patterns, while the internal sector’s sample showed a different distribution pattern, compared to those groups (Figure 5).

Table 5. Results from *post hoc* pair-wise tests for composition data according to meteorological/oceanographical condition (High Riverine Discharges (HRD), Frontal Systems (FS) and Regular Weather Conditions (RWC)) per Sector (Internal, Median and External).

Sector	*Internal*		*Median*		*External*	
Condition	t	P(perm)	t	P(perm)	t	P(perm)
HRD X FS	2.7299	**0.0001**	1.1346	0.2406	2.3466	**0.0001**
HRD X RWC	3.8831	**0.0001**	1.5996	**0.0042**	1.8326	**0.0018**
FS X RWC	1.9231	**0.0006**	2.0743	**0.003**	1.1988	0.1894

Table 6. Results from SIMPER analysis for similarities of composition per Sector (Internal, Median and External) within meteorological/oceanographical condition (High Riverine Discharges (HRD), Frontal Systems (FS) and Regular Weather Conditions (RWC)). Results are shown in percentage of contribution to similarity (%). Compositions contributing more than 10% are in bold.

Condition	*HRD*			*FS*			*RWC*		
Sector	Internal	Median	External	Internal	Median	External	Internal	Median	External
Rubber	**30.8**	8.2	9.6	5.0	7.4	3.6	2.8	**11.1**	**12.3**
Foam/Styrofoam	**20.0**	**12.8**	**33.0**	5.3	**38.6**	**14.4**	5.2	**26.4**	**19.2**
Wood	**10.8**	**14.2**	1.7	7.0	**19.7**	0.5	2.2	**11.4**	2.7
Metal	5.4	**28.4**	9.0	9.5	4.3	**18.4**	**10.3**	7.8	**22.5**
Paper	2.3	**20.7**	**20.2**	5.5	**12.1**	4.5	7.7	6.9	**18.2**
Plastic	**12.5**	7.7	**14.8**	3.2	**12.7**	3.6	0.6	7.0	4.3
Fabric	3.4	5.1	7.2	**21.9**	2.9	**48.8**	2.0	**18.7**	8.7
Glass Ceramic	**11.2**	2.8	4.4	**13.8**	1.9	6.2	**39.1**	**10.4**	**10.8**
Other	3.7	0.2	0.2	**28.9**	0.4	0.1	**30.2**	0.2	1.3
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table 7. Results from *post hoc* pair-wise tests for composition data according to Sector (Internal, Median and External) per meteorological/oceanographical condition (High Riverine Discharges (HRD), Frontal Systems (FS) and Regular Weather Conditions (RWC)).

Condition	*HRD*		*FS*		*RWC*	
Sector	t	P(perm)	t	P(perm)	t	P(perm)
I X M	1.8062	0.2027	0.87818	0.6934	1.5248	0.1966
I X E	1.655	0.1014	1.614	**0.0806**	1.5441	**0.0939**
E X M	0.97046	0.2976	0.90168	0.7803	1.1149	0.2962

The outcomes for composition suggests an increase of items during HRD, which was reflected in greater numbers for this variable (Table 5). It also supports some differentiation among internal sector regarding the other sectors, since its similarity is influenced by less floatable items, as, “ceramic and glass”, and by “other” compositions. On the other hand, “foamed plastics”, “wood” and “metal”, which are floatable or normally locally generated (*i.e.* beverage cans) were significant for the other sectors (Table 6). Spatial variances were subtle (Table 7). Graphical pattern of dispersion in the nMDS was support differentiation from internal and the other sectors (Figure 5).

3.3.2 Sources

PERMANOVA detected significant differences for the beaches and the interaction between sectors and conditions, for most probable sources (Table 4). Like ANOVA, great variability among beaches within sectors and conditions offset differences between sectors. Consequently, sectors only differed within each condition, for sources. Great variances among beaches, especially of the median sector, were observed and focus is given in comparing Internal and External sectors, supported by SIMPER from sectors.

When comparing conditions per sectors, pair-wise tests detected a greater number for HRD in most of the sectors. It was possible to demonstrate the existence of a gradient regarding sources of items in the internal sector HRD>FS>RWC. While for the external sector, testing only indicated greater figures for HRD and in the median sector, tests indicated that RWC was lower than the other situations (Table 8).

SIMPER indicated that each sector's similarity was influenced by different sources. Internal was mainly influenced by "sewage related", "domestic" and "ships" items, the intermediate sector by "beach users" and "fisheries" and the external by "fisheries", "sewage related" and "unknown" sourced items (Table 9). These great contributions of each sector, serve as a proxy for closer to sources. An increase in "fisheries" items for all the sectors within the HRD was observed. And a significant decrease in "ships" items was also notable during RWC in the internal sector.

Pair-wise analysis detected only marginal differences when comparing sectors per conditions: internal sector differed from external, for FS and RWC; while internal differed from median sector, for RWC. These results indicate great variances between beaches, offsetting variations among sectors (Table 10). SIMPER indicated that the great contribution of "ships" sourced items for the internal sector was the responsible for dissimilarities to the external under FS (56.5%) and RWC (55.5%) and to the median sectors under RWC (65.8%). nMDS results for sources (Stress=0.09) indicated a similar differentiation of the cohesion of RWC samples in relation to the other conditions, especially to HRD samples. This segregation supports the importance of the HRD for the dynamic of the litter assemblage. Samples of different sectors seem to have a similar dispersion under HRD conditions (Figure 5).

Considering sectors, there is clear differentiation within the internal sector beaches where HRD samples were segregated from samples of FS and RWC. A similar pattern was observed for samples of the external sector, where samples for HRD show a different dispersion. The median sector, despite of the outlying grouping from Canto das Pedras, under FS, seems to be extremely cohesive. These results indicated the importance of environmental conditions for the assemblage of litter.

Table 8. Results from *post hoc* pair-wise tests for most probable sources data according to meteorological/oceanographical condition (High Riverine Discharges (HRD), Frontal Systems (FS) and Regular Weather Conditions (RWC)) per Sector (Internal, Median and External).

Sector	*Internal*		*Median*		*External*	
Condition	t	P(perm)	t	P(perm)	t	P(perm)
HRD X FS	3.4111	**0.0001**	1.0225	0.3401	3.9763	**0.0001**
HRD X RWC	5.5197	**0.0001**	3.018	**0.0001**	3.2163	**0.0001**
FS X RWC	1.8299	**0.028**	2.5389	**0.0014**	1.3157	0.1386

Table 9. Results from SIMPER analysis for similarities of most probable sources per Sector (Internal, Median and External) within meteorological/oceanographical condition (High Riverine Discharges (HRD), Frontal Systems (FS) and Regular Weather Conditions (RWC)). Results are shown in percentage of contribution to similarity (%). Sources contributing more than 20% are in bold.

Condition	*HRD*			*FS*			*RWC*		
Sector	Internal	Median	External	Internal	Median	External	Internal	Median	External
Domestic	**27.4**	14.2	10.5	9.4	17.2	11.6	2.6	19.1	15.0
Unknown	11.9	15.5	11.9	5.8	**29.3**	**23.7**	3.5	18.4	**24.7**
Ships	4.9	0.02	0.05	**58.7**	0.02	0.05	**79.5**	0.0	0.04
Fisheries	17.1	19.3	**47.4**	6.4	6.0	**28.8**	5.8	**40.8**	**35.7**
Sewage related	**26.8**	17.7	14.2	16.0	**20.8**	**23.6**	7.0	9.7	16.6
Beach user	11.9	**33.3**	16.0	3.7	**26.8**	12.3	1.6	12.1	7.9
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 10. Results from *post hoc* pair-wise tests for most probable source data according to Sector (Internal, Median and External) per meteorological/oceanographical condition (High Riverine Discharges (HRD), Frontal Systems (FS) and Regular Weather Conditions (RWC)).

Condition	*HRD*		*FS*		*RWC*	
Sector	t	P(perm)	t	P(perm)	t	P(perm)
I X M	2.1973	0.1048	0.87865	0.7101	1.6992	**0.0996**
I X E	1.4229	0.2984	1.7298	**0.0823**	2.1016	**0.0994**
E X M	0.98741	0.5032	0.81082	0.8362	1.1041	0.4031

Outcomes from analysis of sources suggest a similar pattern as observed from composition: an increase in number of items, during HRD (Table 5). The Internal sector differed from the others especially because their similarities were influenced by “ships” and “domestic” sourced items, while the external sector was influenced by “fisheries” items. The median sector was the most influenced by “beach users” sources. “Sewage related” items appeared to be wide spread, since they contributed to the similarities of all sectors in most conditions. Graphical pattern of dispersion in the nMDS was especially different for internal sector in relation to the other sectors. Generally, the contribution of “domestic” items to similarities within sectors, under HRD, proportionally decreased along the estuarine gradient from internal (27.4%), to median (14.2%)

and the external sector (10.5%). The same pattern was observed for "sewage related" items (26.8%, 17.7% and 1.2%), even though they appeared as a relevant contributor for all the sectors, in most conditions.

The smallest contribution in the external sector from "domestic" and "sewage related" items was observed under HRD (10.5% and 14.2%) and not under RWC (15% and 16.6%). The smallest proportion of contribution from "unknown" sourced (3.5%) and "fisheries" (5.8%) items, under RWC, were observed in the internal sector. Under FS, the importance of "fisheries" items for the external sector (28.8%) was greater if compared of the contribution of these items to the median (6%) and internal (6.6%) sectors.

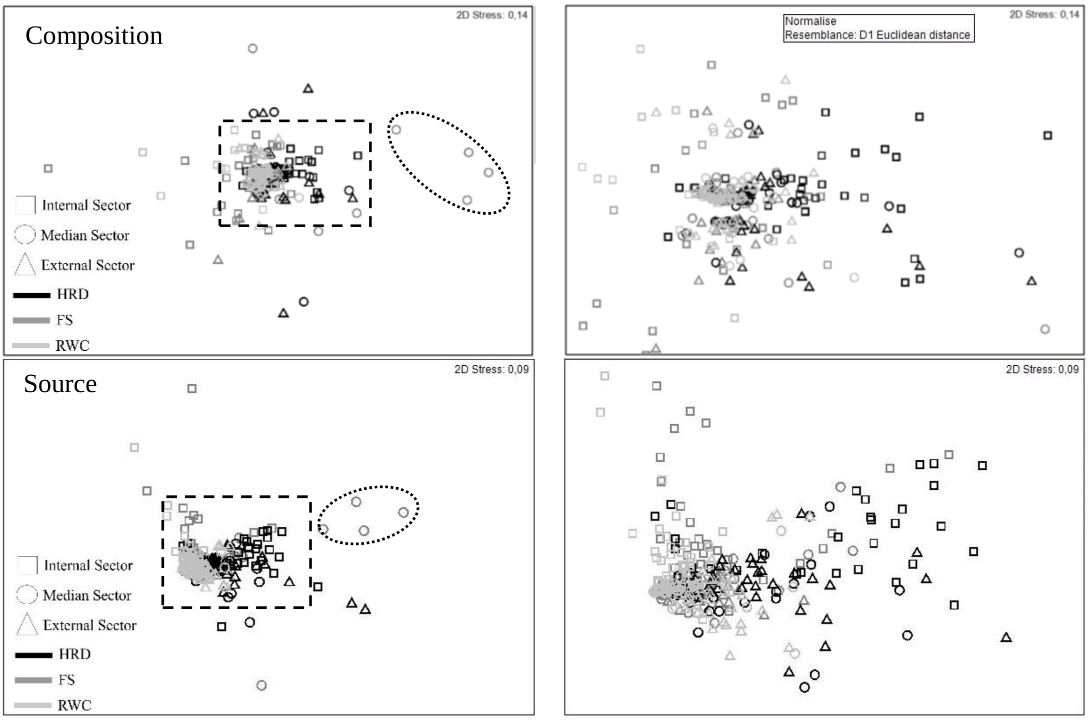

Figure 5. nMDS grouping of samples, regarding litter composition (Composition) and most probable sources (Sources). Simbols represented different sectors, internal (squares); median (circles) and external (triangle). Colors represent conditions: HRD (black), FS (dark grey) and RWC (light grey). Traced circle represents outlying samples obtained in Canto das Pedras, during a FS condition. Results from nMDS grouping regarding the interaction of condition and sector for litter composition (top left), followed by a detailed zoom of the same nMDS (top rigth). Results from nMDS grouping regarding the interaction of condition and sector for most probable sources (bottom left), followed by a detailed zoom of the same nMDS (bottom right). Traced squares represents the area that was zoomed in. Data Set was normalized prior running nMDS.

4. Discussion

4.1 General compositional pattern

The dominance of plastic observed in this study has also been described in several international studies (Derraik, 2002; Gregory, 2009; Jambeck *et al.*, 2015), but also previously studies in the PEC (Krelling and Chierigatti, 2014; Krelling, *chapter 5*; Possatto *et al.*, 2015). Fragmented plastic items are a worldwide threat due to the difficulty in removing them from the natural environment (Barnes *et al.*, 2009) and they appear as a significant impact for the PEC region.

The most common types of items found in the region were also mostly composed by plastic and the results are comparable to previous studies. For instance, four formats of the top-ten list of the present study were also recorded by Schulz *et al.* (2013) in a study for the OSPAR Region: caps/lids, fishing lines, cotton bud sticks and wrappings. The author considered that those items were abundant and represented a potential risk to wildlife. These patterns are also valid for the PEC (Krelling, *chapter 6*), since those items were abundantly found along the gradient and impacts over wildlife due to marine debris were already observed. For the PEC, it was estimated that 69.7% of juveniles of sea turtles *Chelonia mydas* have ingested anthropogenic litter (Guebert-Bartholo *et al.*, 2011) and 23% of sea birds, which may feed in the region, showed plastic items in their gut contents (Pelanda, 2007). Understanding the extension of the impacts seem to be imperative in the PEC, especially considering the importance of this estuarine gradient in a worldwide perspective (Unesco, 2002, 1999).

The analysis considering item types (Cheshire *et al.*, 2009) is innovative for the region and, apparently, there is no comparable data to provide a baseline about beach litter in the PEC. In a study of the benthic litter in the PEC, Possatto *et al.* (2015) observed that plastic items accounted for most of the types (70%), which were shopping bags, food packages, candy wrappers and cups. Some similarities are observed between stranded and benthic litter in the region. For instance, packages and wrappings were common items, showing relevant contributions, 13.1% and 31%, for beached and benthic litter respectively. The diversity of item types found in each study, 84 and 10 respectively, may be responsible for differences in relative numbers between the studies. Actions, *i.e.* policies, focusing in reducing, reusing and recycling packaging have the potential to reduce the marine debris loads (Liu *et al.*, 2013). These results reinforce the importance of considering item types for future studies in the region. Especially due to the fact that Brazilian National Policy for Waste (Brasil, 2010) is a window of opportunity for inserting the marine debris in decision-makers' agenda.

The characterization of types also permitted a detection of a great quantity of tar balls (825), exclusively in the internal sector (further discussed below). Surprisingly, it is uncommon that marine debris research efforts include such an item type (Ivar do Sul and Costa, 2007), especially when considering that international studies have already reported several impacts, including the ingestion of tar balls by sea turtles (Owens *et al.*, 2002). It seems essential that insertion of this litter type is made when analysing marine debris in environments where wildlife is already under anthropogenic pressure (Guebert-Bartholo *et al.*, 2011; Pelanda, 2007). On top of this, these items are being transported to beaches in Environmental Protected Areas in a World Heritage Site

(Unesco, 1999) and they are a clear concern to coastal recreational areas and to the seafood industry (Figure 6; Goodman, 2003). Results indicate a gap of knowledge about the extent of the impacts of this item in a worldwide perspective, because a few studies are regularly conducted (Warnock *et al.*, 2015). The evidences found at the present, suggest that tar balls may have an important role in the assemblage of items, especially in estuarine regions with harbour facilities.

Figure 6. Picture of tar balls (a) found on the beaches of the innermost part of gradient with ships in the mooring area for Paranaguá's harbour. b) Intense traffic of ships in the region close to the internal sector of the PEC. c) Example of a map with ships traffic and mooring in the region. Ships moored (circles) and ships in movement (arrows) are commonly observed, including tankers. Source: Pictures a) and b) from personal archive and c) obtained from www.marinetraffic.com, in January, 17th 2017.

