Marine Debris in Gulf Saint Vincent Bioregion

Report for the Adelaide and Mount Lofty Natural Resources and Management Board

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CARING FOR OUR COUNTRY
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This project was initiated as a collaborative project with the Adelaide and Mount Lofty Ranges Natural Resources Management Board, Kangaroo Island Natural Resources Management Board and the Northern and Yorke Natural Resources Management Board as part of a Memorandum of Understanding in relation to Collaborative Approaches to the Management of Gulf St Vincent by Natural Resource Management Boards. The project was supported by the Whale and Dolphin Conservation Society Australasia, the South Australian Museum, Department of Natural Resources and Environment, OceanWatch Australia Ltd and SeaNet SA, hosted by Wildcatch Fisheries SA, regional and city councils, Clean-Up Australia and SeaLink and would not have been possible without the invaluable assistance of community volunteers.

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Executive Summary

Marine Debris is a matter of environmental significance. '*Injury and fatality to vertebrate marine life caused by ingestion of, or entanglement in, harmful marine debris*' was listed in August 2003 as a key threatening process under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act, 1999).

This collaborative project, supported by the Australian Government's Caring for our Country initiative, between three Natural Resource Management Boards and partners around Gulf St Vincent, sought to implement local level actions to address the national *Threat Abatement Plan for the impacts of marine debris on vertebrate marine life* (Marine Debris Threat Abatement Plan) to minimise impacts on marine species and ecological communities. The project had four main components that related to the objectives of the Marine Debris Threat Abatement Plan: Awareness and Behaviour Change, Removal, Prevention and Behaviour Change, Understanding Impacts to Marine Wildlife and Monitoring.

This study aimed to investigate and identify the knowledge gaps of the potential sources of marine debris that are likely, or could, potentially impact marine wildlife and ecological communities within the Gulf Saint Vincent (GSV) bioregion. Of the 985 kg and 12,603 items of marine debris recovered, the survey results identified 10 major debris categories that could be potentially harmful either directly through ingestion or entanglement to wildlife and further identified a number of sources of debris that should be mitigated to reduce their impact on coastal and marine ecological systems.

Debris types were predominantly comprised plastics consisting of fragments, packaging, containers, and fishing and boating and aquaculture related debris that originates from both terrestrial and marine based sources. The most commonly encountered debris type (by number) across the GSV bioregion, were hard-polymer plastic fragments. In eastern GSV, debris was dominated by plastic food packaging (wrappers) presumably associated with the proximity to metropolitan Adelaide.

The most polluted survey sites within the GSV bioregion based on item densities were Rocky River, Sandhurst Beach and Sandy Creek (Kangaroo Island), and O'Sullivan Beach, Hallett Cove and Willunga of eastern shores of GSV. These sites showed also high litter abundances but low overall mass predominantly because their compositions contained a large percent of light weight plastic debris.

Rocky River, comprised the highest density and mass of debris attributable to driftwood, but its highest ranking was also because it contained the smallest search area. Conversely, Willunga beach produced the third highest abundance of debris but showed lower density because it was the largest site surveyed. Significant debris items by weight included car tyres (Stansbury and Port Vincent), a refrigerator (Point Morrison) and on western Gulf St. Vincent (Black Point and Mullowurtie Point) a large number of plastic oyster baskets and debris related to oyster aquaculture leases.

Of fishing, boating and aquaculture-related debris, rope fragments were the predominant type of debris by number. Commercial oyster aquaculture debris in NW Gulf St. Vincent comprised the largest proportion by mass of debris.

The item mean densities recorded for GSV bioregion are lower than reported mean densities elsewhere in Australia; for example Cable Bay, Western Australia, south, central and north Sydney beaches, are comparable to Fog Bay, NSW , but globally significantly lower. Within South Australia, the mean mass densities of debris found per region are comparable to those recorded from biennial surveys of marine litter on Kangaroo Island but possibly higher than the standing crop density based on estimates for 1991 Anxious Bay surveys on the Far West coast.

The majority of debris found around urban sites is most likely terrestrial-based in its origin. This was supported by the higher occurrence and abundances of packaging associated with common use food items and general housing products observed on the beaches of eastern GSV. O'Sullivan Beach, Hallett Cove and Willunga Beach comprised 50% of all packaging and 40% of household products, with plastic food wrappers and fast- food plastic drinking straws most commonly encountered debris. The eastern coastline of GSV has significant river and storm water outlets which are probable vectors of the debris from terrestrial systems.

Containers, which largely comprised plastic PET bottles and hard-polymer lids from PET bottles, were found in greater abundance at remote sites rather than urban sites. This may relate to oceanographic factors or could possibly be a positive reflection on the state's bottle recycling refund scheme whereby urban sites are more accessible to beach-goers than remote sites. The surveys found relatively low numbers of plastic bags. However, as there is no previous baseline information on the coastal deposition of plastic bags, no inference to the 2009 state's reduction scheme for plastic shopping bags (*Plastic Shopping Bags Waste Avoidance Bill* 2009) can be made.

Marine rope fragments are a common occurring debris type across the gulf and on Kangaroo Island. Two significant rope debris items found during the survey period, (but not part of the debris surveys), included a collection of bundled rope that contained a deceased juvenile Australian sea lion, and around 3 tonnes of rope collected off Cape Hart, Kangaroo Island. The origin of these was not determined.

Examination of marine mammal standings in the Gulf indicates that entanglement in marine debris and fishing gear is a threat to marine mammals. Marine debris and in particular plastic fragments are of particular concern for seabirds and other wildlife. Entanglement in rope and fishing gear and packaging is a risk for marine mammals. The project also indentified some possible underlying marine mammal health matters that need further investigation.

The current project has produced a survey manual based on the recent international methodologies developed from a collaborative approach by United Nations Environment Programme (UNEP, 2009). This has facilitated its application across a range of organisations, engaged local community volunteers and improved knowledge and understanding of current debris impacting marine wildlife and ecological communities in Gulf St Vincent and Kangaroo Island.

There are many protocols, conventions, strategies and reports relating to reduction of marine debris at international and national levels. Within South Australia there are a range of waste management initiatives and awareness programs and Environmental Protection Authority codes of conduct relating to vessels and boating facilities and wharves. Whilst much has progressed, the quantities of debris recovered in this study are still of great concern, particularly the high proportion of plastics debris, given their global increase and longevity in the environment.