The dominance of items not attributable to a single most probable source is an already observed pattern not only by international studies but also in studies conducted in the region (Ferrari, 2009; Krelling and Chierigatti, 2014; Slavin *et al.*, 2012; Veiga *et al.*, 2016). It appears to be also a valid pattern for estuarine gradients and the southern outlet of the PEC (46.6%). This corroborates findings from Krelling (*chapter 5*) that found a proportion of 55.7% for the PEC gradient. On the other hand, Ferrari (2009) found a higher proportion (70%) in an island in the northern PEC's outlet. These different results, comparing the PEC's gradient and the northern areas, suggest variances occurring not only in larger scales, but in smaller scales, as well. However further comprehensive testing must be conducted since methodological differences may also be responsible for such differentiation.

The observation that "beach users" (16.6%) and "domestic" items (15.9%) also represented significant sources of items for the present study is an interesting pattern. These findings reinforce a couple of statements of previous studies, especially regarding marine litter composition. For instance, most "beach user" items were found in the median sector while the internal sector showed less items of this source. The first is the sector where most users are normally observed along the year while the former is a Restricted Protected Area, therefore less visited. These findings reinforce that the kind or the intensity of usage influence debris found at beaches (Eastman *et al.*, 2013; Thiel *et al.*, 2013), suggesting it as an also valid pattern to estuarine environments. The other pattern is that most of "domestic" items were found in the internal sector (47.6%) and this source was also the determinant for most of the similarities within this sector (together with "sewage related" and "ships" items). It is possible to assume that proximity to source positively affect litter assemblage (Leite *et al.*, 2014) is valid for PEC as well. This whole set of evidences is also supported by previous studies which suggest the innermost part of the estuary, especially urban centres, as significant origins of marine litter (Procopiak *et al.*, 2007; Krelling, *chapter 5*).

4.2 Oceanographic and meteorological conditions and marine debris quantity and quality

In terms of oceanographic and meteorological conditions, it was an *a priori* assumption that increased riverine discharges would generate an increase in the overall abundance of items and in the number of types (richness of types) of marine debris. As predicted, it influenced positively not only the total overall abundance and the richness of types, but also most of the sources studied (domestic, fisheries and unsourced items). Such results are similar to previous studies where it was observed that land-generated items, as from the innermost part of the PEC, are put into the system through riverine flushes (Kataoka *et al.*, 2013). Also, the increase of "fisheries" items under this condition is in accordance with previous studies which observed that fishing monofilament are brought from adjacent subtidal habitats to the beaches due to storms (Smith and Markic, 2013). For the present, monofilaments (69.9%) represented a great part of all "fisheries" sourced items, followed by ropes (17.9%) and a similar pattern may have occurred for the PEC.

It is worth of mention, that a different pattern was observed regarding "ships" sourced items, which showed smaller quantities during HRD and the greatest quantities during RWC. This intriguing result may be associated to the fact that most of the items attributed to this source is tar balls (95.2%) and they have different characteristics if compared to other marine litter items regarding transportation rates, volatilization of contents and weathering (Warnock *et al.*, 2015). An additional explication that can be postulated is that less harbour activities occur during rainy periods, which meets HRD. Such environmental limitation reduces ships traffic and mooring, reducing activities which can potentially generate tar balls, *i.e.* less ballast water flushing, tank cleaning and discharges of tank washings or spills into the estuary (Peters and Siuda, 2014). The numbers indicating that the internal sector houses 100-times more items from this source than the other sectors, reinforce the conjecture that ships are the most probable source of those items. Consequently, it is supposed that, if an increase in marine traffic occurs in the region, *i.e.* harbour expansion, impacts over the protect areas will be intensified, if adequate management strategies are not put into practice. Even though such patterns must be studied in future research, the present results indicate that oceanographic and meteorological conditions may influence differently tar balls displacement and distribution in an estuarine gradient.

In a general manner, it was demonstrated that high riverine discharges are capable of transporting items through the whole estuarine gradient (Krelling, *chapter 5*). The fact that both extremes of the gradient, internal and external sectors, showed greater overall abundance, richness of types and quantities of several sources, under HRD, reinforce such assumption. In fact, the only exception was "sewage related" items that appear to have a ubiquitous distribution. Such ubiquity may be related to the fact that most of the items associated to this source (88.5%) were cotton buds, which is a widespread item and normally found entangled in natural debris. It commonly appears in different studies all around the world (Schulz *et al.*, 2013; Williams *et al.*, 2003) as a prevalent sewage related debris.

It was also demonstrated that internal beaches presented higher quantities of "domestic" and "sewage related" items, showing nearly two times more items from these sources if compared to the other sectors. Such an assumption is also supported by multivariate analysis that indicated a decreasing importance in the contribution of "domestic" and "sewage related" items to the similarities within sectors (I>M>E), even though, the abundance of those items showed a different distribution (I>E>M). Nevertheless, beaches in the innermost area of the gradient were more impacted by these items, probably because they were closer to the source, as previously stated, reinforcing this pattern to PEC (Leite *et al.*, 2014; Neves *et al.*, 2011; Slavin *et al.*, 2012). On top of that, the PEC is a tidal dominated estuarine system (Marone and Jamiyanna, 1997), were the internal sector is more directly influenced by riverine inflows that might be acting as a significant source of litter to these beaches (Ivar do Sul and Costa, 2013; Procopiak *et al.*, 2007). Considering that higher overall abundance of items and richness of types of items in the internal sector could be observed during high riverine discharge (HRD) and that internal sector presented higher quantities of "domestic" and "sewage related" items, but a clear gradient was not observed (I>M>E) for those sources, hypothesis I was refused.

It is also important to mention that the high quantities recorded in the internal sector for this study differed from a previous study, which observed smaller quantities of items in the innermost part of the PEC (Krelling, *chapter 5*). However, these variances are probably related to differences in beach profiles (Rosa and Borzone, 2008), beach directions and location (Walker *et al.*, 2006) and types of associated vegetation, which also affect retention of marine litter (Ivar do Sul *et al.*, 2014). Consequently, studies considering influence of these physiographical aspects must be further conducted in estuarine settings.

It was also an *a priori* assumption that an increase in southerly winds, characterizing Frontal Systems, would increase the number of beached “fisheries” and “unknown” sourced items, especially in the external sector. Indeed, these sources were significant for similarities in the external sector. However, as mentioned above, high riverine discharges appeared to be the dominant process in increasing the amount of these debris items, not only in the internal sector, but also in the external sector. Especially to the external sector, the number of items during HRD (2,009) overcame the other two conditions together (1,728). It is postulated that sourcing in open ocean beaches may be even more complicated, since the ocean acts as a buffer, concentrating several sourced items. These whole set of findings suggest that the *a priori* assumption was incorrect, and hypothesis II could be already refused. Even though, further discussion can enlighten the influence of frontal system over the region.

It is possible that the influence of Frontal System in the external sector act inversely then expected, reducing litter in open ocean beach, due to the action of a cross-direction wind generating along-shore drifts (Noernberg *et al.*, 2007), instead of bringing litter to the sector. Also, other physical processes of small and median-scale may transport superficial waters, and consequently floating marine debris, may drift to offshore. This assumption finds support in previous studies which state the importance of along-shore drifts for sediment transportation in the region, and a similar process may occur with marine debris (Martins *et al.*, 2004; Noernberg *et al.*, 2007; Quadros *et al.*, 2007). Other international studies also observed that correlations between debris loads and the strength and direction of the wind (Eriksson *et al.*, 2013; Thornton and Jackson, 1998) can affect distribution of items in scale of the beach (Smith and Markic, 2013). In addition, depending on the intensity of winds, marine debris may be blown from the intertidal area to the backshore, increasing items on the inland (Thiel *et al.*, 2013). Consequently, a “natural cleaning” of external sector due to the action of FS – in relation to the beaches direction (~45°) – can be deduced, especially considering that RWC showed a greater number of “fisheries” and “unknown” sourced items, if compared to FS. It is also possible that items from the external sector may be transported to the median sector during such conditions. Unfortunately, it is not possible to affirm that this transportation is occurring following the NE longshore current, especially due to outlying numbers of items in the median sector (Canto das Pedras beach), which prevented a thorough analysis about this specific process. However, such a suggestion must be further tested, using a similar approach adopted in previous studies to analyse retention patterns (Ivar do Sul *et al.*, 2014) but applied to sand beaches. Considering the extreme influence of HRD in the assemblage of marine debris all along the gradient, it is suggested that investigations focusing in other environmental conditions, must be conducted with absence of HRD.

There was also an *a priori* assumption that during RWC, it would be observed the smallest overall abundance and richness of types. Indeed, the lowest numbers for both factors were observed during this condition for internal and median sectors. However, such pattern was not similar in the external sector and the lowest overall abundance occurred in FS. As already discussed before, the sector seems to be negatively influenced by FS. On top of that, there exists a probable interaction among marine debris from external and the median sector, which may be affected by FS in association with other events, such as tidal waves and tidal currents, as already observed for sediment transport in the region (Martins *et al.*, 2004; Quadros *et al.*, 2007). Such assumption was also observed by previous studies, which demonstrate a limited interaction between the external sector to the internal areas of the PEC, while a more active exchange of marine debris between the external and the median sectors may occur (Krelling, *chapter 5*). Nevertheless, investigating separately not only FS, but RWC in different contexts, may promote the comprehension of other subtle effects that may be offset by HRD in this study. In fact, the input from rivers might have represented such an intense factor to the estuarine gradient that made distinction between SF and RWC unobservable in some situations. These inferences, find support in previous results that observed rivers transporting large amount of litter and natural debris from land (Kataoka *et al.*, 2013; Rech *et al.*, 2014). Such pattern was demonstrated valid for the PEC and should be taken into account in future investigations.

Another expected outcome, was that “fisheries” and “unknown” sourced items would be present in lower quantities in the internal sector if compared to the external, under RWC. This pattern, indeed, was confirmed. In fact, that might be related to the previous observed buffer function of the ocean in the region and closeness to source. Items are accumulated in the water column of the open ocean and the sea is apparently still beaching these sourced items in the external sector, even without influence of significant events. Consequently, internal sector, due to limited entrance of items from the external area, presents less of those items. Such postulation could explain also the reason for not finding a reduced number of items from the “domestic” source in the external sector. Since items are exported from the PEC, it could be expected that the ocean also accumulates “domestic” items. On the other hand, differences between external and internal sectors could be also expected due to proximity to the source, since the internal sector is beside (<10km) the biggest urban centre of the region. So, considering that the lowest overall abundance and Richness of types were not observed in the whole gradient under the RWC situation and that “domestic” and “sewage related” items showed a homogeneous distribution in both internal and external sectors, hypothesis III was refused.

4.5 Innovation, limitations and management consequences

This study is innovative by focusing in the influence of oceanographical and meteorological events over the marine debris quantities and qualities, as an alternative for merely analysing broad climatic seasons. A great effort was put in characterizing each specific event by using the best available information, however there were some limitations due to technical and natural characteristics. The unavailability of real time data, *i.e.* riverine discharges, may have limited some interpretations. For instance, collecting in the next day after an intense riverine discharge event may have a different effect than collecting four days after the same event. As well, collecting in the day after an event, may have prevented that marine debris items from the inner part of the gradient to reach the external sector, since the mean renewal time is estimated in 3.5 days. It is possible that such limitation, specifically in the case of HRD, may have restricted the real influence of such event over the other sectors of the gradient. On the other hand, since it was observed an increasing in "domestic" items in the external sector in a short period (1-3 days) still under HRD, it is possible to postulate that the extreme intensity of influx of freshwater could have diminished, even temporarily, the renewal time of the water of the PEC. These limitations have implications for future marine debris studies and investigating thoroughly these possibilities is demanded. Such objectives were above the scope of the present, but with more intense temporal surveillance, *i.e.* daily fieldwork through longer periods may define, for instance, if there exists a ideal sampling window or if there exists a differential renewal time for the water, depending on the different oceanographic and meteorological events.

Another limiting aspect, which is intrinsic while working in natural environments, is the impossibility of completely isolate the environmental condition investigated. For instance, one of the samples of HRD also presented southerly winds. In fact, such limitation is not exclusive of the present study, but to any which is conducted in natural environments. Also, outlying overlapping of drift lines was observed and generated an uncommon high quantity of items in one of the beaches (Canto das Pedras). Even though it represents an outlying condition, results reinforce previous evidences that the uneven distribution of drift lines, especially between tidal cycles, may cause important variation in the estimates of beached marine debris (Moreira *et al.*, 2016). These limitations are acknowledged and results might be considered with caution for generalization. In spite of such limitations the events analysed showed some distinctive patterns, in a general manner, supporting the adoption of these discrete factors. Consequently, it is possible to assume that considering characteristic events, may be useful to detect temporal patterns in estuarine gradient settings.

Finally, it was demonstrated that this sort of research might support managerial actions in long-term. Even though generalization should be done with caution, it is postulated that cleaning and preventing efforts might be more effective adopting heterogeneous strategies depending on spatial location and oceanographical and meteorological conditions. Collecting marine debris from beaches would be more effective after HRD events. The exactly period that cleaning should take place is not defined, but present findings suggests a period shorter than 4 days. Also, during Frontal Systems situation, cleaning efforts could be diverted to the outlet area, due an increasing of items at that sector, associated to the "natural clearance" of the open-ocean beaches. These suppositions, might not be applicable for seasons with higher intensity of use, due to increased locally generated litter, *i.e.* beach users littering, but it enlightens long-term strategies. On the other hand, for the estuarine area, the best apparent solution is to adopt a transboundary approach, even in the short-term. This approach is recalled as being the adequate option at cutting off litter directly at source, since several items are suggested of being originated in cities of the region, the preventing effort must consider such urban enters. Indirectly, it is expected that such approach will resound in the other sectors, since PEC exports debris. In this scenario, the Brazilian Waste Management Policy (Brasil, 2010) may play an important role, since promoting adequate waste management and regional approaches to manage waste are instruments of this policy. By integrating research and adequate managerial efforts, the investments in marine debris control would be better directed.

5. Conclusions

As a conclusion, it was demonstrated that riverine discharges influence positively the overall abundance of items and richness of types of marine debris. This condition similarly influenced “Domestic”, “fisheries” and “unsourced” items quantities. The tide-dominated environment, *i.e.* internal sector, demonstrated to have more quantities and quality of items, if compared to the rest of the gradient under HRD. Even though greater numbers of “domestic” and “sewage related” sourced items were observed in that environment, it was not demonstrated the formation a clear gradient among the sectors (I>M>E) for these items. Hypothesis I was refused.

It was not possible to demonstrate that Frontal System increased, to the greatest numbers, items from “fisheries” and “unknown” sourced items along the whole gradient. Actually, the expected pattern was observed during HRD in most of the sectors while a general homogeneity of those items was present under FS conditions. The only exception was a differentiation between Internal and External sectors, regarding “unknown” sourced items (I>E) for this FS condition. The gradient of greater quantities of “fisheries” and “unknown” sourced items along the gradient (E>M>I) did not occur during FS, as expected, but appeared during RWC. It is concluded that the FS acts oppositely than expected, cleaning the open ocean beaches instead of increasing beaching of litter. Hypothesis II was refused.

It was not possible to demonstrate that the RWC was the condition showing smaller overall abundance of items and richness of types for the whole gradient. It was demonstrated that such pattern is valid for the internal and median sectors, but for the external sector it appeared under FS influence. The smallest number of “fisheries” items in the internal sector was identified under the RWC. But there was no indication that there were smaller numbers of “unknown” sourced items, for the internal sector, under this condition. Similarly, it was not possible to identify a reduction in land-generated (“domestic” and “sewage related”) items in the external sector items during RWC. Hypothesis III was refused.

Finally, it is demonstrated that the ocean acts as a buffer of items of every source for the region of the PEC. Like other coastal areas, the PEC’s coastal waters are treated as the fate for the litter end of life, which makes the establishment of the effect from each single oceanographical and meteorological condition over the quantity and quality of marine debris, a complex task in the open-ocean beaches, especially in an estuarine setting. For instance, a combination of environmental events or a combination of physiographical factors may be responsible by marine debris quantity and quality in wave dominated environments.

The present research was dedicated to specific events, which is innovative, to comprehend the influence of oceanographic and meteorological condition over marine debris. The adoption of an unconventional temporal approach demonstrated differences between the influences of each condition per sector of the estuarine gradient. It demonstrates that the application of such approach may distinguish temporal variations that could be offset if a conventional seasonal approach was to be adopted.

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7. Differences in perception and reaction of tourist groups to beach marine debris that can influence a loss of tourism revenue in coastal areas

Diferenças de percepção e reação de grupos de turistas à presença de lixo marinho em praias e a influência sobre a perda de receita em áreas costeiras.