While the origin of some debris may be international, a large proportion recovered in this study was likely related to both local terrestrial and marine based sources. There is a need for continued awareness, education and engagement programs at a local level that should target local fishing and boating, and other terrestrial-based user groups. Whilst a range of initiatives relating to improving waste reception facilities at local South Australian boating facilities have occurred, there is always a need to review these facilities and ensure adequate resourcing is available for local authorities to provide, improve and maintain waste disposal and recycling on the coast.

The local community support and enthusiastic volunteer effort for this project is a reflection that there is community will to address this global issue at a local level. Local and regional communities however need support and coordination to successfully undertake and maintain their involvement in initiatives such as this project. The support of the Australian Government and regional Natural Resources Management bodies, state agencies local government and non-government organisations was instrumental in implementing this project.

RECOMMENDATIONS

- Continuation of marine debris surveys at the same spatial scale to determine current and future accumulation and potential changes in sources of pollution to the GSV bioregion.
- Nationally standardise marine debris sampling protocols so datasets are comparable in order to develop a national coordinated strategic plan to mitigate harmful effects of marine debris.
- Support consistent, long-term monitoring, investigation, recording and management of data on vertebrate marine life harmed and killed by the physical and chemical impacts of marine debris; including continued monitoring of marine mammal mortalities for the Gulf St Vincent Bioregion and support for adequate archiving of data and specimens to ensure long term availability.
- Continued efforts to improve waste management practices on land and at sea, particularly through regional and local review and improvement of port, boating hub and beach (and catchment) waste and recycling facilities; awareness of best practice waste management for vessels, improving solid pollutant (litter) control strategies in waterways.
- Develop national and statewide working groups or networks to address key objectives and outcomes of the *Threat Abatement Plan for the impacts of marine debris on vertebrate marine life* at local, cross-regional and state levels and facilitate action at regional and local levels.
- Develop a Southern Australian Marine Debris Guide to identify potential sources of debris recovered within the Southern Ocean, similar to that produced for Northern Australia.

Introduction

Marine debris (marine litter) is an increasing and persistent problem that impacts on our estuarine, coastal and oceanic marine ecosystems. Given its structural diversity (i.e. plastic, metal, wood, ceramic, glass) and abundance from terrestrial and marine-based sources, its influence is globally extensive and increasingly reported as a significant threat to both marine life and inshore ecological communities (Thiel et al. 2003; Abu-Hilal and Al-Najjar, 2009; Gregory et al. 2009; Keller et al. 2010; Carson et al. 2011).

With the development and introduction of synthetic organic polymers (plastics) as common use items in households and commercial-based industry, the subsistence of plastic pollutants as litter in both terrestrial and marine-based systems has grown significantly (Derraik, 2002). While plastics and components thereof offer convenience, versatility, and durability, their reusability and structural integrity is often short-lived (Barnes et al. 2009). As a result, millions of tonnes of plastic pollutants are annually discarded worldwide. These either become integrated as waste in terrestrial land-fills, or enter marine systems through translocative processes (i.e. storm-water, rivers and streams) originating from urban-based waterways and catchments, or are directly deposited through intentional dumping on land or at sea (Vauk & Schrey, 1987; for reviews see Derraik, 2002, Iva du Sol and Costa, 2007). Further, given the buoyant hydrophobic properties of plastic (Teuten et al. 2011), enables the potential for greater dispersal than other debris, thus the congregation of pollution along oceanic convergence and frontal zones and its subsequent and final deposition can originate from local or distant transoceanic sources.

Worldwide, the risks to marine wildlife and ecosystem health from the impacts of marine debris are well documented with examples of its deleterious effects existing at almost all trophic levels from echinoderms, crustaceans and cephalopods to higher-order consumers such as teleost fish, seabirds, cetaceans, pinnipeds and sharks (Day, 1988; Hoss et al. 1990; Laist, 1997; Jackson et al. 2000; Graham et al. 2009; Aloy et al. 2011). Direct ingestion of marine debris resulting from either unintentional consumption or misidentification as prey can facilitate blockages of the gastro-intestinal (GI) tract, lead to ulceration, and increase the potential risk of starvation and death (Auman *et al*. 1997; Hutton *et al*. 2008; Mrosovsky et al. 2009; Jacobsen et al. 2010; Carey, 2011), cetacean mortality from respiratory asphyxiation has also been reported (Gorzelany et al. 1997; Gomercic et al. 2009), while entanglement related mortality and sub-lethal effects (infection, reduced foraging ability, starvation) resulting from direct physical interaction with mostly fishing-related floating debris (e.g. nets and ropes and monofilament line) are known to impact seabird, cetacean, and pinniped species alike (Laist, 1997; Page et al. 2004; Moore et al. 2009; Jacobsen et al. 2010). Passive ingestion of persistent organic pollutants

(POPs) (e.g. polychlorinated biphenyls (PCBs), organochlorine pesticides (OCPs), polycyclic aromatic hydrocarbons, petroleum hydrocarbons, polybrominated diphenylethers, alkylphenols and bisphenol) adsorbed within marine-based plastic debris are also, known disruptors of endocrine regulatory pathways, thus small predatory species such as seabirds and fish that ingest plastics are susceptible to their bio-accumulative effects, which can be also transferred up the food chain (Neal, 1985; Oehlmann et al. 2009; Teuten et al. 2009; Bustnes et al. 2010; Colabuono et al. 2010).

In Australian waters, the disposal of plastic and harmful waste at sea is prohibited under MARPOL legislation (International Convention for the Prevention of Pollution from Ships, Annex V (1973/1978/1989) and the Australian Protection of the Sea Act, 1983 (*Prevention of Pollution from Ships*), yet plastic still remains the dominant and growing source of synthetic anthropogenic marine-pollution (e.g. Whiting, 1998; Eglington et al. 2006; NRETA, 2006; Kinloch 2007; Lashmar et al. 2010; Loisier, 2011). Thus, increases in quantity and harmful types of marine debris are coupled with the potential for increased risk of entanglement or ingestion, as have been reported for endemic pinniped, cetacean, seabird and marine reptiles and other transitory species (Jones, 1995; Bone 1998; Page et al. 2004; NRETA, 2006; Hutton et al. 2008; Kemper and Tomo, 2005, 2011; Carey, 2011). Accordingly, harmful marine debris that threatens the survival and abundance of native species or ecological communities was listed under the Australian Commonwealth Environment Protection and Biodiversity Conservation Act (EPBC, 1999) (DEWHA, 2009). In response, the EPBC Act listing propagated the need to quantify the impact of debris by identifying key knowledge gaps of its potential sources, further necessitating the formulation of a national management strategy to mitigate its harmful effects on marine species.

The South Australian marine bioregion extending from Cape Spencer, Yorke Peninsula (35º 16’ S, 136° 53' E) to Cape Jaffa (36º 57' S, 139º 40' E) is an area of high ecological significance supported by one of the most productive regions of South Australia (van Ruth et al. 2010) (Fig.1). The area, occurring within south east Great Australian Bight (GAB) comprises one of two major South Australian gulf systems, Gulf St. Vincent (GSV), two major water passages; Investigator Strait (IS) and Backstairs Passage (BP) and Encounter Bay that extends easterly to the Bonney Coast (Middleton and Bye, 2007). The region between GSV and Encounter Bay is punctuated topographically by Kangaroo Island (KI), which, except for exposed southerly facing locations, significantly reduces the severity and influence of the Southern Ocean. GSV and its surrounding waters provide important breeding and /or foraging habitat for a wide diversity of local, migratory and itinerant marine and coastal species including EPBC vulnerable and endangered listed Australian sea lion (*Neophoca cinerea*), Southern Right whale (*Eubalaena australis*), Humpback Whale (*Megaptera novaeangliae*), Albatross (*Diomedea* spp.), Giant Petrel (*Macronectes* spp.), Great white shark (*Carcharodon carcharias*), leatherback, loggerhead and green turtle (*Caretta caretta*, *Chelonia mydas*, *Dermochelys coriacea,* respectively), and other species including New Zealand fur seal (*Arctocephalus forsteri*), Indo-Pacific bottlenose (*Tursiops aduncus*) and Short-beaked common dolphin (*Tursiops truncatus*), little penguin (*Eudyptula minor*) and toothed and baleen whales (see Bone, 1998; Kemper and Tomo, 2011) (Appendix 1). The bioregion is also important nursery grounds for a large number of fish and invertebrate species, and sustains some of South Australia's largest marine **c**ommercial fisheries including southern rock lobster (*Jasus edwardsii*), green and black lip abalone (*Haliotis rubra*, *Haliotis laevigata*), the second largest statewide western king prawn (*Melicertus latisulcatus*) fishery, Australian sardine (*Sardinops sagax*), multi-species marine scale fishery, and blue swimmer crab (*Portunus pelagicus*) (Knight & Tsolos, 2010; ABARES, 2011).The region also accommodates the largest population centre of South Australia.

Quantitative information of the impact of marine and terrestrial sources of debris within the majority of this bioregion has never been fully documented. The only studies occurred on Kangaroo Island, for which biennial beach surveys indicated plastic was the major contributor to pollution. In the report by Lashmar et al. 2007 and Kinloch et al. 2009, coastal environments surrounding urban centres were significantly impacted by terrestrial soft-plastic debris (i.e. food wrappers), but exposed and remote open ocean beaches debris constituted fishing-related and hard plastics (Lashmar et al. 2007, Kinloch et al. 2009). While this appears to be a common occurrence for beaches exposed to the Southern Ocean and has been reported for South Australian beaches within east, south east, and central Great Australian Bight (GAB) region (Anxious Bay (1991-2000) Edyvane et al. 2004; Robe (1997-2005) Eglington et al. 2005; central GAB (2010-2011) Loisier, 2011), respectively), information on passive gulf-based systems such as Gulf St. Vincent are negligible.

Marine debris surveys are part of the Gulf St. Vincent Marine Threat Abatement project, initiated by the Adelaide and Mount Lofty Ranges Natural Resources Management Board (AMLRNRMB) and supported through the Australian Government's Caring for Our Country initiative. This is a collaborative project between three Natural Resource Management Boards (AMLR, Kangaroo Island and Northern and Yorke), Whale and Dolphin Conservation Society, South Australian Museum and other organisations. The objectives of this study were to address the Australian Government's *Threat Abatement Plan for the impacts of marine debris on vertebrate marine life* to provide information of the current local and regional impacts of marine debris to marine species and ecological communities within coastal and marine ecosystems within the GSV bioregion.

The Marine Debris Threat Abatement Plan for Gulf St. Vincent aimed to implement objectives of the *Threat Abatement Plan for the impacts of marine debris on vertebrate marine life* (TAP) at a local level. The objectives of the TAP are:

1. Contribute to the long-term prevention of the incidence of harmful marine debris.
2. Remove existing harmful marine debris from the marine environment.
3. Mitigate the impacts of harmful marine debris on marine species and ecological communities.
4. Monitor the quantities, origins and impacts of marine debris and assess the effectiveness of management arrangements over time for the strategic reduction of debris.

Materials and methods

1.1 Assessment of marine debris study area and site selection

Hydrological movement within Gulf St. Vincent (GSV) occurs predominantly between April-August (Bye, 1976). It originates from west-east coastal and South Australian currents introduced as westerly inflows through northern Investigator Strait, and outflows easterly through the Backstairs Passage toward the Bonney Coast. Alternatively, outflows through Backstairs Passage cyclonically return through Investigator Strait and re-circulate to GSV (Bye, 1976; Middleton and Bye, 2007; Bye and Kämpf, 2008). Waters surrounding Fleurieu Peninsula, Yorke Peninsula and Kangaroo Island are similarly, influenced by the eastward moving currents, but on exposed south facing coasts are further subject to greater offshore oceanic conditions originating from complex weather systems and cyclonic eddies coinciding with the westerly movement of the Flinders Current (Bye, 1972, Bye and Kämpf, 2008). During the austral summer, the severity of oceanic conditions lessen, the coastal current reverts to a predominantly east-westerly regime, inducing a decrease in gulf circulation and oceanic movement (Bye, 1976).

To coincide with higher oceanic movement within the GSV region and surrounding waters, marine debris surveys were conducted at the end of the austral winter between August and October, 2010. The spatial extent of the surveys incorporated 38 study sites sub-divided into 4 main regions; East and West Gulf St. Vincent (n = 16), Fleurieu Peninsula (n = 4), lower Yorke Peninsula (n=6), and Kangaroo Island (n = 12) (Fig. 1, Table 1-3). Sites were geographically allocated based on beach parameters developed for the surveys (e.g. Wace, 1995; Edyvane et al. 2004; Cheshire and Westphalen, 2007) (Table 4) to minimise potential for external factors (i.e. urbanisation, catchments, rivers, storm water) influencing the survey collections. Excluding sites adjacent to major urban centres, site remoteness was considered important, to reduce the impact of urban land-based debris and debris deposited from day-day visitations. Beach dynamics were further assessed using beach descriptions by Short, (2001, 2006).