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Differences in perception and reaction of tourist groups to beach marine debris that can influence a loss of tourism revenue in coastal areas

Abstract

Marine debris is the most conspicuous pollutant that makes beaches aesthetically unappealing to users. The perceptions and reactions of beach users to stranded litter were compared between second-home owners and users (SHOU) and non-recurrent tourists (T). A questionnaire was applied to obtain socio-economic characteristics; assessment of the overall beach quality and perception of beach litter pollution (perception); hypothetical scenarios of marine litter pollution and deterrence (reaction); and potential alternative destinations in the case of deterrence (economic effect). Questionnaires (n=319) were applied at two Brazilian subtropical beaches, with different physiographical settings (Pontal do Sul, PS, estuarine beach; Ipanema, I, open-ocean beach). Beach users' groups differed regarding daily expenses (T>SHOU), period of permanence per trip (SHOU>T) and trip frequency (SHOU>T). The open-ocean beach (I) was rated the worst regarding overall beach quality. Marine debris generation was mainly attributed to local "beach users", in the open-ocean beach (I). "Marine" (or non-local) sources were four times more frequently cited in the estuarine beach (PS). Perception on actual litter pollution and litter deterrence scenarios, did not vary between beaches or groups. More than 85% of beachgoers would avoid a beach visit if a worst scenario (>15items/m^2) occurred and most users would choose a neighboring state beach destination. Stranded litter may potentially reduce local tourism income by 39.1%, representing losses of up to US$ 8.5 million per year. These figures are proxies to support the trade-off local authority's make between investments to prevent/remove beach litter and the potential reduction in income from a tourist destination change.

Keywords: *marine debris; second home; public perception; economic effects; tourism*

1. Introduction

Coastal systems, such as beaches, coral reefs and estuaries, are the main worldwide providers of ecosystem services of leisure and recreation, with a high cultural and aesthetic value [1]. Human pressure over coastal resources compromises the quality of the environment, which is crucial for several local coastal communities and national economies [2]. Some stressors are globalized across coastal areas, such as, marine debris [3,4], which impacts coastal tourism [5].

The amount of marine debris in the ocean and beaches is a growing problem [6,7]. Preventing its generation at source is an accepted worldwide mitigation strategy [8], but debris removal from the environment is recalled as an additional measure to reduce marine litter impacts [9]. Once in the sea, marine debris may become a transboundary problem, crossing political limits (municipal, state or national) that demands new management arrangements. In transboundary contexts, the synergy between marine debris and tourism is especially complex since items may originate in regions other than the places where the litter is stranded and where tourism activities occur. In such locations, the main motivation of local authorities to remove beach litter is the potential negative economic impacts caused by litter presence to tourism revenues [10], which have rarely been evaluated and used as a contribution to management actions [11].

It is known that several aspects influence visitors' beach choice, such as, beach length and shoreline characteristics [12], as well as scenery, water quality, landscape, crowding and amenities [5,13–15]. Also, among several factors that influence the return of visitors to a certain destination, the overall trip satisfaction is consensually one of the most important [15]. As can be seen, in order to improve the beach users' experience, not only over-crowding should be taken into account, but also other aspects that users may consider important [16], such as, marine debris.

Specifically for the selection of beaches for recreation, marine debris is an important aspect taken in account by visitors [17–20]. Stranded litter is considered by beach users to be one of the five most important aspects regarding beach quality in Europe [21], USA [22], Mexico [22] and in the Caribbean [13,14]. Even though there is allochthonous marine debris generation, items may also be locally generated by tourists [23] and socio-economic aspects may influence littering behavior in different ways. For instance, some studies indicated that lower income and educational levels are related to a higher littering behavior [17,24]. On the other hand, other researchers found that these factors did not influence littering behavior, but age did with youngsters tending to litter more [25]. Even though factors influencing littering behavior may vary, the very presence of litter is generally perceived as unpleasant, especially for beach users [26,27]. For example, beach award programmes consider marine litter as a negative aspect when assessing beaches [28] and the European Union classify marine debris as an indicator of environmental quality [29].

Besides littering behavior, a previous study suggested that socio-economic characteristics of users influence their perceptions regarding the amounts and impacts of marine debris [30]. The authors observed that lower levels of education, in association to the location (beach) where the respondent was approached, could explain their concern about beach marine debris [30]. If this is a general pattern, it is expected that groups with different socio-economic characteristics, visiting different beaches, will have different perceptions of the environment.

Regarding beach users' groups, there are several possibilities of segregating user groups in a certain environment, depending on the issue under investigation or the study objective [31]. For instance, beach users may be divided by the uses they make of the beach (*e.g.*, sun bathing and sports), geographical origins, income, age or gender. However, the type of accommodation, which underlie the level of attachment to the place, is rarely addressed [32–34], including the possible distinction of socio-economic profile and perception between Second Home Owners/Users (SHOU) and other type of tourists in coastal areas.

SHOU are conceptually, the intermediate level between non-recurrent tourists and year-round residents regarding site fidelity [32]. SHOU presents a higher sense of place than tourists, emphasizing the importance of local environmental quality and consider the region as an important escape for everyday activities. Non-recurrent tourists (hereafter referred as Tourists, (T) would be considered as holding a weak and inconstant destination connection, being deterred to visit a given site that does not anymore fit in with their interest, due to loss of environmental quality or perceived/presumed obsolescent socioeconomic status. Similarly, SHOU also values the quality of environmental attributes, while selecting vacation places [33] and a degraded environment represents a potential decline in second-home market values, also declining SHOU's topophilia [34,35]. However, it is hypothesized that SHOU would be more tolerant to tourist destination discouragement, since there exists a higher attachment with the location (*e.g.*, property investment and connection to local people), when compared to Tourists [34,36]. It is expected then that threats to the beach environment, such as, marine debris, will be perceived differently by these groups (see below), eliciting different responses in terms of site deterrence and change of destinations.

Even though holding distinct levels of site attachment, both groups represent income to coastal tourism. As marine debris influences the perception/satisfaction of beach users, especially regarding overall beach quality, an increase in the amount of debris may generate a potential loss of income to the coastal economy and municipalities [12]. Consequently, varied economic effects may occur depending on the proportion of discouragement between these groups. The way marine debris affects tourism depends on the perception of beach users and is site specific [19,20]. Therefore, it is fundamental to understand which tourist groups use a given beach together with their perceptions and reactions to marine debris. Ultimately, these users' characteristics may influence the intensity and extension of potential economic impacts to a given locality, due to the presence of marine litter. Identifying the income from tourism and the possible losses due to marine debris allow estimating thresholds of acceptance of pollution levels by tourists. Nonetheless, it is expected that litter will affect differently each user group, *i.e.* deter tourists more than SHOU.

Economic losses due to stranded litter should consider not only costs involved for cleaning the environment but also the reduction of visitors' interest for a certain site [12,37,38], which may cause revenue reduction to tourist municipalities and countries. Identifying tourism income may also enlighten the limits of investing in palliative measures even though, essential analysis of the effect of aesthetical deterioration has not been fully explored regarding marine litter's economic impacts on tourism [39–41].

A case study in New Jersey and New York, in 1987-1988, estimated mean potential losses due to beach closures of US$1.1 billion, 14.2% associated to waste wash-ups [38]. Another study on 21 economies in the Asian-Pacific region in 2008 estimated an impact of *circa* US$622 million on the marine tourism industry due to marine litter [42]. Other authors observed that 97% of the Cape Peninsula's (South Africa) beach visitors would avoid visiting if there were more than 10 litter items per square metre [43]. The same authors estimated that beach cleaning expenditures represented approximately 20% of the recreational value (income) to the Cape Peninsula [43]. Another study, identified a reduction of 63% of visitors to Geoje Islands, in South Korea, due to marine debris coming from an estuarine area and estimated the economic effects to be between US$29 – 37 million in 2011 [44]. Considering the results of these studies, understanding the economic effects of discouraging visitors, due to the growing marine litter problem over tourism is a relevant step in supporting valid decision-making.

Therefore, the present study aimed at providing new information on the socio-economic aspects of marine litter by addressing the role of tourist groups (Second Home Owners/Users and Tourists) on the potential economic impacts of beach debris. Sources of information were socio-economic profile, perception on the actual litter contamination and the overall beach quality, together with reaction to stranded marine debris scenarios. The rationale of this study was structured on four hypotheses.

The socio-economic characteristics (yearly income, level of education, daily per person expenditure, frequency of trips and period of permanence) and the perception on beach environment and beach litter (actual beach pollution scenario and the overall beach quality and/or probable marine debris origins) were supposed to vary between beach user groups and beaches (Hypothesis I). It was also hypothesized that the “deterring scenario”, defined by number of items/m^2 that elicit users to change vacation destination, will depend on user groups, *i.e.*, tourists will be dissuaded by smaller amounts of litter than SHOU, and on beaches, *i.e.*, the worse the actual beach scenario, the higher the user’s tolerance to future litter scenarios (Hypothesis II; Ipanema (I) > Pontal do Sul (PS)). Alternative vacation destinations (beaches within the same municipality, in a different municipality in the same state or in a different state) were supposed to differ between user’s groups, with SHOU presenting a smaller mobility then tourists (T; Hypothesis III). Finally, it was hypothesized that an increase in stranded litter will cause a potential negative economic effect, which will also depend on user’s group (Hypothesis IV; T>SHOU). The estimated economic impact will be discussed regarding the trade-off between costs of cleaning and loss of tourist revenue under a transboundary approach along the estuarine gradient.

2. Study Area

2.1 Regional characteristics

The study area is located in the coast of Paraná state, southern subtropical coast of Brazil (25º30’S e 48º30’W). It is short in extension (~98km) and bordered by bays [45,46]and is a common destination for second home tourism, searching for sun, sand and beach, especially with people coming from the state capital (Curitiba) and cities of the State interior [47]. The most visited state’s protected area is located in Mel Island where approximately 112,000 people, mostly tourists, visit during summer seasons [48]. Paraná’s coastal population density is 41.9 inhabitants/km^2, but in summer periods this number increases and can reach 252.5 individuals/km^2 [49]. Some cities depend significantly on tourism during summer periods and from “property” taxes (IPTU) paid by home-owners to municipalities. For example, in Pontal do Paraná and Matinhos (Figure 1) the proportion of IPTU per inhabitant (per year) are among some of the highest of Brazil, US$151.72 and US$106.65 (R$632.20 and R$444.40), respectively [50]. These high values suggest a small fixed population during most of the year [51], which indicates the local administration depends significantly on contributions from exogenous people (SHOU), most of them interested in seasonal sun-and-beach tourism [52]. Besides using hotels and bed and breakfast accommodations, tourists also rent properties in vacation destinations, such as, Pontal do Paraná, representing an income for property owners, due to rentals, and the municipalities, due to expenditure in local commerce.

2.2 Sampling sites

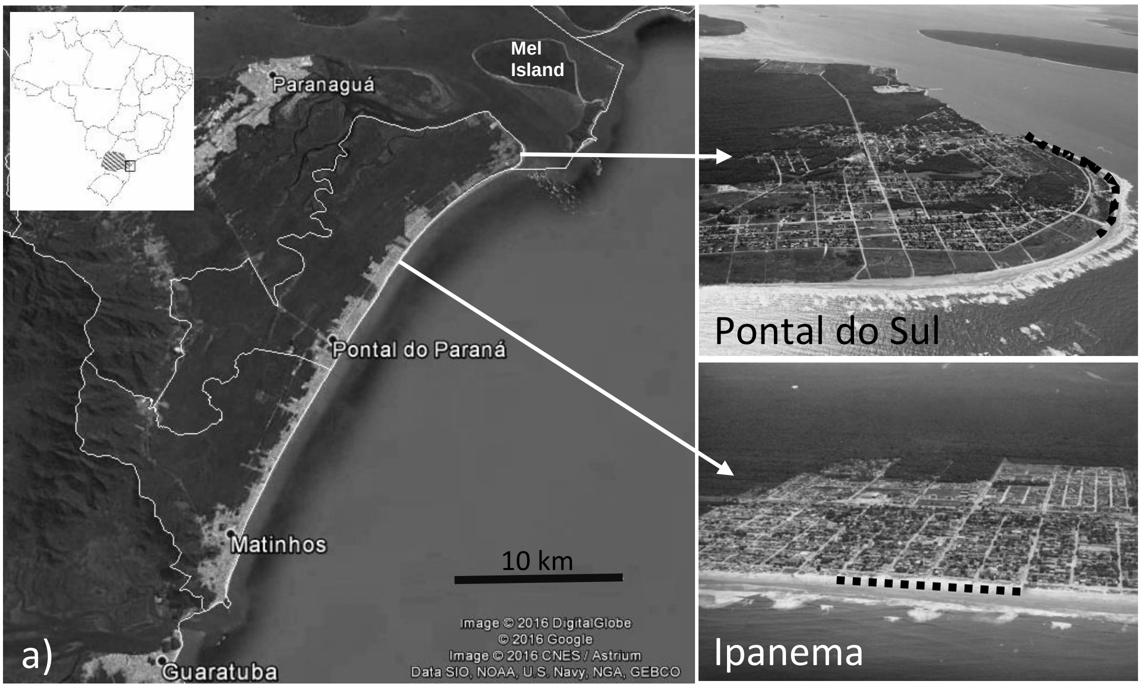
The study sites are located in the municipality of Pontal do Paraná (Figure 1). This location was selected because more than 70% of the visitors are second home owners/users [53] and it is one of the most important tourist destinations in the coastal region of Paraná state [54]. The region encompasses a complex setting with human settlements, harboring activities and tourism [46,49]. Within this complexity, there exist evidences of a transboundary exportation of marine debris, from highly urbanized areas in the inner part of an estuarine complex to the tourist beaches of Pontal do Paraná [55]. Beach cleaning is mainly payed for by the state and partially by the municipality [56]. There is apparently no direct support or efforts from the potential “source” municipalities to prevent litter input to the environment, or its removal from beaches. The two selected sites, Pontal do Sul (PS) and Ipanema (I), are close to parking areas and easily accessible on foot but possess differences regarding geographical distance from the estuarine complex, landscape and intensity of use, as described below.

2*.2.1 Pontal do Sul*

Pontal do Sul is a three-kilometer long seaside district with approximately fifty-meter wide beaches. The area is in the outlet of the Paranaguá Estuarine Complex - PEC, possessing calm waters due to protection from the direct action of oceanic waves by the formation of a coastal shoal in the outlet of PEC [45]. It is a common destination for SHOU, locals (residents) and tourists. During the summer periods of 2015 and 2016 it was accessible by car, with (limited) availability of facilities during summer periods, such, as restaurants with restrooms, parking areas, lifeguards and beach showers. The landscape is dominated by vegetation and sparse buildings, which are used as restaurants. The seascape is mainly characterized by Mel Island, which forms the other margin of the southern outlet (Figure 1). The area is considered by visitors as being more environmentally conserved when compared to other beaches of Pontal do Paraná, probably due to the maintenance of wide areas of coastal plain vegetation [57]. Marine debris pollution at the beach was evaluated in a previous study and a mean (±standard error) value of 6.3 (±0.7) items per linear metre across shore was recorded [58].

2.2.2 Ipanema

Ipanema is also a three-kilometer long beach strip approximately 80-meter width. The beach is completely exposed to the Atlantic Ocean and suffers from the direct action of oceanic waves (Figure 1). It is also a common destination for SHOU, locals and tourists. However, there is higher availability of lifeguards, parking areas, chemical toilets, beach showers and itinerant facilities (*e.g.*, food on the beach) for users. It is approximately 13 kilometers southward from the PEC's outlet and is normally more crowded than Pontal do Sul due to the greater urbanization of the area. The landscape is dominated by a rudimentary promenade with an urbanized and easily accessible area. A previous study on a neighboring area 4 kilometers north in the same beach stretch suggests a mean (±standard error) marine litter pollution level of approximately 6.9 (±0.5) items per linear meter [58].



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Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Figure 1. Study area exhibit. a) Location of Paraná State, in southern Brazil (top left). Delimitation of some municipalities of Paraná coast (white lines), especially the neighboring territories of Pontal do Paraná (center of the figure): Paranaguá, in the NW border including Mel Island; Matinhos, in the S – SW border. Guaratuba is the southernmost municipality of Paraná's oceanic coast. "Pontal do Sul" detailed sampling area (dotted line). "Ipanema" detailed sampling area (dotted line). Image sources: a) Google Earth; "Pontal do Sul" marcioantoniassi.wordpress.com and "Ipanema" correioatlantico.com.br (all accessed in 27 of january, 2017).