Figure 1.Study sites used for the marine debris surveys for Gulf St. Vincent, Lower Yorke Peninsula, Fleurieu Peninsula, and Kangaroo Island. Blue line indicates NRM regions; Adelaide and Mount Lofty Ranges, Northern and Yorke, and Kangaroo Island.

Table 1. Study sites, coordinates, transect length and beach area used for marine debris surveys across east and west coasts Gulf St. Vincent, South Australia.

Site	Transect Point 1	Transect Point 2	Site area (m^2)	Est. beach width (m)	Transect length (m)
Gulf St. Vincent West					
Tiddy Widdy beach	34°23'32.12"S 137°57'11.81"E	34°23'56.07"S 137°56'43.05"E	21987.42	30	1000
Mullowurtie Point	34°31'9.48"S 137°53'13.56"E	34°31'39.46"S 137°53'7.76"E	13829.34	60	1000
Black Point	34° 38' 21.7746"S 137° 53'43.731"E	34° 37'55.57"S 137° 54'03.70"E	11788.11	30	1000
Long beach	34°50'32.045"S 137°49'05.42"E	34°50'6.86"S 137°49'28.04"E	16236.13	30	1000
South Stansbury	34° 55' 35.64"S 137°47' 17.46"E	34° 55' 09.31"S 137° 47' 38.85"E	15043.86	40	1000
Point Hicks	35°02' 41.0814"S 137°45' 27.7079"E	35° 2'18.22"S 137°45'50.86"E	11131.94	30	1000
Wattle Bay	35° 8'5.96"S 137°43'4.91"E	35° 7'55.11"S 137°43'41.74"E	14817.65	50	1000
Gulf St. Vincent East					
Great Sandy beach	34°27'39.50"S 138°15'36.78"E	34°28'11.53"S 138°15'44.17"E	20322.59	35	1000
North Parham	34°25'1.78"S 138°15'2.52"E	34°25'16.90"S 138°15'8.80"E	13263.45	50	1000
Tennyson	34°52'41.41"S 138°28'54.19"E	34°53'12.97"S 138°29'3.62"E	28700.79	30	1000
Hallet Cove	35° 4'0.80"S 138°29'55.43"E	35° 3'31.15"S 138°30'11.51"E	14333.37	30	1000
O' Sullivans beach	35° 7'16.05"S 138°28'3.84"E	35° 7'47.87"S 138°28'10.81"E	46937.24	40	1000
Willunga beach	35°14'54.19"S 138°27'43.25"E	35°15'27.30"S 138°27'41.11"E	52434.85	30-40	1000
Carackalinga	35°26 6.11"S 138°18' 53.62E	35°25'38.13"S 138°19'13.52"E	39839.56	40	1000
Rapid Bay	35°31'14.17"S 138°11'53.78"E	35°31'27.77"S 138°11'18.29"E	37546.55		1000
Morgans beach	35° 35'28.62"S 138°06'30.97"E	35° 35'51.61"S 138°06'5.29"E	22350.85	30	1000
Total			**380563.70**		**16000**

Table 2. Study sites, coordinates, transect length and beach area used for marine debris surveys across lower Yorke Peninsula and lower Fleurieu Peninsula, South Australia.

Site	Transect Point 1	Transect Point 2	Site area (m^2)	Est. beach width (m)	Transect length (m)
Lower Fleurieu Peninsula					
Lands End	35°37'26.92"S 138° 5'44.06"E	35°37'13.02"S 138° 5'43.54"E	7515.48	30	451
Tunkalilla	35° 38'19.36"S 138°18'39.9"E	35° 38'16.91"S 138°17'59.6"E	34052.96	40	1000
Waitpinga beach	35°38'4.15"S 138°29'55.81"E	35°37'55.95"S 138°29'17.24"E	30971.2	40	1000
Victor Harbor East	35°32'18.01"S 138°38'58.68"E	35°32'30.21"S 138°38'22.19"E	17799.01	20	1000
Lower Yorke Peninsula					
Kemps bay	35° 8' 28.6938"S 137° 36' 9.399"E	35° 8'49.22"S 137°36'40.11"E	35325.85	30	1000
Bangalee beach	35°14'22.1172"S 137°9'18.3306"E	35° 14' 21.48"S 137° 9' 1.2096"E	8646.98	20	455
Chinamans B	35°17'16.40"S 136°54'53.44"E	35°17'12.52"S 136°54'41.69"E	4722.64	15	300
Chinamans A	35°17'13.07"S 136°54'54.82"E	35°17'6.93"S 136°55'21.27"E	15541.13	25	730
Cable Bay	35°17'14.49"S 136°53'51.45"E	35°17'7.94"S 136°54'20.40"E	7113.37	10	750
Cape Spencer	35° 17' 41.1246"S 136° 52' 44.3166"E	35° 17' 55.95"S 136° 52' 50.1348"E	22619.33	40	545
Total			**184307.95**		**7231**

Table 3. Study sites, coordinates, transect length and beach area used for marine debris surveys across Kangaroo Island, South Australia.

Site	Transect Point 1	Transect Point 2	Site area (m^2)	Est. beach width (m)	Transect length (m)
Kangaroo Island					
West Bay	35°53'2.47"S 136°32'56.64"E	35°53'16.80"S 136°33'4.26"E	49099.57	50	485
Red Banks	35°44'15.66"S 137°42'46.81"E	35°44'5.47"S 137°43'23.36"E	9149.69	30	1000
Destrees Bay	35°59'11.59"S 137°36'55.45"E	35°58'42.04"S 137°37'9.10"E	15343.73	30	1000
Sandhurst	35°51'38.20"S 137°51'28.59"E	35°51'48.78"S 137°52'6.21"E	25385.88	20	1000
Bales Bay	35°59'37.73"S 137°21'6.51"E	35°59'51.99"S 137°21'41.41"E	41945.65	30	1000
American beach	35°45'55.92"S 137°52'57.65"E	35°45'34.84"S 137°53'27.87"E	22807.63	28	1000
Point Morrison	35°44'2.80"S 137°47'9.15"E	35°44'11.95"S 137°47'23.14"E	13644.76	25	1000
Rocky Point	35°47'35.16"S 137°51'22.94"E	35°47'48.50"S 137°50'46.78"E	31636.49	20	1000
Vivonne Bay	35°58'31.90"S 137°11'42.90"E	35°58'28.10"S 137°12'22.50"E	38760.92	30	1000
Cape Gantheaume	36°03'48.12"S 137°27'5.14"E	36°4'5.71"S 137°27'29.52"E	27501.23	40	871
Sandy Beach	35°57'13.82"S 136°37'28.3439"E	35°57'22.1039"S 136°37'45.876"E	22149.27	88	508
Rocky River	35°57'52.69"S 136°39'11.28"E	35°57'54.06"S 136°39'13.64"E	3392.88	118	72
Total			**300817.70**		**9,936**

Table 4. Beach parameters and site examples used for marine debris survey site selection, South Australia.

Beach identification	FP1	FP2	FP4
Common name	Tunkalilla	Waitpinga	Victor Harbor East
Latitude	35°38'16.65"S	35°38'5.13"S	35°32'26.75"S
Longitude	138°18'15.24"E	138°29'59.70"E	138°38'28.52"E
Geographical			
Direction w ind current	SW	SW	SW
Direction ocean current	SW	S	W
Aspect	S	SW	S
Beach curvature/profile			
linear (L), concave (CA), convex (CO), sinsoidal/tierral (S/T)	L	CO	L/CO
Beach length (m)	5000	3200	2000+
Nearest river	ephemeral creek	ephemeral creek	hindmarsh river mouth
distance(m)	500	500	1000
direction	N+S	W	W
input direct indirect	direct	direct if flow ing	direct
Geomorphological			
Sand (S) gravel (G) shingle (Sh) pebble beach (PB) Rock (R)	S	S	S
Nourished by offshore sands, rather than by nearby rivers contributing land-based sediments	Y	Y	Y
Landw ard limit	grass	sand	sand rockflats
Having a uniform sediment compartment, at least 5 km long, w ith minimal longshore drift of sand.	Y	Y	Y
Rear beach can be described easily and rubbish removed easily	Y	Y	Y
Beach w idth at low tide (m)	60	30	30
Beach gradient			
Moderate to low (15-45 degree slope) beach gradients.	Y	Y	Y
Small tidal range	Y	Y	Y
Tidal mud flats/large tide flats-dangerous tides and debris shunting	N	N	N
Bathymetry			
Direct Offshore bathymetry (m)	5	5	5
Offhsore bathymetry characteristic gradual (G) Steep (S:5-30m)	S	S	S
Offshore structures			
No dense subtidal seagrass (SG), algal grow th, reef structures(R) offshore, unvegetated soft bottom (U	RF+S	N	RF
Clear access to the sea (not blocked by breakw aters or jetties)	Y	Y	Y
Ecological impact			
No endangered/threatened species nesting on beach	N	N	N
Sensitive beach vegetation			
Social Impacts			
Remote from human settlements, seldom visited by tourists, and w ithout easy access to motor vehicles	Y	Y	N
Nearest township	Cape Jervois	Victor Harbour	Victor Harbour
distance(km)	18000	14000	1500
direction	W	E	W
Fisheries			
Nearby inshore fisheries, Marine fishing areas (MFA)	Y	Y	Y
Marine scale(MS)	MS44B	MS44	MS44
Blue Crab(BC)			
Crayfish(CR)	CR(44)	CR(44)	CR(44)
Shark(SH)			
ABALone(AB)	AB(25A)	AB(25B)	AB(25C)
Praw n(PR)			
Sardine(SD)	SD44B	SD(44B)	SD(45)
Nearby anchorages	N	N	Y
Cultural Impacts			N
Not on aborgincal land or involve cultural heritage sites-council agreements	N	N	N
Economic			
Within reach of a refuse centre	Y	Y	Y
Within council locations (state council region)	Yankalilla	Yankalilla	Victor Harbour
Site access			
Access year round.	Y	Y	Y
Access 4WD(4) or 2WD(2)	4	2	2
Subjective			
Not previously used for litter surveys	N		
Can be sampled any time of year/periodically	Y	Y	Y
Main beach usage sw imming (S), fishing (F) boating(B), recreational (R)	FSR	FSR	RF
Boat access	N	N	N
Anchorages	N	N	N
Remote	Y	Y	N
Comments			
Access coordinates			35°32'28.95"S
Access coordinates			138°38'16.21"E
Road type	Farm property	Main road	Main road
Beach access	4w d	2w d	2w d
JPG Image for site	Y	Y	Y
Search area mapping for site	Y	Y	Y

1.2 Marine debris survey methods

For most sites within the region this is the first standardised quantitative survey of marine debris to be conducted. Other important litter awareness activities (i.e. Clean Up Australia Day) are undertaken within the region annually and report major rubbish types and most polluted sites but these do not differentiate between marine and terrestrial litter sources and are variable with regards to collection methods. Data here are expressed as standing crop ((unit quantity of debris) per (unit length of beach)) (Cheshire et al., 2009) as temporal flux rates (debris accumulation rate) could not be assessed. The majority of coastline within the survey region comprises short fragmented beaches with variable profiles (curvature, shape) (Short, 2006) (Appendix 2). Given the irregularity of debris deposition resulting from environmental conditions (i.e. long-shore and offshore currents, wind, tide, temperature) (Ribic et al. 1992; Samarasinghe and Mason, 2003; Middleton and Bye, 2007) and differences in buoyancy between debris types (i.e. glass, plastic, ceramic) (Morrison, 1999; Bravo et al. 2009; Santos et al., 2009) all debris collections comprised the area from the low tide line to the base of the beach vegetation, cliff area or first primary dune on the upper section of the beach. Where sites showed large tidal range, beach width was standardised to 50 m from the high-tide line. For most sites the sampling unit consisted a 1000 m linear transect parallel to the coastline. For beaches ≤ 1000 m, a whole beach approach was used as the sampling unit. All debris items upwards in size of ~15mm from the longest axis within each sampling unit were collected. Each item was characterised according to the debris categories developed for this study based from the UNEP/IOC Guidelines on Survey and Monitoring of Marine Debris (Cheshire et al. 2009). Items within each category were photographed counted and weighed to the nearest 100 gm.

Debris density was determined for mass and abundance of items collected (number items / search area (m^2)) (mass (gm) / search area (m^2)). The importance of representing site pollution rank (density) by both indexes is shown in Table 5. Based on mass alone, the simple model equally ranks density even though one item may only be collected (i.e. a refrigerator), thus potentially biasing rank order to sites containing denser and heavier items compared to sites containing a large number of lighter items (i.e. plastic bags). Conversely, based on items alone, rank order increases with the number of items, however, if this is represented by a large number of small items (i.e. fragmented plastic pieces) then rank order will bias towards those sites.