3. Material and Methods

3.1 Questionnaire

The aim of the questionnaire was to characterize beach users' socio-economic, perceptions and reactions, especially regarding the potential negative economic impacts of marine debris (Supplementary Information A). The complete questionnaire is composed of 12 questions focused on: (i) the socio-economic characteristics of beach users, *i.e.*, user category (Tourist or SHOU), yearly income, educational level, daily expenditure (2 questions), frequency of trips and period of permanence; and perception about beach characteristics, *i.e.* actual beach pollution scenario, overall beach quality and probable origin of debris (Hypothesis I); (ii) potential of deterrence of beachgoers due to increasing of pollution, *i.e.* deterring pollution scenario (Hypothesis II) and (iii) alternative destinations (Hypothesis III). Also, calculated was the potential associated economic effects, using (iv) users' category, daily expenses, mean period of permanence and deterring scenario (Hypothesis IV). (Full description of each question usage and analysis is available in Supplementary Information B).

The answers given for deterrent scenario was compared to the answer given to the actual scenario. This comparison aimed at estimating the necessary increment (named "Delta") in beach pollution levels, represented by chosen scenarios that would deter users. The Delta between scenarios was estimated by subtracting the number chosen to the actual scenario from the number of the deterring scenario. For example, a respondent chose "scenario 4" for the question about the actual pollution and "scenario 6" for the question about deterring scenario (4-6=2). This means that an interval (Delta) of 2 scenarios of worsening would be necessary to deter this beach user. This difference was calculated to all respondents who answered both questions. Respondents who obtained a negative value in this calculation were excluded, since it suggested that a lower pollution scenario than the actual would deter him/her. Such a pattern was observed in 11 questionnaires and may represent confounding or inattentive answering, and a total of 196 questionnaires were used for such comparison.

Fieldwork was conducted during the period of highest presence of beach users, *i.e.* the southern hemisphere summer periods of 2015 and 2016 (January and February of each year). A pilot study was conducted, applying 33 questionnaires during January 2015 to determine the best sampling strategy regarding sample size and time availability [31].

The full survey was conducted during weekends since there were a higher number of users available during these periods. Selection of interviewees prioritized individuals resting under beach sunshades (Figure 2). Interviewers walked freely through the beach area and the closest adult, resting under one of the sunshades, was asked as to whether they would like to fill in the questionnaire. In case they were not interested, interviewers followed to the next sunshade and conducted the same procedure. The questionnaires were delivered to respondents and after approximately 20 minutes, personnel of the project collected the questionnaires back. In the case that different families were under the same sunshade, only one respondent of each family was invited to answer the questionnaire. Every sunshade was visited.

Figure 2. Fieldwork illustration. Approaching beach users for delivering the questionnaire (picture on the left). Beach users answering questionnaires in Pontal do Sul beach (picture on the right).

In total, 319 questionnaires were given to beach users. The non-response rate was approximately 2.6% (8), which is below levels observed in previous studies, that could reach nearly 40% depending on the method used [59]. Analysis considered separately the totality of answers provided for each question. Respondents were free to leave questions that they were unwilling or not comfortable to answer. As a consequence, absolute numbers used for analysis in each question varied. For instance, only 202 respondents provided information to characterize their daily per person expenditure. For some questions respondents selected more than one answer, so the total number of answers was sometimes bigger than the number of questionnaires. An example is the case of users' perceptions on the most probable origin of beach marine debris, 369 answers were obtained. Taking those aspects into account, the results were mostly presented showing the relative frequency (%). Out of 319 participants, 273 provided information which characterized them as tourist (135) or second home owner/user (138). The 273 questionnaires that were used for this analysis, returned a standard error of 7% [31].

3.2 Potential economic effects calculation and data utilized

The definition of economic effects is "*the lost sales of producers*" [44]. For analyzing beach pollution economic effects, lost sales may be represented by a decrease in attendance and consumption in a certain beach – due to increased pollution – potentially reducing the local economic activity. This economic activity change can be measured by changes in consumers' spending [60]. For the present study, it is considered that once the beach user is deterred from visiting due to a hypothetical beach pollution scenario, individual daily expenditure is not spent on goods and services at that place anymore. Consequently, it is expected that differences will be observed between the economic effects per beach users' groups, since they presumably possess different daily expenses (Hypothesis IV).

Depending on respondent's choice of alternative destinations, those losses will impact the municipality or the State. Respondents which stated that their most probable alternative destination would be another municipality, but still in the State of Paraná, were accounted for in calculation of the economic effects to the municipality of Pontal do Paraná (where both studied beaches are located). Answers stating destinations to other States were accounted to calculate economic effects to the State of Paraná. These two approaches were adopted, firstly, because marine debris was recognized as a transboundary concern for the PEC's region [55]. Consequently, understanding regional impacts may support adoption of a transboundary approach to prevent marine debris. Secondly, the State Government is historically the main investor in beach cleaning, which is a legal responsibility of municipalities. Understanding the potential losses not only to the municipality, as a noticeable direct concern, but also to the State, will inform decision-makers from both governmental levels about the risks of not executing beach cleanings or other mitigation strategies.

The economic effects due to a potential increase in marine debris were estimated using an adapted formulae proposed by Jang *et al.* (2014) [44]. Beach users were divided into Tourists and SHOU, since differences were observed in daily expenditure and period of permanence among those groups (Tables 1 and 2).

The expected deterred number of beachgoers was multiplied by the stated average beach users' group daily expenditure [44]. This product was then multiplied by the estimated number of days spent by each group coming to Pontal do Paraná (Eq. 1). The result is an estimate of the potential negative economic effects due to beach avoidance. Data utilized for these estimates was obtained from official sources (see below) and from answers to the questionnaires (explained before).

$$DTR= \{[(n^* b) * (P)] * (D)\} * d \quad (1)$$

"DTR" is the potential decrease in tourism revenue due to an increase in marine debris; "n" is the estimated total number of visitors to Pontal do Paraná of each user group (SHOU or T); "b" is the percentage of visitors that have beaches and/or scenic beauty as motivation for choosing a destination, "P" is the potential reduction of beach goers at the estimated scenario (percentage); "D" is the average daily expenditure per person, which is different for each group of beach user; "d" is the estimated number of days spent at the beach by users' group per trip.

The number of visitors (n) and percentage of visitors that have beaches and/or scenic beauty as motivation for traveling (b) were obtained or estimated from official data (see detailed description in Supplementary Information C). Percentage of beach users deterred (P), daily expenditure per person (D) and estimated number of days spent at the coast of Paraná (d) were obtained through application of the questionnaires (see above). Conservatively, in order to reduce bias, the frequency of trips was disregarded and estimations were calculated considering only one trip per year.

3.3 Statistical Analysis

The data set was analyzed using chi-squared (χ^2) tests for independence [31] to determine if answers were dependent on beach users' categories and beach where respondents were interviewed (geographical difference). Contingence tables were built considering interaction between beaches and user's group. Consequently, each column of the tables represented: Tourists of Pontal do Sul; Tourists of Ipanema; SHOU of Pontal do Sul; and SHOU of Ipanema. The Null Hypotheses for these tests considered that variables were independent of beaches and users' groups. When significant effects were observed, additional chi-squared tests for independence within each category (beaches and users group) were performed separately. In order to determine the most commonly chosen scenarios and the necessary increment in beach pollution levels, for deterring users, a chi-squared "goodness-of-fit" test was performed [61]. This test compared the observed value (number of answers to a certain scenario/delta) with the expected value for each question (an equal mean number of answers to each question/delta). If the test indicated a significant difference, the number of answers was analyzed to determine if the scenario was most commonly chosen (greater than the expected) or less commonly chosen (lower than the mean). The Null Hypotheses for these tests was that the proportion of answers was identical to all scenarios. Consequently, if an answer was chosen significantly above or below the mean, it was assumed that the choice was intentional and/or influenced by users' perception.

4. Results

4.1 Socio-economic characteristics of beach users and perception

There were a similar number of respondents from user categories, Tourists (135) and SHOU (138). However, the number of SHOU in Pontal do Sul (82; 57.2%) was higher than in Ipanema (56; 42.4%) ($\chi^2=6.13$; df=1; $p<0.05$; n=273; Yates corrected). About one-fifth of respondents (20.4%) did not reveal their income. Approximately one-third of respondents stated having median (33.2%) or high (35%) yearly incomes' levels each, which are "between US$5,041.95 and US$15,129.01" or "above US$ 15,129.02", respectively. Respondents with incomes lower than US$ 5,041.94 represented only 11.3%. Income did not vary regarding beaches or users' groups (Table 1; Figure 3).

Education level differed between beaches and user groups (Table 1 and 2; Figure 3). Most respondents in Pontal do Sul (39.1%) cited "College/University", while those in Ipanema indicated mainly "High School" (41.4%), followed by "College/University" (34.3%). A marginal difference was observed between beach users' groups, with most SHOU citing proportionally more "College/University" (42.2%), while most of the answers from Tourists were "High school" (42.7%).

Beach users' groups differed regarding daily per person expenditure and frequency of beach trips (Tables 1 and 2; Figure 3), but only the latter varied between studied locations (Table 2). The mean value of daily expenditure (± standard error) for SHOU was US$14.24 (±4.22), while Tourists spent on average US$23.93 (±8.09) per day. SHOU had more than twice (22.4%) the number of respondents spending <US$ 4.80/day in comparison to Tourists (9.6%), while Tourists had more than twice (23%) the number of

respondents spending >US$24.00/day in relation to SHOU (9.1%; Tables 1 and 2; Figure 3). From respondents stating that they came more than once to the beach, SHOU is represented by 58.4%. While respondents affirming that they came only once to the beach, the most part (62%) was taken by Tourists (Table 1 and 2; Figure 3). Comparing beaches, most visitors that indicated visiting only once a year were in Ipanema (63.6%), while visitors that stated visiting between two and ten, and more than ten times were in Pontal do Sul, 63.6% and 80%, respectively.

The period of permanence differed regarding beach users' group and marginally between beaches (Tables 1 and 2; Figure 3). The mean value (± standard error) of period of permanence for SHOU was 6.8 (± 0.85) days and for Tourists was 3.5 (± 0.34) days. From respondents, who affirmed staying 1 day, 86.3% were Tourists. On the other hand, SHOU dominated all the other categories of answers to number of days. Respondents who stated that they stayed between two and ten days (67%), and for periods greater than 10 days (95%) were SHOU. The marginal difference between beaches is associated to a greater number of respondents staying 1 day or more than ten days in Pontal do Sul, 63.6% and 70% respectively.

Table 1. Comparisons of respondents' perceptions between beach users' groups (Tourist and Second Home Owners/Users - SHOU) and beaches (Pontal do Sul and Ipanema), in combination. Results of the overall chi-squared contingency table (χ^2), degrees of freedom (df), p-value (p) and the total absolute number of answers analyzed (n).

	χ^2	*df*	*p*	*n*
Income	4.82	6	NS	218
Level of education	23.93	12	<0.05	266
Daily expenditure	19.05	6	<0.01	202
Frequency of trips	34.54	6	<0.001	258
Period of permanence	43.97	6	<0.001	209
Actual scenario	20.63	18	NS	239
Overall beach quality	37.10	12	<0.001	264
Marine debris origins	54.03	16	<0.001	330
Deterring scenario	14.77	18	NS	269

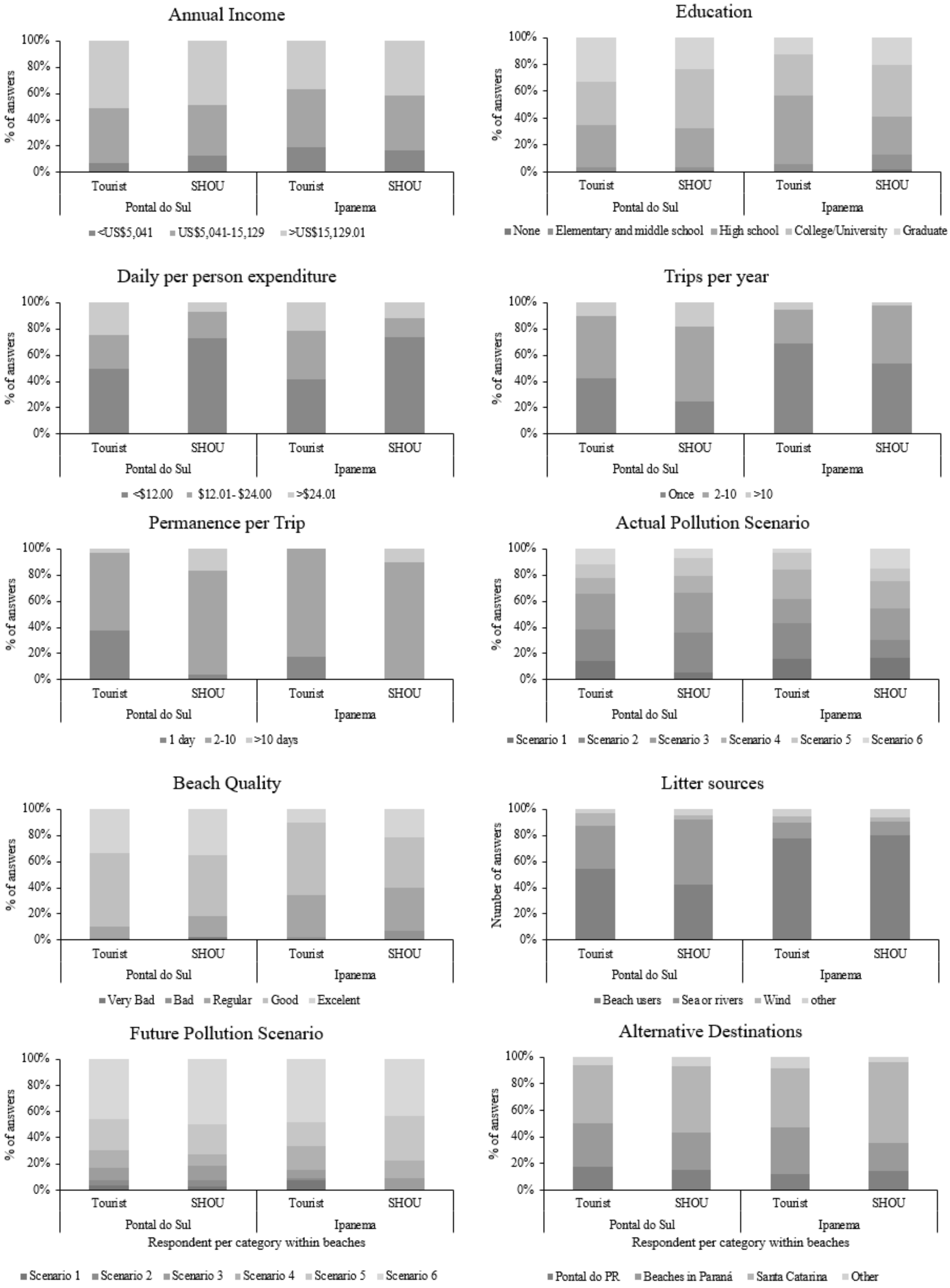

Figure 3. Comparisons of respondents' perceptions (y axis, in percentage of answers) between beach users' groups (Tourist and Second Home Owners/Users - SHOU) and beaches (Pontal do Sul and Ipanema). Results of the chi-squared tests of independence for these data are presented in Table 1 and 2. Refer to text to details on answers categories.

The actual scenario of marine litter pollution was not influenced by respondents' category or by the place where they were interviewed (Table 1; Figure 3). However, beachgoers elicited with more frequency Scenario 2 (24.6%) and Scenario 3 (25%) for the actual beach pollution (actual scenario "goodness-of-fit": χ^2=30.81, df=5, p<0.001 n=236; Figure 4). It means that users perceive that Paraná beaches are facing a pollution level between 1.5 and 3 items per linear beach metre or 1 to 2.5 items.m^{-2}. A low proportion of respondents considered that beaches are facing Scenario 6 (8.9%). Thus, it is assumed that users refuse the idea that beaches face such a level of pollution (more than 30 items per linear meter or 15 items/m^{-2}).

The perception of overall beach quality, with a focus on the whole setting of the beach, was significantly different between Pontal do Sul and Ipanema (Table 1 and 2; Figure 3). Ipanema was mostly evaluated as 'Regular' (32.3%) to 'Good' (47.7%), while Pontal do Sul was mostly considered 'Good' (50.7%) or 'Excellent' (34.3%). There was also a significant difference in perception regarding the most probable origin of marine debris between beaches but not user groups (Tables 1 and 2). The most common chosen option in both beaches was *"left by beach users"*, representing 77.5% of the answers given in Ipanema and 45.8% in Pontal do Sul. However, the answer *"brought by the sea"* was nearly four times more frequent in Pontal do Sul (35.3%) than in Ipanema (8.9%; Figure 3).

4.2 Users' perception regarding deterring scenarios

The scenario in which users would be deterred of visiting the beach and the choice of alternative beaches was not influenced by neither respondent category nor the beach they were interviewed (Table 1; Figure 3). Even though no significant differences were observed between users' groups or beaches regarding deterring scenarios (Table 1), respondents showed preferences for eliciting the scenario when they would be deterred (deterring scenario "good-of-fit": χ^2=193.78 df=5 p<0.001; Figure 4). According to the perception of users, some (20.4%) would be deterred if scenario 4 (or lower) was observed, which represents a maximum concentration of 5 items per linear beach metre (2.5 items/m^2). If pollution reached a concentration of approximately 12 items per linear beach metre (6 items/m^2) an additional 18.3% would be deterred. It represents an added total of 38.7% of beach users being deterred due to scenario 5 or lower. Approximately 45.2% stated that they would be deterred especially if pollution reached scenario 6.

Consequently, scenario 6 (more than 30 items per linear beach metre or 15 items/m^2), would deter an accumulated 83.9% of the total of beach users of Pontal do Paraná. A relevant proportion of respondents (16.1%) affirmed that would not be deterred in any of the cases ("none" answers). Also, there were three respondents who selected Scenario 1 (totally clean) as the deterring scenario. These questionnaires were excluded from the scenarios' choice analysis and the calculation of the economic effects, since the term 'deterring' to these users may not be related to the presence of beach marine debris, or respondents may have confused scenarios when choosing the answers.

Beach or beach users' group did not influence results of the comparison of actual and deterring scenarios (χ^2=14.31, df=15, n=196). Results indicated that if the beach experienced an increase of at least 2 scenarios/deltas of pollution (goodness-of-fit: χ^2=15.26, df=5, n=196), most of the beach users (65.8%) would be deterred (Figure 4). For the present, it represents a mean (±standard error) increasing of 13.1 items (± 1.26) per linear metre.

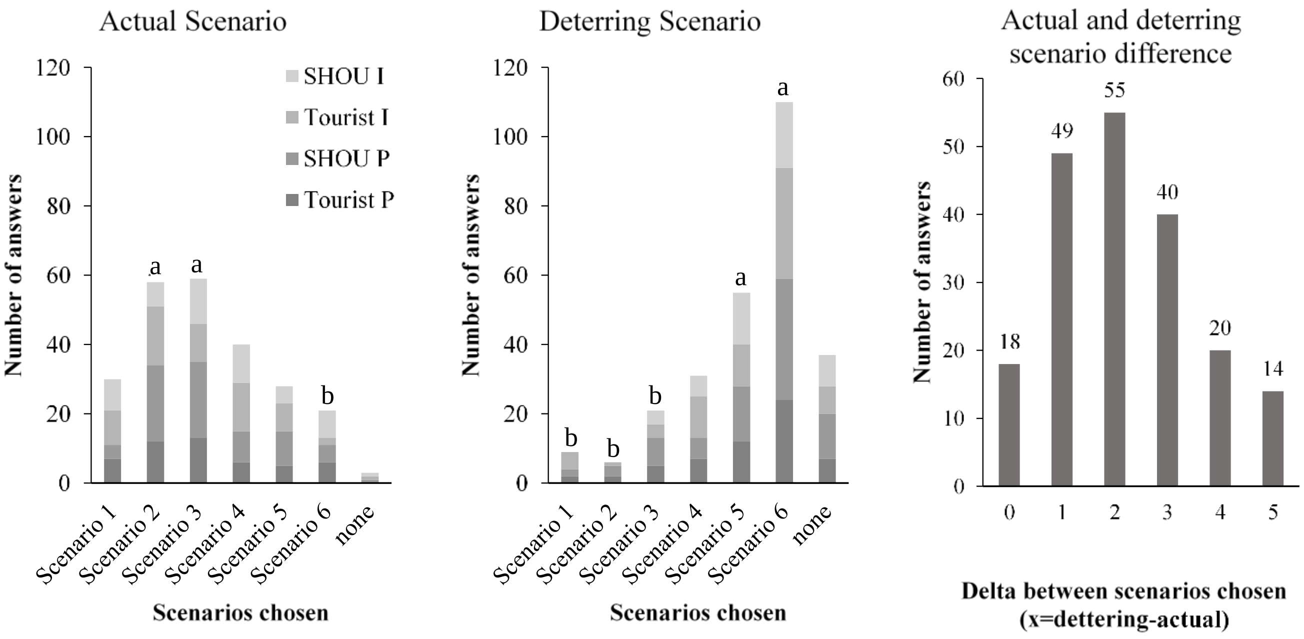

Figure 4. Marine litter pollution scenarios. "Actual Scenario" - Absolute number of respondents which recognized the actual scenario (n=239) of the beach per scenario; "none" answers (3) represent respondents that considered that none of the pictures represented the actual scenario of pollution. "Deterring Scenarios" – the number of respondents regarding which scenario the respondent would be discouraged from visiting (n=269). "None" answers (37) represents individuals that would not be deterred in any of the pollution scenarios presented. Tourist P = Tourist of Pontal do Sul; SHOU P = Second Home Owner/User of Pontal do Sul; Tourist I = Tourist of Ipanema; SHOU I = Second home Owner/User of Ipanema are respective for both actual and deterring scenarios. "a" represents scenarios more frequently chosen and "b" scenarios less frequently chosen according chi-squared goodness-of-fit tests, which means that the observed value for the specific answer was different (lower or greater) than the expected value for each question (equal to all answers; α=0.05). "None" answers were disregarded for these chi-tests of both scenarios choice. "Actual and deterring scenario difference" – the result of the subtraction of the actual scenario number from the deterring scenario number (Delta, x axis).

Users which indicated other beaches in Pontal do Paraná (43) as alternative destinations represented 14.7%. The majority of Tourists (85.4%) and SHOU (85.1%) stated that they would choose a destination other than Pontal do Paraná, with 25% indicating other beaches within the State of Paraná (73). 51.7% of Tourists and 59.6% of SHOU stated that they would choose a destination other than the Paraná State coast. Most of the respondents (143; 49%) indicated Santa Catarina, the neighboring state, as the most probable alternative destination. From the respondents that answered '*others*' (19), only ten indicated the probable destination they would choose. Most respondents (9) indicated the Brazilian northeastern coast and only one indicated São Paulo, another neighboring State, as their probable destinations (Figures 3 and 5).

4.3 Potential Economic Effects

The choice of deterring scenarios was not influenced by beach user category or the beach of the respondent (Table 1; Figure 3). However economic effects due to SHOU deterring were greater than Tourist deterring for all calculated losses and considering both conservative and extended estimates, differently than previously hypothesized (Table 3). Even though Tourists showed a higher per person daily expenditure, SHOU were greater in number and showed a longer period of permanence. Estimates considered the most chosen deterring scenarios, which consequently could generate a potential loss of tourism revenue (Scenarios 5 and 6). On top of which, scenario 4 was also included in the calculations. This inclusion occurred by the fact that there is evidence that the quantities of items found in the study area are nearer to 6.3 marine debris items per linear metre of beach, in Pontal do Sul, and approximately 6.9 in a nearby area of Ipanema [58]. These findings indicate that the actual year-round marine debris pollution of these beaches is probably between Scenarios 4 and 5. It means that, if beach cleaning is not undertaken, then this is the scenario users will probably be facing. The economic effects are presented cumulatively so that the value and percentages for "scenario 4" (table 3), for instance, represents the cumulative number of users deterred in scenarios 2, 3 and 4. Scenario 5, is also presented considering accumulation from all less polluted scenarios in addition to deterring new individuals, whilst scenario 6 present the whole pool of deterred users.

If Scenario 4 took place 19.9% of the Tourists and 23.3% of the SHOU would be already discouraged and approximately 20.4% of the beach users would be already discouraged.

This impact would represent a potential decrease in total incomes from tourism varying from 4% to 10.5% for Pontal do Paraná municipality (Figure 5). Decreased Tourism Revenue (DTR) for Pontal do Paraná is estimated from US$880,000 to US$2.29 million considering a conservative (~21% of visitors) and an extended estimate (~55% of visitors), respectively (Table 3; Figure 5). For the State of Paraná, the DTR estimates varied from US$600,000 to US$1.56 million, considering the same estimates, respectively (Figure 5).

Table 3. Results of calculation of the economic effects. Results are presented considering two estimates of number of beach goers: a conservative, where 21.2% of visitors are considered beach goers and an extended one, which considers 55.1%. The calculation of each pollution scenario considers that users deterred under lower levels of pollution, would be also deterred in consecutive more polluted scenarios. Values are cumulative presented and results were rounded to the nearest thousand.

Number of beach goers		*Conservative (21.2%)*		*Extended (55.1%)*	
Pollution Scenario	User group	City	State	City	State
5 items per linear metre (Scenario 4 or lower)	Tourist	$ 210,000	$ 130,000	$ 540,000	$ 330,000
	SHOU	$ 670,000	$ 470,000	$ 1,750,000	$ 1,230,000
	Total	**$ 880,000**	**$ 600,000**	**$ 2,290,000**	**$ 1,560,000**
12 items per linear metre (Scenario 5 or lower)	Tourist	$ 450,000	$ 270,000	$ 1,160,000	$ 705,000
	SHOU	$ 1,200,000	$ 840,000	$ 3,120,000	$ 2,180,000
	Total	**$ 1,650,000**	**$ 1,110,000**	**$ 4,280,000**	**$ 2,885,000**
30 items per linear metre (Scenario)	Tourist	$ 870,000	$ 520,000	$ 2,250,000	$ 1,360,000
	SHOU	$ 2,400,000	$ 1,700,000	$ 6,280,000	$ 4,400,000
	Total	**$ 3,270,000**	**$ 2,220,000**	**$ 8,530,000**	**$ 5,760,000**

If scenario 5 took place an additional 22.8% of the Tourists and 18% of SHOU would be deterred from visiting. This would represent a total discouragement of 38.7% of the beach users, considering the percentage already indicated in Scenario 4. Such a figure would suggest that 7.5% and 19.6% from the total visitors' expenditures would be lost to the municipality, considering a conservative and extended estimate, respectively. Accumulated DTR would vary from US$1.65 million up to US$4.28 million to the municipality and from US$1.11 million to US$2.88 million to the Coastal tourism of State of Paraná (Figure 5).

In the worst case, scenario 6, a deterrence of an additional 39.7% of Tourists and 42.1% of SHOU would be observed. That would represent a discouragement of 83.9% of beach users. The total loss for tourism income is estimated to vary from 15% to 39.1% for the municipality. Considering conservative and extended estimates, respectively, that would represent a decrease in tourism revenue varying from US$3.27 million to US$8.53 million for the municipality of Pontal do Paraná and from US$2.22 million to US$5.76 million to the Coast of the State of Paraná (Figure 5).

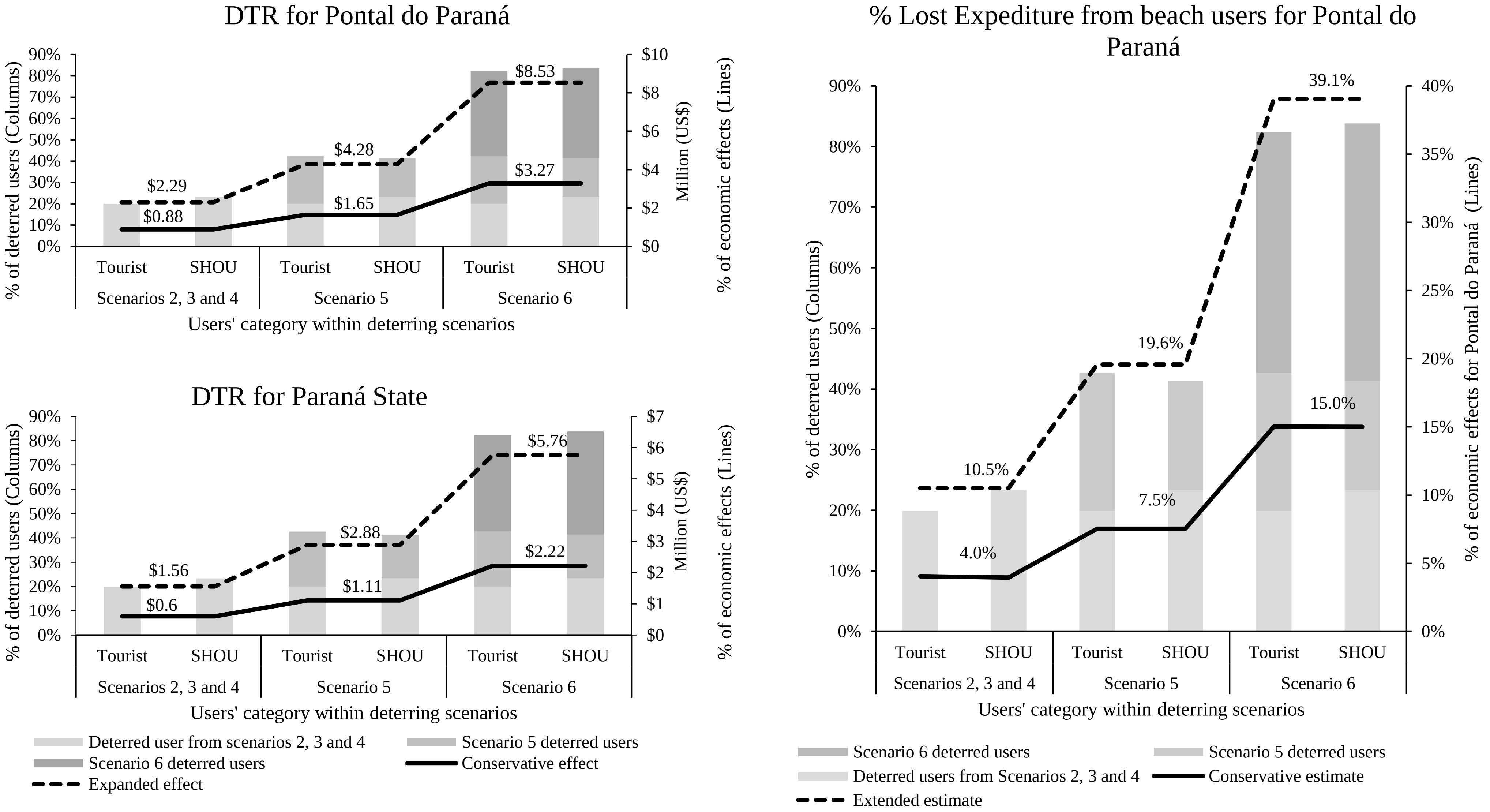

Figure 5. Decreased Tourism Revenues (DTR) for the municipality of Pontal do Paraná (top left) and the State of Paraná (bottom left) due to beach pollution increasing. Percentage of DRT for the municipality (right). Scenarios were cumulatively analyzed for beach users' groups (Tourist and SHOU) within each scenario. Scenario 4 represents all users which chose deterring scenarios 2, 3 or 4 (light grey columns); Deterring Scenario 5 represents users already deterred in lower scenarios (light grey) in addition to deterred users in scenario 5 (median grey columns) and Scenario 6 new deterred users (dark grey columns) were added to the previous.

5. Discussion

5.1 Socio-economic characteristics of beach users and perception

As predicted in Hypothesis I, differences in socio-economic characteristics were observed among beach users' groups (daily per person expenditure, frequency of trips and permanence period) and between the beaches (Education levels and frequency of trips). Education levels, only marginally segregated beach users' groups while period of permanence marginally segregated beaches. Income did not differentiate beach users or perception over the beach environment. These results proved that there exist different groups within beach users, namely: SHOU and Tourists.

Findings revealed that the socio-economic characteristics, *i.e.* traveling behavior, seem to be especially useful for segregating beach users' groups. Findings that second home owners/users travel more frequently and stay longer in the destination, even spending less in a daily basis, supports such an assumption. This approach to differentiate groups, might be used additionally in association with others routinely adopted to characterize beach users, such as residents and non-residents [25] or locals and foreigners [13].

In fact, results indicating that SHOU possess a different pattern in comparison to non-recurrent tourists are also in accordance to previous literature about repeat visitors. For instance, in the Balearic Islands (Spain), results indicated that SHOU may have their expectations truly satisfied by the destination and develop a feeling of loyalty to the place [62]. It is possible to infer that this might be the reason for such repeated and longer visits to the same site. On the other hand, it was observed that a significant proportion of users spend only one day at the beach (25.2%) within Tourist groups (19). Such information suggests the possibility of a complimentary refinement in segregating users within the Tourist group. There may be another category of user, *i.e.* the "day-use" beach visitor, which was not investigated under the scope of the present study, but might also represent another segregating factor for beach users.