1.3 Marine debris fragmented plastics sampling

Fragmented plastics are known to impact marine predatory species such as seabirds that can misidentify fragmented plastic as small prey. For each survey site, five 1m x 1m quadrates were placed at random along the transect length and approximately 30 cm of the surface sand sieved. Fragments of plastic were collected from each sieve and stored in vials or bags. Data was recorded on data sheets provided within the Marine Debris Survey Information Guide.

Table 5. Example of relationship between density-mass (total mass / search area m^2) and density-abundance (total items / search area m^2) and their relative pollution rank order. Higher density values indicate higher pollution rank (kg-items / m^2).

Number items	Mass (kg)	Search area (m^2)	Density-mass (kg / m^2)	Density-items (items / m^2)
1	50	2500	0.02	0.0004
2	50	2500	0.02	0.0008
3	50	2500	0.02	0.0012
4	50	2500	0.02	0.0016
5	50	2500	0.02	0.002
6	50	2500	0.02	0.0024
7	50	2500	0.02	0.0028
8	50	2500	0.02	0.0032
9	50	2500	0.02	0.0036
10	50	2500	0.02	0.004
11	50	2500	0.02	0.0044
12	50	2500	0.02	0.0048
13	50	2500	0.02	0.0052
14	50	2500	0.02	0.0056
15	50	2500	0.02	0.006

1.4 Marine debris workshops, media, volunteer and council participation

Two workshops (metropolitan and regional) were advertised and initially conducted for the public to raise the profile of the marine debris surveys and to determine community interest in data collection for the marine debris program. (Supplementary 2). Volunteers including community groups, progress associations, and primary and secondary schools registered their interest at each workshop. Volunteers were then coordinated for debris survey collections depending on their residing location. The Marine Debris Survey Information Guide (MDSIG) (Peters, 2010) outlining the background to impacts of marine debris, personal requirements, sampling procedures, and all worksheets was sent to each volunteer prior to each survey. The MDSIG also listed the recycling centres for debris disposal once surveys were complete (Appendix 4). Additionally, we provided photographic material, maps, and GPS co-ordinates of each site to each volunteer. Participants were required to fill in a volunteer safety registration and preexisting medical condition form prior to commencement of each survey. A risk assessment for each site was determined prior to each survey (Table 6.).

1.5 Assessment of Gross pollutant trap (GPT) and trash rack (TR) debris recovery.

Organic and inorganic pollutants were monitored by the AMLRNRMB through Gross Pollutant traps (GPT) and Trash Rack (TR) recovery systems for the reporting period of the MDTAP for May 2008 - Dec 2010 although the mass volume data has been collected since May, 1995. Nineteen sites are solely managed by AMLRNRMB with 6 sites cost shared with local councils. For simplicity the data for GPT and TR are combined volumes presented as metric tonnes (1000 kg-t) for i) annual mass of inorganic and organic pollutants intercepted historically (May 1995-April 2009) and for the reporting period of the TAP for May 2008 – April 2010. The data provides an indication of the quantities of land-based organic and inorganic debris intercepted from highly urbanised catchments and prevented from entering Gulf St. Vincent. This provides a relative indication of inputs from similar catchments where GPT and TR are not yet installed (see Fig. 7).

Table 6. Marine debris survey site risk assessments and examples used to determine appropriateness for volunteers to complete the surveys safely.

Hazard-Risk Assessment			**Location name**											
			Kemps Bay	**Bangalee Beach**	**Cape Spencer**	**Cable Bay**	**Point Hicks**	**Wattle Bay**	**She Oaks Flat South**	**Long Beach Port Vincent**	**Stansbury**	**Tiddy Widdy**	**Mullowurtie Point**	**Black Point**
Weather	**Hazard/ Risk**	**Application**	**YP1**	**YP2**	**YP3**	**YP4**	**GSVWZ3A**	**GSVWZ3B**	**GSVWZ2A**	**GSVWZ2B**	**GSVWZ2C**	**GSVWZ1A**	**GSVWZ1B**	**GSVWZ1C**
Sun exposure	Sunburn	All participants	2	2	2	2	2	2	2	2	2	2	2	2
Extreme hot/cold/wet/windy weather conditions	Dehydration, heat exhaustion, hypothermia	All participants	2	2	2	2	2	2	2	2	2	2	2	2
Other														
Rubbish and sharp objects	Cuts, scratches, infections, needle stick injury	All participants	2	2	2	2	2	2	2	2	2	2	2	2
Insects and dogs and poisonous plants	Bites and stings, allergic reaction, infection	All participants	1	1	1	1	1	1	1	1	1	1	1	1
Snakes	Snake bite injury	All participants	1	1	1	1	1	1	1	1	1	1	1	1
Bushfire risk	Injury from fire or smoke	All participants	1	1	1	1	1	1	1	1	1	1	1	1
Site														
Car access	Difficult or dangerous access to site	All participants	2	1	1	1	1	1	1	1	1	1	1	2
Steep slopes, wet or uneven ground	Injuries from slipping/tripping	All participants	3	3	2	1	2	1	1	1	1	1	2	1
Uneven tracks dangerous access point	Ankle Injuries	All participants	2	2	2	1	1	1	1	1	1	1	1	2
Cliff edges	Falling/death	All participants	2	1	1	1	1	1	1	2	1	1	2	1
Cliff edges	Rockfall	All participants	1	2	2	2	1	1	1	2	1	1	2	1
Dangerous or diffcult beach structure	Drowning, injury, infection	All participants	1	2	1	1	2	1	1	1	1	1	2	1
Working near water	Drowning, injury, infection	All participants	2	2	1	2	2	2	2	2	2	2	2	2
Coastal Intertidal work	Large waves	All participants	2	1	2	2	1	1	1	1	1	1	1	1
Coastal Intertidal work	Hazardous marine life	All participants	1	1	1	1	1	1	1	1	1	1	1	1
Working alone or in isolated areas	Injury, exposure to weather, becoming lost	All participants	1	2	2	1	1	1	1	1	1	1	1	1
Large tidal range	Risk of swamping/drowning	All participants	1	2	1	1	2	2	1	1	2	1	1	1
Ability to move rubbish	Injury	All participants	2	2	2	2	2	1	1	1	1	1	1	1
Number parameters indicating high risk			**1**	**1**	0	0	0	0	0	0	0	0	0	0
Site Photograph (Y/N)			Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
RISK LEVEL	**1 = Low risk**	Relatively safe site, no significant danger to participants.												
	2 = Medium risk	Medium safety precautions required to be followed.												
	3 = High risk.	Not to be undertaken by volunteers unless NRM staff present or by NRM staff only.												