Nevertheless, the merit of the present work is not limited to finding evidence of differences among groups, it also reinforced the view that environmental beach settings can partially explain different perceptions along the estuarine gradient [30].

Also, evidence suggest that users' perception of actual pollution scenario, from both beaches is not in consonance with the year-round pollution estimates. An *a priori* assumption was that users from a worse evaluated beach would consider it more polluted. In fact, users from both beaches indicated that pollution levels would be ranging from 1.5 to 3 items per linear metre while evidence suggest levels of pollution nearly in accord to scenarios 4 and 5. Accordingly, beach users seem to perceive less than half of the actual number of marine debris items. Considering both, evidences, two hypotheses can be proposed: is it a lack of awareness for users or they are used to higher pollution levels; or are beach cleaning efforts so efficient as to reduce pollution scenarios during the vacation period? Evidence indicates that the second option is more likely to be in place. First, there is a long-term programme of the State Government for awareness on litter collection (Paraná Verão), this programme distributes plastic bags and fliers to make beachgoers aware about littering and install rubbish bins along the beaches. Secondly, the State Government invests in cleaning efforts during summer periods (Further discussed below).

The perception of users from Ipanema about overall beach quality was worse than in Pontal do Sul. As mentioned above, it may be related to the fact that beach users have rated the overall quality of the beach they were in. Consequently, it is possible that several factors may have influenced respondents' perception. Not only crowding, which is a factor supposed to reduce beach attractiveness [12], but also water quality/clarity, lack of infra-structure and marine litter may have an important role in their perception, since most of these were already mentioned as significant problems of Ipanema beach [30].

Differences observed in eliciting marine debris origins also revealed the importance of the environmental setting over the users' perception. For instance, by attributing a higher proportional importance of "marine and riverine" sources of litter, users of Pontal do Sul reinforced that the proximity to the outlet might have influenced their perception. Pontal do Sul has the estuary as part of its scenery, while Ipanema is distant from the outlet and houses larger crowds. Crowding may also be the cause for users of Ipanema attributing, in a greater proportion, litter origin to beach users. Both assumptions, are also based on a known pattern that scenery plays an important role over beach users [5,63]. Since perception is both a reaction of senses to external stimuli and an intentional action where some phenomena are registered or blocked [35], it is expected that scenic patterns play a significant role as external stimulus. Those are inferences about the patterns observed, but there are certainly other aspects that influence users' perception and users' attitudes, such as, the importance of previous personal experiences [62] and overall travel satisfaction [15]. However, evaluating all possible influences was not under the scope of the present study. Nevertheless, the present results reinforce the viewpoint that groups with diverse socio-economic characteristics, visiting beaches with different physiographical settings, all have different perceptions of the environment.

Even though Hypothesis I was fully corroborated, complementary assumptions based on the present differences must be carefully analyzed. For instance, there is literature discussing socio-economic aspects influencing beach choice [5,13,30,64], but there is little information about the influence of socio-economic aspects over the environmental perception of beach users. In a thorough review of marine debris studies in Latin America, only three out of 70 studies, dealt with knowledge/perception of beach users [26]. The present findings indicate that testing similar hypotheses in different coastal settings is essential. Establishing a corpus of literature about beach users' socio-economic groupings, public perception and sense of place applied to marine debris is urgently needed.

5.2 Users' perception regarding deterring scenarios

Even though there is a clear distinction among groups and beaches, findings suggest that the selection of "a deterring scenario", defined by number of items/m^2 that cause users to change vacation destination, did not depend on users' groups or on beaches. Consequently, Hypothesis II, which stated that tourists would be dissuaded by smaller amounts of litter and that beaches with worse actual beach scenario would present users with higher tolerance to future litter scenarios, was refused.

An *a priori* assumption considered that the non-recurrent tourist show a weaker connection with the place they are visiting [32] and because of that they would be easily deterred from visiting. The probable expectation that scenarios of lower debris concentrations would be chosen more frequently by this group than SHOU, underestimates the previously stated role of environmental quality for second home owners [33]. It seems that similar to a study case in South Africa (Hartbeespoort), environmental quality is an important reason for owning a second home [34] in Pontal do Paraná, Brazil. Findings suggest that second home owners recurrently visit the beaches where they have homes because of satisfaction instead of by *inertia*, as previously hypothesized [62]. It seems that it is not the case and if SHOU would be deterred, they would probable behave similarly to Tourists. These outcomes also suggest that the quantity of marine debris is a common concern for all visitors of this estuarine gradient.

Results reinforce that this pattern is valid for similar estuarine gradients, in coastal areas of several countries [13,17,18,21,65].

It is worth mentioning that when beach users picked a deterring scenario while filling the questionnaire, represents an intention. It means that there is a possibility that respondents may be diverted from their intention to stop visiting a certain site, *i.e.* due to marine debris, especially depending on external influences. The attitude is a cultural posture supported by a series of experiences [35] and some of these experiences may influence their effective future discouragement when deciding the next trip destination. In short, it means that effective discouragement may vary and it is possible that with these results, a worst-case scenario setting could be envisaged. Recognizing such a limitation, evidence suggesting that marine litter, by itself, has the potential to deter beach users is revealing. It also reinforces the findings of Balance *et al.* (2000), since figures for deterrence due to marine debris in this estuarine region are above 85% of the beach users, in cases where 15 items/m^2 were observed. The transboundary character of marine debris is similarly reinforced by the evidence that most of those deterred users (above 50%) would chose alternative destinations out of the state.

This high percentage of deterred beach users is a clear setback for local and state authorities. Respondents showed a clear preference for destinations in the neighboring state of Santa Catarina, irrespectively if they were Tourists or SHOU. This is a regionally known pattern since the short Paraná coastline makes the longer and more scenically diverse coastline of Santa Catarina [66] an appealing destination. Consequently, Hypotheses II and III were refused since no differences were observed between SHOU and Tourists choices of alternative destinations. It emphasizes that the economic effects appear to be a regional concern.

Even though choice of alternative destinations was not influenced by the beach or by beach users' group, it is noteworthy that it might have happened due to different reasons for each group. As expected and previously hypothesized, non-recurrent tourists show a lower sense of place and they tend to select other destinations. However, a hypothesis may be proposed for such unexpected SHOU behavior. It is possible that with a diminished attractiveness, a lower sense of place may have arisen [34]. As a consequence, SHOU may accept to have to travel longer distances, spending more for reaching cleaner beaches [12], with an additional (positive) outcome, *i.e.* the opportunity of renting their properties to other visitors. Even though, such supposition is in accord with previous literature, testing complimentary hypothesis in the future, *i.e.* the potential attitudes of SHOU to their properties in such a hypothetical situation (selling, renting or keeping), would be elucidative. Independently of the reason of such behavior, if this future scenario took place, it could represent the declining of the district [67] and a consequent decreased tourism revenue (DRT) might be observed in Pontal do Paraná and in Paraná Coast.

5.3 Potential economic effects

Regarding projections of DTR, as expected, a significant number of users would be deterred due to marine debris. However, the user's group did not influence deterring scenario choices. Consequently, Hypothesis IV, which considered that the negative economic effect would be dependent on user's group (T>SHOU), was refused. Opposite to what was expected, SHOU presented a higher contribution to the potential economic losses due to a greater proportion of individuals (70.5%) and a greater period of permanence per trip (6.8 days) if compared to tourists (29.5% and 3.5 days, respectively). Even disregarding the influence of a greater frequency of traveling, it appears that SHOU spend approximately US$96.83 per trip while Tourists US$83.75. That is very revealing because SHOU is established as the most significant income for the municipality. Consequently, if this beach user group chooses other destinations to spend their vacations, a reduction of incomes might be severe for the municipality (lost expenses of 39.1% of the total incomes from tourism). This might be a pattern to be tested in other coastal cities where second residences play a significant role. It should be mentioned that estimates of lost expenses (%) presented here assumed that other visitors of Pontal do Paraná, which are not necessarily beach users, show a similar daily expense pattern to beach users. However, differences between these groups might exist. Since this analysis was above the scope of the present study, the best approximation was done with the available information and a thorough characterization of visitors of the Coast of Paraná. Nevertheless, these percentages might be considered an adequate approximation and may be supportive for proposing adequate management measures.

Indeed, the present results pose clear challenges to managers, since beaches especially to second home owners/users, appear to be a very important asset. It is known that marine debris is a growing threat [68] and coastal areas will keep increasing in population numbers [69]. Consequently, potential loss expenses may occur due to marine debris, in case beach pollution is not controlled and maintained under acceptable thresholds. Findings revealed a probable threshold to beach users for marine debris, represented by a greater selection of scenarios 5 and 6. It suggests, especially considering the worst case, that a greater part of users (83.6%) would not tolerate pollution levels above 30 items per linear metre (15 items/m^2). The numbers estimated for the municipality of Pontal do Paraná as potential lost expenses are comparable to another previous study [44], which found similar individual economic effects (Table 4).

Results for the most conservative scenario of economic effects to Pontal do Paraná (~US$3.2 million) indicate an average potential impact of US$64 per decreased visitor, a value similar to the US$66 estimated by Jang *et al.* (2014) [44] for Geoje Islands (Table 4). Comparisons of these values to the costs of cleaning will guide the trade-off between new preventive approaches for marine debris management [70] or if palliative beach cleaning will keep on taking place.

Table 4. Comparison with other similar case studies, which estimated lost expenses due to marine debris.

Case	***Lost expenses from debris (million US$) (a)***	***Decreased visitors (million man-days) (b)***	***Lost expenses per visitor (US$) (c=a/b)***
New York Bight [a]	2788	72	39
Geoje Island, South Korea [b]	37	0.56	66
This Study	3.2	0.05 [c]	64

[a] Ofiara and Brown (1999) in 1987. Loss expense extracted by Jang *et al.* (2014)

[b] Jang *et al.* (2014) considering loss expense due to marine debris severe event in 2011.

[c] Considering the most conservative potential decreased number of beach user (22.1%) for scenario 6 in 2015

The State Government invest exclusively during the period of summer vacations an amount of US$432,000 (R$1,8million) for additional waste collection and treatment in Pontal do Paraná [56]. This amount is complemented by US$16,300 (R$49,000) from the local administration [56]. It is estimated that out of this amount, nearly US$200,000 is spent exclusively on beach cleaning. Approximately 40 people collect on a daily basis for a period of 53 days, *circa* 8 m^3 of anthropogenic and natural debris along nearly 25 kilometres of beaches of Pontal do Paraná (Jefferson Scheifer, *pers. comm.*). Considering that the most conservative scenario estimates 49,800 beach users in Pontal do Paraná this additional cost of cleaning represents approximately US$4 per beach user.

Compared to the potential lost expenses (US$64), cleaning cost is a small part (6.2%) mainly sponsored by the State. This is a lower proportion compared to the one observed by Ballance *et al.* (2000) that estimated costs of cleaning beaches represented approximately 20% of the total recreational value in the Cape Peninsula. Considering the present set-up in Pontal do Paraná, it indicates that palliative solutions will keep being prioritized.

5.4 Implications for management and policy

Findings pose practical implications for management and policy makers of the region. A previous study indicated the existence of a transboundary exportation of marine debris between neighboring municipalities, where Pontal do Paraná is the potential sink of items originated in municipalities of the innermost the Paranaguá Estuarine Complex [55].

According to Brazilian Law, there exist watershed' committees which are responsible for debating and advising institutions for acting in a transboundary level, considering the whole watershed [71]. Even though, most of the aspects approached by these committees focuses on water quality, marine litter should become a concern. Therefore, assessment of marine litter inputs, not only in the PEC but also in other regions impacted by litter, may become part of watershed action plans. Such an approach may facilitate decision making regarding its prevention at source [55].

In addition, findings reiterate the importance of the full implementation of the Federal Waste Management Policy [72], since the mismanaged waste of the PEC may represent a significant part of the litter that impacts on the tourist zone of the State [55]. This Policy supports the integration of municipalities, through the establishment of consortiums for the implementation of shared landfills, besides other tools also proposed by the Honolulu Strategy (e.g., circular economy, recycling, and education). Adopting a similar approach could be beneficial for preventing marine debris generation, especially for the municipalities, which are sources or sinks within the same watershed.

Finally, it is only through integrated and transboundary planning that it would be possible for adequate management of the sources and sinks of litter. Such approaches can promote the avoidance of impacts over beach users and municipalities, and the application of resources in preventive strategies rather than palliative actions.

6. Conclusions

Results indicate that Second Home Owners/Users and Tourists are effectively distinguishable groups of beach users due to their travelling habits. Tourist spend proportionally more on a daily basis, however SHOU travel more frequently and stay longer in the destination. Findings suggest that perception about the beach environment varied according to geographical location. The oceanic beach, Ipanema, was rated worse by its users, while the estuarine beach, Pontal do Sul, showed a greater proportion of respondents recognizing the influence of marine and riverine litter influxes. These associated results confirm the proposed pattern that groups with different socio-economic characteristics in different beaches with distinct environmental setting differently perceive the beach environment. Hypothesis I was therefore corroborated.

Tourists were not dissuaded by smaller amounts of litter than SHOU and user's tolerance to future litter pollution scenarios was not influenced by the user category or the beach they were at. Scenario 6 was the most commonly chosen deterring scenario, irrespective of the beach where nearly 85% of beach goers would be deterred. Hypothesis II was refuted.

Also, no differences were observed regarding possible alternative destinations. In the main the stated option was to travel to destinations out of the State of Paraná reinforcing the transboundary component of marine debris, also regarding beach users' migration. Consequently, Hypothesis III was not corroborated.

Finally, it was concluded that the total amount of lost expenditure is greater from SHOU, when compared to Tourists since they are greater in user numbers and stay longer. Hypothesis IV was also refused. In case the worst scenario of pollution took place in Pontal do Paraná (30 item per linear meter or 15 items /m^2), the annual economic effects would range from US$ 3.2 to US$8.5 million, while in the state of Paraná these figures varied from US$ 2.2 to US$ 5.7 million. The proportion of loss from tourism income would range from 15% to 39.1% for the municipality of Pontal do Paraná. For 2015, the costs of beach cleaning, mostly paid by the state, are nearly 6.2% of the potential economic losses, consequently it is inferred that palliative measures will still be prioritized in relation to structuring and introducing long-term preventive measures that involve a transboundary approach. However, results reiterate the importance of adopting integrated and transboundary policies and strategies for overcoming the marine debris threat, which appeared to be a risk for both the environment and for coastal socio-economics.

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Supplementary Information A - Questionnaire

1) Do you own a house in this beach or are you stay in a relative's house (without paying a rent?) ( ) No ( ) Yes what is the approximate size of the house? _______m^2

2) What is the monthly income of your house?
( )less than R$788,00 ( )between R$789,00 and R$1576,00 ( ) between R$1577,00 and R$3152,00
( ) between R$3153,00 and R$4728,00 ( ) between R$4729,00 and R$6304,00 ( )more than R$6305,00

3) What is your educational level?
( )None ( )Fundamental ( )high school ( )under graduate ( )specialization ( )masters ( ) Phd

4) What is your estimated daily cost at the beach including all expenditures (food, renting, buying things while enjoying the beach and other expenses)? R$_____________

5) How many persons are included in the value stated in the previous answer? ____

6) During the last year, how many trips did you make to this beach? *"a trip" is considered as traveling from your home city to this beach*
( )once ( )2-5 times ( )6-10 times ( )11-15 times
( )16-20 times ( )21-25 times ( )More than 26 times

7) How many days do you stay in this beach in each trip? ___

8) Which scenario, at the end of the questionnaire, better represents the actual scenario of the present beach, regarding presence of litter? Choose only one option. (Figure 6)
( )scenario 1 ( )scenario 2 ( )scenario 3 ( )scenario 4 ( )scenario 5 ( )scenario 6 ( ) none of them

9) How do you evaluate this beach? Elicit an option from 1 to 5, where 1 represents that the beach is "very bad" and 5 it is "excellent".

	very bad	bad	indifferent	good	excellent
This beach is...	1	2	3	4	5

10) In your opinion, which is the main source of litter found in this beach? Choose only one option
( )Left by beach users ( )brought by wind ( )through the sea ( )through rivers
( )Others (which source?)____

11) Considering the same scenarios, in which of them would you be deterred of coming to this beach? Choose only one option (1 to 6) – (Figure 6)
( )scenario 1 ( )scenario 2 ( )scenario 3 ( )scenario 4 ( )scenario 5 ( )scenario 6 ( ) I would not stop coming to this beach

12) In case you would stop coming to this beach, what would be the most probable alternative beach you would choose? Choose only one option
( ) Other beaches of Pontal do Paraná municipality ( ) Matinhos/Caiobá ( ) Guaratuba
( ) Paranaguá (do Mel Island) ( ) Beaches of Santa Catarina state ( ) Other beaches. which? _______________

Supplementary Information B – Questions and analysis

6.1 Socio-economic characteristics of beach users and perception

The first definition of the questionnaire was the user category. The answer to a closed-ended question (with only a "yes" or "no" answers) regarding the type of accommodation determined to which beach users' category the respondent would be attributed. The respondent was categorized as a Second Home Owner or User (SHOU) if the answer "yes" was given to the question *"Do you own a house in this beach or are you staying in a relative's or friend's house (i.e. without paying rental)?"* If the answer was "no", respondent was categorized as a Tourist. Also, if the respondents have not answered to that question or if they affirmed being a year-round resident, they were excluded from the analysis.