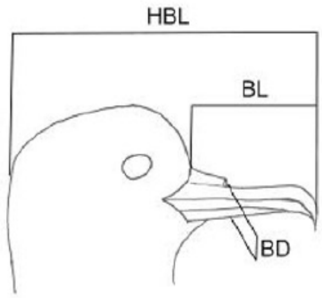
1.6 Investigation of marine debris ingestion by seabirds, Short-tailed shearwater (Puffinis tenuirostris) (STSW).

The Short-tailed shearwater (*Ardenna tenuirostris*: *Puffinus tenuirostris*) is globally, one of the most highly abundant, wide ranging migratory procellariiformes (shearwaters and petrels) with a population estimate of 23 million individuals. During the austral winter the species exploits productive regions within the Northern Pacific and Bering Sea, northern hemisphere, and seasonally returns in the austral summer to breed, inhabiting coastal islands off south-eastern Australia from Tasmania, Victoria, and South Australia whilst foraging in productive waters of the Southern Pacific ocean (Hunt et al. 1981, Shuntov, 1961; Einoder et al. 2009). Shearwaters employ surface-subsurface pursuit feeding behavior. Individuals consume prey localised at surface waters or dive and utilise euphotic prey up to depths of 40m (Hunt et al. 1996; Einoder et al. 2009). Thus, using a dual-feeding strategy, enables them to target a wide range of congregational species including Australian anchovy (*Engraulis australis*), Australian pilchard (*Sardinops sagax*), Australian krill (*Nyctiphanes australis*), Jack mackerel (*Trachurus declivis*), euphausiids, crustaceans, amphipods, and cephalopods (Baltz & Morejohn 1976, 1977; Ogi et al. 1980; Sanger, 1983, 1988; Montague et al. 1984; Einoder et al. 2009). The significant distances covered during migration (15,000 km) and intergenerational energy transfer from parents to offspring during breeding, means the energy requirements of individuals are large, thus consumption of rich food resources for successful breeding and migration are essential.

Procellarid seabirds are also known consumers of floating marine debris. Reports of plastics ingestion, predominantly surface-submerged small fragmented pieces, industrial pellets and monofilament line extend to species in both hemispheres, with amounts consumed varying spatially between species but typically related to feeding behavior and proventriculus-gizzard induced retention digestive physiology (Furness, 1985; Robards et al.1995; Vliestra and Parga, 2002; Colabuono et al. 2010). The effects of plastic ingestion are not however, equivocal between species (e.g. Ryan, 1987), although direct autonomous effects can constitute mechanical ulceration and lesion of the gut resulting in death or reduction of individual fitness (Sievert & Sileo, 1993). Indirectly, plastic ingestion can implicate poorer body condition resulting from impaired ingestion, and available assimilation of prey (i.e. Laysan Albatross (*Phoebastria immutabilis*), Sievert & Sileo, 1993; Flesh-footed Shearwaters (*Puffinus carneipes*), Wedge-tailed Shearwaters (*Puffinus pacificus*), Hutton et al. 2008; Short-tailed shearwater (*Ardenna* tenuirostris), Carey, 2011). Furthermore, plastic ingestion by seabirds and other high-trophic order predators can lead to disruption of physiological pathways, particularly in endocrine function, from bioaccumulative toxicity of persistent organic pollutants (POPs) absorbed within plastic fragments (e.g.

polychlorinated biphenyls (PCBs) and organochlorine pesticides (OCPs)) (Tanabe et. al 2002; Colabuono et al. 2010).

Life history patterns suggest mortality events in Short-tailed shearwater's occur primarily after transoceanic migration where stored energy reserves of adult and yearlings are exhausted, thus leading to death by starvation or drowning (Douglas & Setton, 1955; Baduini et al. 2001). To investigate the consumption of plastics by the short-tailed shearwater deceased birds were collected for analysis during a major mortality event across south and eastern Australia during October 2010. Deceased specimens were collected on 2 occasions from south facing coasts Victor Harbor, South Australia (-35° 30' 50.4"S, 138° 46' 12"E). Avian necropsy followed the recommendations outlined by the National Wildlife Health Centre Manual, Hawaii (NWHC) (Work, M., 2000). Carcasses were photographed, and body mass calculated using digital scales to nearest 100gm. Skeletal traits were measured using vernier calipers; Head-bill length (HBL: supra-occipital to bill frontal edge) , bill length (BL: edge of forehead feathering to bill distal hook), and bill depth (BD: concave dorsal surface in front of anterior nostrils) (Fig. 2). To determine the sex of each specimen we applied the discriminant function outlined as:



$$D = -56.325 + 1.964 * BD + 0.493 * HBL$$

where BD is bill depth and HBL is head + bill length (Einoder et al. 2008; Reynolds et al. 2008).

Figure 2.Morphometric measurements used to discriminate sex in deceased short-tailed shearwaters collected for gut sampling. (HBL) Head-bill length, (BL) bill length, (BD) bill depth (Einoder et al. 2008).

Examination results were documented on datasheets, with particular attention to remains recovered from the digestive tract (proventriculus (pre-stomach) and ventriculus (gizzard), small and large intestine). Stomach contents were isolated by washing through nested sieves (smallest 100µm).

Marine debris data assessment and analyses

Due to the nature of debris classification and the data entry, the debris collections could be assessed using a number of parameters. Overall, major debris composition (plastic, foamed plastic, cloth, glass and ceramic, metal, paper and cardboard, rubber, wood, composite) were determined for each region and site. Data was broadly assessed by region (East GSV, West GSV, Kangaroo Island (KI), lower Yorke Peninsula (LYP), and lower Fleurieu Peninsula (LFP)), energy status (high energy vs. low energy beaches), and population level (urban and rural). Data was further categorised into major polluting groups (general housing, fishing and boating, packaging, building, smoking, sanitary, and unknown sources) which enabled us to determine the potential items and debris types likely to be hazardous to marine species and ecological communities.