To determine socio-economic characteristics of beach users, respondents were asked to inform their monthly income, level of education, approximately daily expenditure – including also the value attributed to accommodation, if that was the case, frequency of trips during the last 12 months and the estimated number of days they stay at the beach per trip.

Questions regarding income, education levels and frequency of trips were closed-ended and respondents had to elicit a single most adequate option. For each aspect, depending on the answer, respondents were included in a specific class. For income, they were divided in three classes: earning less than 2 minimum wages per month (yearly incomes lower than US$ 5,041.94); more than 2 but less than 6 (between US$5,041.95 and US$15,129.01) and more than 6 minimum wages per month (above US$ 15,129.02). For establishing these classes, the monthly Brazilian minimum wage of 2016 Fiscal Year was considered, which is approximately US$211. For educational levels, there were five classes (None; Elementary and Middle School; High School; College/University; and Graduate). Regarding frequency of trips, three classes were created (once; between two and ten; and more than ten trips per year).

For establishing daily per person expenditure, each respondent was invited to answer two open-ended questions. In the first, the respondent estimated the daily expenditure, including food, lodging/accommodation, buying things while enjoying the beach and other expenses. In the second, the respondent stated the number of people included in the previously informed value. Dividing the daily cost by the number of individuals, the daily per person expenditure was estimated. Respondents were grouped in three categories (spending less than US$ 4.80/day; between US$ 4.80 and US$24.00 and more than US$24.00/day). When no answer was given to one of these questions, the corresponding questionnaire was excluded from calculation of the mean daily per person expenditure.

For determining mean permanence period, respondents could answer an open-ended question, informing the mean number of days spent on that site per trip. When respondents specified spending also an extra longer period, on top of the informed answer, *i.e.* working holidays or family's vacations, the number of days of this period was divided by the number of trips they gave to obtain a mean value for being added to the "per trip" mean period. For example, a respondent stated visiting the beach five times per year, staying two days per trip. However, this same respondent also informed that he spent the vacation time at the site, which is a fifteen-day period. For determining the mean number of days per trip for this respondent, this vacation period (15 days) was divided by the number of trips per year (5 trips) and the result (3 days) was added to the informed mean per trip period (2 days). The mean number of days of permanence per trip for this respondent was 5 days. Three classes of permanence were created (one day; between two and ten; more than 10 days of permanence per trip). The mean number of days obtained through this question for SHOU (6.8) and Tourists (3.5) were used for calculating economic effects (further explained in section 3.4, regarding item "d" of the formulae).

To obtain user perception about the beach environment, respondents were asked to answer three questions. In the first, the users elicited one scenario (named actual scenario), among six options and an additional "none" option, that better represented the actual condition of the beach they were at, regarding the presence of litter. This question specifically regards the presence of beach litter. The six photographs represented different scenarios of number/density of marine debris in an area of approximately 4 m^2 (density= 0; 1; 1.5; 2.5; 6; 15 $items.m^{-2}$ or quantities per linear meter of beach=0; 1.5; 3; 5; 12; 30 $items.m^{-1}$; Figure 2). Pictures were included as a visual support, since usage of photographs has been tested in previous studies and considered a useful technique for assessing beach users' views on litter pollution [18,73]. Scenarios in the pictures were created using marine debris items collected from a nearby area. Photographs were taken on the beach, with an uneven disposition of items, simulating a real setting (Figure 6).

Regarding perception about the overall quality of the beach, which is different from the actual scenario of litter pollution, they were invited to answer a close-ended question where they were required to pick the most adequate adjective to the site (five options from "very bad" to "excellent"). This question aimed to gather the perception of users about the overall setting of the beach. Several aspects of the beach might have influenced users while answering this question to determine overall beach quality, which are not deeply scrutinized in the present study and might include, but are not limited to: infrastructure and amenities, crowding, safety, water clarity and quality and so on. After thought a single rate should be stated by the respondent. Marine debris may influence such evaluations as well, but this question clearly differs from the actual scenario, since it aimed to understand the overall quality of the beach, while the former focused exclusively to "marine debris" and called for picture support. The last question was a close-ended where some respondents selected more than one answer about their perception of the main litter sources found at the beach they were at (five options). The last alternative to this question ("*others*") allowed respondents to describe another source not included in the list. The answers to the questions above (socio-economic profile and perception on beach environment) composed the set of data to test Hypothesis I.

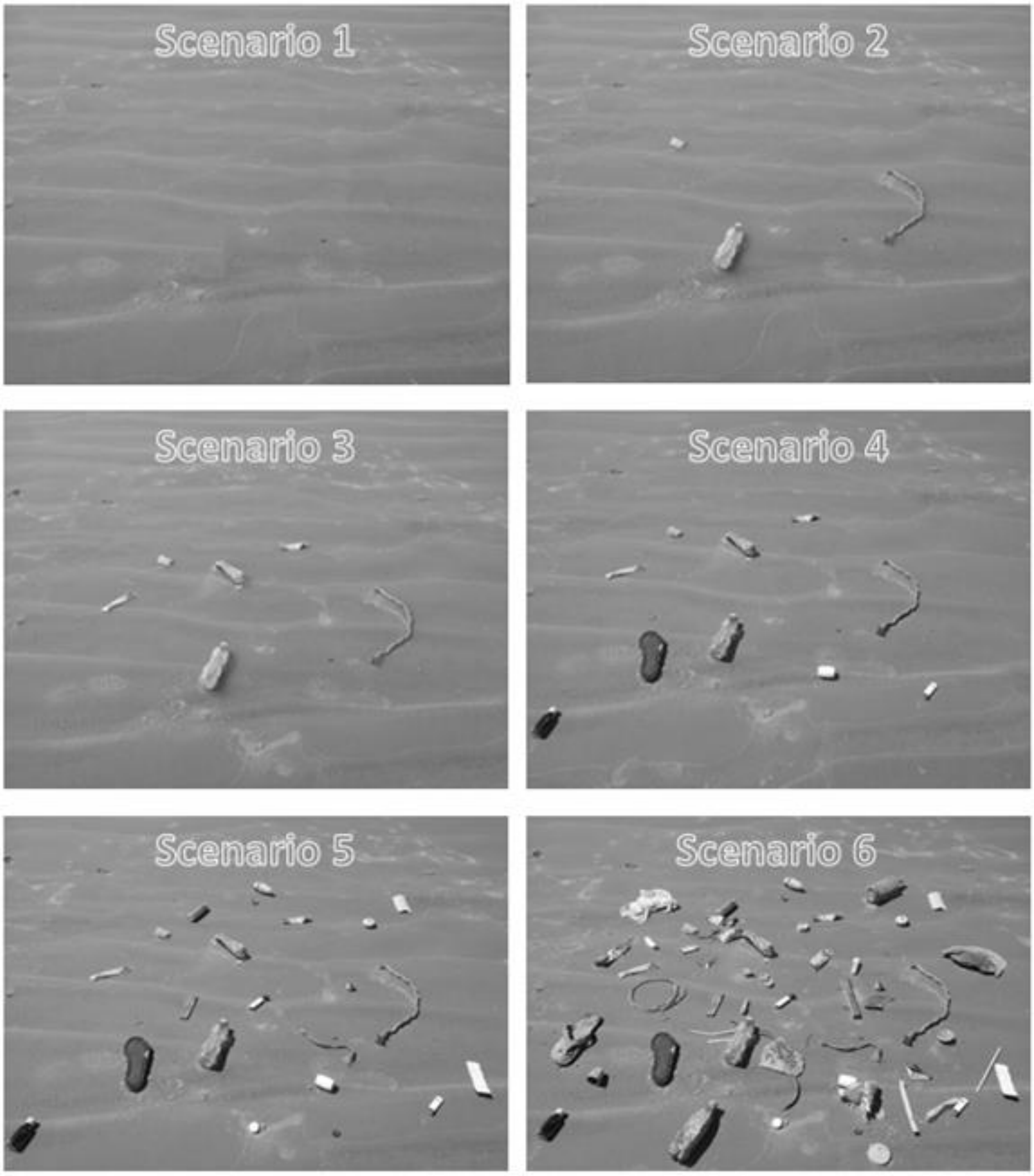

Figure 6 – Photographs with the scenarios of beach litter pollution. Pictures were used for a visual support for answering two questions. Each picture simulates a scenario with an increasing number of items in an area of nearly 4 m^2. The indication of densities (0; 1; 1.5; 2.5; 6; 15 $items.m^{-2}$) or quantity of items per linear meter of beach (0; 1.5; 3; 5; 12; 30 $items.m^{-1}$) allow comparison with previous studies and make the present study comparable to future ones.

6.2 User perception regarding deterring scenarios

This was obtained using two close-ended questions. The first aimed to evaluate the respondents' perception on a hypothetical future scenario where marine debris could be considered as to be so severe as to deter them from visiting that beach. Users were invited to elicit one scenario, among the six options already mentioned above (Figure 6). It was assumed that the respondent considers any pollution scenario greater than the chosen one unappealing for visitation, as well. Consequently, the number of deterred users and associated economic effects were approached cumulatively for more polluted successive scenarios. The most prompted scenarios were than identified and were considered for economic effect calculations.

In the second question, respondents elicited, from a list, potential alternative destinations in case they were deterred from visiting that beach. In this question, respondents choose one destination, among six options ("Other beaches of Pontal do Paraná", "Matinhos/Caiobá", "Guaratuba", "Paranaguá (Mel Island)" and "Beaches of Santa Catarina state") that would be the most probable alternative beach in case of deterrence. On top of the unambiguous options, there was an alternative "*others"*, where respondents could include another destination not listed. The options of destinations given were chosen to support the interpretation about transboundary impacts of deterring visits at two levels: Local (for Pontal do Paraná) in case users chose a different option than "other beaches of Paraná," or Regional (for Paraná state), in case respondent elicited "beaches of Santa Catarina" or "other". The answers to these two questions composed the data set to test Hypotheses II and III, respectively. This information was also used for calculating potential economic effects.

Supplementary Information C – Estimated data from official sources

7.1 Number of visitors (n)

The official data about the number of visitors [47,52] aggregates seven municipalities of the Paraná Coast. Consequently, the number of visitors of Pontal do Paraná (n) had to be estimated based on the Plan for Integrated Development of the Sustainable Tourism of Paraná – PDITS (2012). For that, passenger numbers departing from each coastal city during summer months (December, January and February) was used as a proxy to determine the proportion of travelers/visitors in each city, including Pontal do Paraná [52]. To the extent of our knowledge, the most recent systematized number of departures from municipality bus stations (2007-2009) was used in the development of the PDITS and the same set of data was used in the present study. Using summer month data, the proportion of passengers attributed to Pontal do Paraná was 6.2% of travelers coming to the Paraná coast.

PDITS' projection estimated 3,748,542 visitors for the whole coast of Paraná for 2015 [52]. Considering the above percentage (6.2%), the annual visitor number estimated was nearly 235,000 for Pontal do Paraná, which is a similar figure to that provided by the General Secretary of the Federation of Hosting Companies and Dining of Paraná, of about 250,000 visitors per year (FETURISMO *pers. comm.*). According to official data, the proportion of Tourists and SHOU in Pontal do Paraná is approximately 29.5%-70.5% [53]. Such a proportion was inferred from the type of accommodation visitors informed during that survey (SHOU = "owner of a second-home" or "using a second-home of a relative or friend" with no rental cost; Tourists = any other option but not residents). Consequently, based in this official estimate, there were approximately 69,300 tourists and 165,700 SHOU in Pontal do Paraná, in 2015. These estimates of number of visitors, as well the estimated values, were rounded to the nearest thousand, following Ballance *et al.* (2000). Numbers above millions were rounded to the nearest tens of thousands in order to avoid spurious accuracy in greater values.

7.2 Percentage of beachgoers (b)

Not all visitors to Pontal do Paraná were beachgoers and the estimate of the number of this type of traveler was based on visitors' traveling motivation. The adoption of this approach is based on previous studies that indicated the existence of a strong association between visitors' motivation for going to the beach and their choice of beach setting [74].

According to PDITS, the main motivation for traveling to the region was the beach for 21.2% of the respondents and places of natural and scenic beauty for 33.9%. Accordingly, a percentage of 55.1% of visitors of Paraná’s coast might be searching for places with scenic and natural beauty and/or beaches [52]. Considering a more conservative estimation, which considers only visitors traveling motived by the beach, the number of potential beachgoers to Pontal do Paraná would be approximately 49,800 (Tourists=14,700 and SHOU=35,100). However, a higher potential number of 129,000 (tourists=38,100 and SHOU=90,900) of beachgoers can be estimated if visitors searching for scenic and natural beauty are included. Calculations for economic effects considered both estimates of number of beachgoers (n) and results are presented according to this potential variability. Also, to obtain the percentage of the potential loss of tourism income to the municipality, *i.e.* Figure 5, it was assumed that all the visitors of Pontal do Paraná, both tourist and SHOU that are not beach users, also have a similar daily expenditure per person than beach users found during the present study. Number of trips was disregarded, since it is unlikely that a homogeneous travelling pattern is observed between beachgoers and non-beachgoers. An approximate value of US$21.8 million was obtained for total expenses, for 2015, considering that all visitors of Pontal do Paraná, beachgoers and non-beachgoers are included. Considering only beach users, and adopting a conservatively approach of a single trip per year, the total expense estimated for 2015 varies from US$4.6 to US$12 million. It means that in case all beach users were deterred, the municipality would lose between 21.1% and 55% of its yearly income from tourism.

8. Conclusão Geral

O lixo marinho é um problema transfronteiriço para a região do Complexo Estuarino de Paranaguá (CEP). O CEP tem um papel fundamental como fonte de resíduos sólidos exportados para áreas adjacentes, especialmente na desembocadura Sul, que foi objeto desse estudo. Pode-se concluir que a exportação de lixo ocorre para todo o gradiente estuarino e há evidências de que todos os municípios do CEP estejam implicados nesse cenário, como fonte ou como sumidouro. A entrada de lixo marinho a partir da parte oceânica é limitada, tendendo a permanecer na área da desembocadura, assim, não atingindo as áreas mais internas do Eixo Leste-Oeste do CEP, sendo condizente com os padrões hidrodinâmicas do Complexo. A adoção de modelagens aplicadas a pequenas escalas auxiliou na determinação das origens geográficas e das trajetórias dos itens encontrados nas praias. Isso é determinante para o conhecimento do ciclo de vida desses itens do lixo marinho, tanto para o CEP quanto para outras regiões similares.

A região oceânica parece estar funcionando como uma zona de acúmulo nas adjacências da desembocadura do CEP, com um transporte inicial no sentido Sul, seguido por um transporte no sentido Norte/Nordeste. Ao longo dessa trajetória eventos oceanográficos e meteorológicos específicos influenciam a distribuição do lixo marinho flutuante e também a intensidade de seu espraiamento. Ao analisar as influências desses eventos (altas vazões dos rios; sistemas frontais e condições meteorológicas regulares) para a região pode-se concluir que o aumento das vazões no sistema estuarino foi determinante para o aumento da abundância de itens, da riqueza de tipos e da quantidade dos itens associados às origens doméstica (continental), de pesca e de origens indefinidas (normalmente oceânicos). Observou-se sob essa condição grandes quantidade de itens domésticos em ambos os extremos do gradiente, reforçando o padrão proposto de que as grandes vazões apresentam intensidade suficiente para transportar o lixo marinho por todo CEP.

A despeito dessa influência comum a todos os setores, a interação entre os setores estuarinos e as condições estudadas ficou evidente em outros aspectos. Por exemplo, enquanto nos setores interno e médio, as menores abundâncias gerais foram observadas durante condições meteorológicas regulares, ou seja, sem eventos de maior intensidade ventos do quadrante Sul ou de vazões, no setor externo, foi a entrada de sistemas frontais que reduziu a abundância geral aos menores valores. Esse último padrão não era esperado, inclusive postulou-se que os sistemas frontais seriam responsáveis pelo aumento da quantidade de lixo marinho, uma vez que a ação dos ventos é sabidamente influente na sua dispersão. Dessa forma a influência observada ocorreu de maneira oposta à esperada para o setor externo. Concluiu-se que a determinação das influências sobre a quantidade e a qualidade do lixo marinho em ambientes de oceano aberto seja mais complexa, estando provavelmente associada à direção de ação dos ventos em relação a costa (~45%), a presença de correntes de deriva e a outros fatores oceanográficos e meteorológicos não estudados aqui. Da mesma maneira, a complexidade da área da desembocadura, no setor intermediário, sugere que a interação de diversos fatores exerce papel importante na composição do lixo marinho, uma vez que esse setor do gradiente apresentou grande variabilidade temporal e espacial ao longo da pesquisa.

A ocorrência de eventos de grandes vazões é mais frequente, mas não se limita, no período de verão, coincidindo com o período de maior uso das praias. Dessa forma, há risco que o aumento futuro de lixo nas praias, pelo aumento de sua geração, associado a uma gestão inadequada, impacte os usuários de praia da região. Há evidências que o local influencia a percepção dos usuários, especialmente em relação as origens do lixo marinho, uma vez que os usuários de Pontal do Sul, que está na desembocadura, mencionaram mais frequentemente o “mar” como principal origem do resíduo, se comparados aos usuários de Ipanema (distante da desembocadura).

Em relação aos usuários de praias de Pontal do Paraná, a divisão *a priori* entre turistas e proprietários de segunda residência (Veranistas) foi comprovada. Veranistas apresentam hábitos de viajar mais frequentemente, permanecendo por mais tempo, mas com um gasto diário menor. Apesar de diferentes percepções, as reações à poluição foram semelhantes entre grupos e locais, indicando que a importância da manutenção da qualidade ambiental da praia é essencial para ambos os grupos. Os usuários, de maneira geral, percebem, um cenário atual de poluição da praia (entre 1,5 e 3 itens de lixo marinho por metro linear de praia) menor do que estudos da região indicam, provavelmente, influenciados pelos resultados da limpeza de praia. Ou seja, as evidências apontam que a limpeza paliativa de praia vem sendo eficiente para seu fim, melhorando a qualidade da praia, sob a percepção dos usuários. Por outro lado, os riscos ao turismo são latentes pois a grande maioria dos usuários (83,9%), independente se veranistas ou turistas, apontou que deixaria de frequentá-la, caso 30 itens por metro ou mais fossem observados. Como a maioria deixaria o munícipio (85,3%) ou o estado (55,4%) em busca de outros destinos, concluiu-se que a evasão de usuários pela presença do lixo marinho, caso ocorra, será um problema transfronteiriço de dois níveis: estadual e intermunicipal. Especialmente considerando as potenciais perdas (entre 15% a 39,1%) da receita total do turismo de Pontal do Paraná há um risco de efeitos econômicos significativos pela dissuasão causada pelo lixo marinho. Para o município, os valores de gastos que seriam perdidos com a dissuasão de visitantes variam de US$3,2 a US$8,5 milhões, enquanto para o estado representariam entre US$2,2 e US$5,7 milhões. As maiores contribuições percentuais a esse montante viriam de Veranistas, visto que estes são a maioria (70,5%) dos visitantes e realizam viagens mais longas (6,8 dias) se comparados aos turistas (3,5 dias). O valor estimado com gastos de limpeza das praias de Pontal do Paraná (US$200 mil), se comparado a esses montantes, representa uma pequena porcentagem (<10%). Como esse valor é majoritariamente investido pelo Governo do Estado, é possível conceber que, apesar das evidências indicarem que o lixo marinho no Complexo Estuarino de Paranaguá é um problema transfronteiriço, este continuará sendo enfrentado de maneira paliativa, através de limpezas de praia, enquanto for economicamente viável e aceito como suficiente e adequado pelos visitantes.

Conclui-se que a aplicação de métodos multidisciplinares auxilia a compreensão da distribuição e das fontes geográficas do lixo marinho em pequena escala. Além disso, demonstrou-se que a compreensão dos fluxos espaço-temporais do lixo marinho no Complexo Estuarino de Paranaguá pode auxiliar na adoção de ações preventivas de geração de lixo marinho, mas também direcionar as medidas paliativas, como a limpeza. Evidencia-se ainda que a gestão inadequada de um problema transfronteiriço (exportação de resíduos entre municípios) tem o potencial de gerar, sinergicamente, outros problemas transfronteiriços de escalas semelhantes ou maiores (evasão de visitantes para outros municípios e estados). Por fim, propõe-se que a associação das Políticas Nacionais aplicadas a região costeira, especialmente a Política Nacional de Resíduos Sólidos, às diretrizes internacionais baseadas na abordagem transfronteiriça, como a estratégia de Honolulu, parece ser o melhor caminho para o enfrentamento do lixo marinho em longo prazo.

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ANEXOS

ANNEX I Supplementary Information **-** Identification composition and types

Class	Material Composition	Litter Code	Litter Form (and examples) *adapted from Cheshire et al., (2009)*
1	Plastic	PL1	Bottle caps & lids
2	Plastic	PL2	Bottles < 2 L
3	Plastic	PL3	Bottles, drums, jerrycans & buckets > 2 L
4	Plastic	PL4	Knives, forks, spoons, straws, stirrers, (cutlery)
5	Plastic	PL5	Drink package rings, six-pack rings, ring carriers
6	Plastic	PL6	Food containers (fast food, cups, lunch boxes & similar)
7	Plastic	PL7	Plastic bags (opaque & clear)
8	Plastic	PL8	Toys & party poppers
9	Plastic	PL9	Gloves
10	Plastic	PL10	Cigarette lighters
11	Plastic	PL11	Cigarettes, butts & filters
12	Plastic	PL12	Syringes
13	Plastic	PL13	Baskets, crates & trays
14	Plastic	PL14	Plastic buoys
15	Plastic	PL15	Mesh bags (vegetable, oyster nets & mussel bags)
16	Plastic	PL16	Sheeting (tarpaulin or other woven plastic bags, palette wrap)
17	Plastic	PL17	Fishing gear (lures, traps & pots)
18	Plastic	PL18	Monofilament line
19	Plastic	PL19	Rope
20	Plastic	PL20	Fishing net
21	Plastic	PL21	Strapping
22	Plastic	PL22	Fibreglass fragments
23	Plastic	PL23	Resin pellets
24.1	Plastic	PL24^{1}	lollipop stick
24.2	Plastic	PL24^{2}	label
24.3	Plastic	PL24^{3}	Unidentified fragments
24.4	Plastic	PL24^{4}	Medicine containers
24.5	Plastic	PL24^{5}	cups and glasses
24.6	Plastic	PL24^{6}	photography materials
24.7	Plastic	PL24^{7}	other wrapping and packaging
24.8	Plastic	PL24^{8}	domestic cleansing (brushes...)
24.9	Plastic	PL24^{9}	domestic appareal
24.10	Plastic	PL24^{10}	plastic seal
24.11	Plastic	PL24^{11}	plastic eletronic parts
24.12	Plastic	PL24^{12}	cosmetics
24.13	Plastic	PL24^{13}	plastic clothing
24.14	Plastic	PL24^{14}	personal hygiene
24.15	Plastic	PL24^{15}	car pieces
24.16	Plastic	PL24^{16}	school supplies
24.17	Plastic	PL24^{17}	unidentified plastic squares
25	Foamed Plastic	EP1	Foam sponge
26	Foamed Plastic	EP2	Cups & food packs

Class	Material Composition	Litter Code	Litter Form (and examples)
27	Foamed Plastic	EP3	Foam buoys
28	Foamed Plastic	EP4	Foam (insulation & packaging)
29.1	Foamed Plastic	EP5¹	Fragments
29.2	Foamed Plastic	EP5²	fisheires foamed items
30	Cloth	TE1	Clothing, shoes, hats & towels
31	Cloth	TE2	Backpacks & bags
32	Cloth	TE3	Canvas, sailcloth & sacking (hessian)
33	Cloth	TE4	Rope & string
34	Cloth	TE5	Carpet & furnishing
35	Cloth	TE6	Other cloth (including rags), toys
36	Glass & ceramic	VC1	Construction material (brick, cement, pipes)
37	Glass & ceramic	VC2	Bottles & jars
38	Glass & ceramic	VC3	Tableware (plates & cups)
39	Glass & ceramic	VC4	Light globes/bulbs
40	Glass & ceramic	VC5	Fluorescent light tubes
41	Glass & ceramic	VC6	Glass buoys
42	Glass & ceramic	VC7	Glass or ceramic fragments
43	Glass & ceramic	VC8	other Glass or ceramic fragments
44	Metal	ME1	Tableware (plates, cups & cutlery)
45	Metal	ME2	Bottle caps, lids & pull tabs
46	Metal	ME3	Aluminium drink cans
47	Metal	ME4	Other cans (< 4 L)
48	Metal	ME5	Gas bottles, drums & buckets (> 4 L)
49	Metal	ME6	Foil wrappers
50	Metal	ME7	Fishing related (sinkers, lures, hooks, traps & pots)
51	Metal	ME8	Fragments
52	Metal	ME9	Wire, wire mesh & barbed wire
53	Metal	ME10	Other, including appliances
53.1	Metal	ME11	Needles
54	Paper & cardboard	PA1	Paper (including newspapers & magazines)
55	Paper & cardboard	PA2	Cardboard boxes & fragments
56	Paper & cardboard	PA3	Cups, food trays, food wrappers, cigarette packs, drink containers
57	Paper & cardboard	PA4	Tubes for fireworks
58	Paper & cardboard	PA5	Other
59	Rubber	BO1	Balloons, balls & toys
60	Rubber	BO2	Footwear (flip-flops)
61	Rubber	BO3	Gloves
62	Rubber	BO4	Tyres
63	Rubber	BO5	Inner-tubes and rubber sheet
64	Rubber	BO6	Rubber bands
65	Rubber	BO7	Condoms
66	Rubber	BO8	Other
67	Wood	MA1	Corks

Class	Material Composition	Litter Code	Litter Form (and examples)
68	Wood	MA2	Fishing traps and pots
69	Wood	MA3	Ice-cream sticks, chip forks, chopsticks & toothpicks
70	Wood	MA4	Processed timber and pallet crates
71	Wood	MA5	Matches & fireworks
72	Wood	MA6	Other
72.1	Wood	MA6¹	pieces of manufactured wood
73	Other	OU1	Paraffin or wax
74	Other	OU2	Sanitary (nappies, cotton buds, tampon applicators, toothbrushes)
75	Other	OU3	Appliances & Electronics
76	Other	OU4	Batteries (torch type)
77	Other	OU5	Other
78	Other	OU6	Charcoal (organic)
79	Other	OU7	Tetrapak
80	Other	OU8	Tar balls
82	Other	OU9	unidentified material needles
83	Other	OU10	unidentified school supplies

ANNEX II - Data set of Composition

	Sector	***Internal***									
	Beach	*Ponta Oeste*			*Gonzaga*			*Cedro*			**subtotal**
	Condition	HRD	FS	RWC	HRD	FS	RWC	HRD	FS	RWC	
Composition	Rubber	17	10	2	22	10	7	23	6	1	**98**
	Foamed plastic	75	44	17	50	11	16	113	49	23	**398**
	Wood	19	23	4	26	32	19	41	32	4	**200**
	Metal	1	2	3	-	7	5	3	1	2	**24**
	Paper	1	1	1	-	2	2	-	1	-	**8**
	Plastic	550	398	133	650	245	173	670	216	138	**3173**
	Clothing and textile	1	2	1	1	12	-	-	2	-	**19**
	Glass and ceramic	4	5	7	10	13	18	3	4	1	**65**
	Others	99	103	224	28	279	86	20	27	49	**915**
	Total	**767**	**588**	**392**	**787**	**611**	**326**	**873**	**338**	**218**	**4900**

	Sector	***Median***									
	Beach	*Canto das Pedras*			*CEM*			*Coruja*			**subtotal**
	Condition	HRD	FS	RWC	HRD	FS	RWC	HRD	FS	RWC	
Composition	Rubber	17	23	9	3	3	3	4	3	1	**66**
	Foamed plastic	70	189	30	15	10	28	11	15	8	**376**
	Wood	36	81	27	9	3	9	14	10	2	**191**
	Metal	6	8	1	4	1	1	3	2	1	**27**
	Paper	2	2	1	-	-	-	3	4	-	**12**
	Plastic	618	857	294	217	87	141	142	179	94	**2629**
	Clothing and textile	-	3	1	2	1	3	1	-	-	**11**
	Glass and ceramic	1	1	2	2	4	1	1	2	-	**14**
	Others	7	31	13	11	3	6	8	4	2	**85**
	Total	**757**	**1195**	**378**	**263**	**112**	**192**	**187**	**219**	**108**	**3411**

	Sector	***External***									
	Beach	*Barrancos*			*Barrancos Sul*			*Guapê*			**subtotal**
	Condition	HRD	FS	RWC	HRD	FS	RWC	HRD	FS	RWC	
Composition	Rubber	10	3	9	19	4	9	6	3	4	**67**
	Foamed plastic	31	33	36	39	16	26	35	29	34	**279**
	Wood	2	1	6	11	1	8	11	3	2	**45**
	Metal	4	2	1	7	5	3	1	5	6	**34**
	Paper	-	-	2	2	-	1	4	1	2	**12**
	Plastic	489	245	293	835	164	292	467	204	215	**3204**
	Clothing and textile	1	4	2	2	-	-	2	4	1	**16**
	Glass and ceramic	3	1	1	2	3	3	-	1	4	**18**
	Other	16	1	19	5	5	8	5	2	1	**62**
	Total	**556**	**290**	**369**	**922**	**198**	**350**	**531**	**252**	**269**	**3737**

ANNEX III – Data set of most probable sources, overall abundance and richness of types

Sector		***Internal***									
Beach		*Ponta Oeste*			*Gonzaga*			*Cedro*			
Condition		HRD	FS	NWC	HRD	FS	NWC	HRD	FS	NWC	***subtotal***
Most probable source	domestic	162	112	30	170	110	58	187	56	26	***911***
	unknown	324	232	106	373	161	143	418	177	81	***2015***
	Ship harbor	86	96	223	18	277	76	7	21	46	***850***
	Fisheries	76	46	11	91	40	14	93	35	40	***446***
	SRD	27	23	1	26	1	10	31	9	7	***135***
	beach user	92	79	21	109	22	25	137	40	18	***543***
	TOTAL	**767**	**588**	**392**	**787**	**611**	**326**	**873**	**338**	**218**	***4900***
Richness of types		47	42	32	45	45	44	46	41	35	*71*
Sector		***Median***									
Beach		*Canto das Pedras*			*CEM*			*Coruja*			
Condition		HRD	FS	RWC	HRD	FS	RWC	HRD	FS	RWC	***subtotal***
Most probable source	domestic	108	221	68	46	21	25	25	12	11	***537***
	unknown	339	618	180	128	58	106	76	71	46	***1622***
	Ship harbor	1	5	-	1	-	-	-	1	-	***8***
	Fisheries	93	90	62	21	14	24	22	16	28	***370***
	SRD	21	42	9	-	-	-	3	2	1	***78***
	beach user	195	219	59	67	19	37	61	117	22	***796***
	TOTAL	**757**	**1195**	**378**	**263**	**112**	**192**	**187**	**219**	**108**	***3411***
Richness of types		44	52	38	35	28	35	37	32	22	*71*
Sector		***External***									
Beach		*Barrancos*			*Barrancos Sul*			*Guapê*			
Condition		HRD	FS	RWC	HRD	FS	RWC	HRD	FS	RWC	***subtotal***
Most probable source	domestic	67	26	63	130	25	23	71	35	27	***467***
	unknown	354	178	194	426	92	205	262	124	148	***1983***
	Ship harbor	-	1	1	5	-	-	-	-	1	***8***
	Fisheries	42	45	54	161	27	69	58	48	44	***548***
	SRD	-	5	4	25	5	11	14	3	7	***74***
	beach user	93	35	53	175	49	42	126	42	42	***657***
	TOTAL	**556**	**290**	**369**	**922**	**198**	**350**	**531**	**252**	**269**	***3737***
Richness of types		38	33	43	47	40	36	38	43	39	*72*