2.1 Statistical analysis

Data generated from the surveys were represented statistically as abundance, mass and density ± standard deviation. Density was calculated for both mass and abundance data for each site and compared per region using parametric one-way analysis of variance (ANOVA) with Tukey's Post hoc tests, providing data assumptions of normality and variance were met (SPSS v.19, 2010). Data were otherwise transformed or non-parametric testing performed.

Variation in debris abundance composition between sites-regions were tested for significance using ANOSIM (Analysis of similarity) using the Bray-Curtis similarity-dissimilarity matrix in Primer v6 (PRIMER-E Ltd.). The R_{ANOSIM} statistic provides a relative measure of separation between groups with R values of zero (0) supporting the null hypothesis, and a value of one (1) indicating samples within defined groups are more similar to one other than samples from other groups.

$$R = \frac{r_B - r_w}{n(n-1)/4}$$

where R is the difference between the average of all rank dissimilarities between objects between groups (r_B) and average of all dissimilarities between objects within groups (r_w). Abundance data was used for the analysis as many items collected could not be represented by weight as a result of their composition (e.g. small plastic pieces). For all analyses, data was bootstrapped 10,000 iterations and a similarity percentage analysis (SIMPER) (Clarke, 1993) was applied to all significant data to identify the discriminating feature of the dissimilarities. Where data were significant, a principle coordinate analysis (PCoA) was used to separate groups.

To evaluate if the extent of each survey provided representative coverage of the number of debris items identified, we calculated 95% of the asymptotic number of sites required to be sampled to adequately represent the types of debris found across combined regions of GSV, KI, LFP and LYP in R (Foundation for Statistical Computing, version 2.12, R Development Core Team, 2010). Initially, one of the sites was selected at random and the total number of debris items identified was calculated at that site. A second site was chosen at random, from the other sites and the number of debris items that it identified was calculated. The procedure was replicated until all sites across the four regions (GSV, KI, LYP, LFP) were included in the calculation of the cumulative number of debris items identified. The data was bootstrapped (Monte Carlo) 10,000 times for each site to estimate the mean and the associated variance (Manly, 1997; Chernick, 1999), calculating the cumulative number of debris items identified by *j* sites ± standard deviation ($\hat{\sigma}_{boot}$):

$$\hat{\sigma}_{boot} = \sqrt{\frac{n-1}{n}}\left(\sqrt{\frac{1}{n(n-1)}\sum_{i=1}^{n}(x_i - x_j)^2}\right)$$

where *n* is the number of iterations, *x* is the mean number of debris items identified by the j^{th} sites at iteration *i* (Chernick, 1999).

The resulting data (mean number of debris items identified by site) was plotted using Curve Expert (v 1.4) (Hyams, 2009). The Gompertz function (y=a*exp(-exp(b-cx)) was applied to calculate the asymptotic number of debris items identified at each site, interpreted as the maximum number of debris items identified by *j* sites. We then calculated the asymptotic number of sites required to be sampled to achieve 95% coverage of the overall debris diversity.

Results

Marine debris

3.1 Overall composition and quantities of marine debris collected

In total, 33.8 ± 0.23 linear kilometres covering 0.87 km^2 of coast were surveyed across 38 sites (Fig. 1, Table 1 - 3). Debris was found at all sites with 12,603 ± 55.5 debris items and 985.2 ± 10.27kg collected. The sampling area of individual sites ranged between 3392.88 - 52434.8 m^2 with an average sampling area of 22781.30 ± 12981.67 m^2 (Table 1 - 3). Overall, the beach area surveyed was not significantly different between regions (all comparisons $P > 0.05$, ANOVA: $F = 2.277$, d.f. = 4, 37, $P = 0.082$). Of the 10 major debris categories (plastic, wood, glass and ceramic, foam, material, metal, paper, rubber, composite, other) plastic was most commonly encountered debris type by number (n = 10041, 80%), mass (505.5 kg, 51.3%) and frequency (53.3% not shown) followed in abundance by glass and ceramic-based items (n = 1282, 10%), but by rubber-based products for mass (113.1 kg, 11.5%) (Table 7). This was predominantly from the collection of rubber tyres (n = 14) which represented 88.8% of the overall mass of rubber collected. This simple result highlights the importance of collecting both abundance (items) and weight related data as single items (e.g. car tyres, televisions) heavily skew results using weight data alone.

Table 7. Total quantity (abundance (number of items) and mass (kg)) by major debris type (%) of debris collected for 38 sites over the collection period.

Major litter category	No. items	%	kg	%
Plastic	10041	79.7	505.5	51.3
Glass and ceramic	1282	10.2	84.2	8.5
Foam	419	3.3	8.4	0.9
Metal	292	2.3	61.8	6.3
Wood	224	1.8	83.6	8.5
Rubber	171	1.4	113.1	11.5
Material and clothing	106	0.8	23.0	2.3
Paper and cardboard	33	0.3	7.8	0.8
Other	23	0.2	16.2	1.6
Composite	12	0.1	81.7	8.3
Total	**12603**	**100**	**985.2**	**100**

Of all the types of plastic debris recovered, 53% (n = 5327 items, 23.24 ± 0.66 kg) were hard fragmented plastic pieces (small n = 4992, large n = 331) unidentified in origin. Plastic packaging (14.2%, n = 1430) commercial or recreational-based fishing debris (13.8%, n = 1382) and containers (13.1%, n = 1316) were the most common plastic items recovered by number after fragmented plastics. By mass, commercial and recreational-based fishing debris were the most polluting items comprising 86% (436.5 ± 23.7 kg) of the overall plastic debris collected (see section 3.6) followed by fragmented plastic pieces (4.6%, 23.2 ± 0.67 kg) and plastic containers (4.4%, 22.02 ± 0.39 kg).

3.2 General site analysis

For 84 % of sites (n = 31), plastic was the major contributing debris type. This ranged between 42.2% – 98.8 % of the total debris composition at each site (Table 8, Appendix 5.). Of this debris group, hard plastic fragments were the dominant debris item detected in 32 sites (84%), and for the remaining sites the major contributors were soft plastics comprising either food wrappers or fishing related debris (~11% each) (see Table 9-12). Glass and ceramic-based items were the most prevalent debris type in five of the remaining sites (range: 37.9% - 84.3%), with foam (81.5%) and wood-based debris (51.1%) in the remaining two sites (Table 8). Plastic was also the major contributor by mass in 61% of sites (n = 23). For the remaining sites, glass was the dominant item (n = 4, 11%) followed by rubber and wood (8 %, n = 3), while metal and composite items (e.g. televisions, chairs) contributed 5% (n = 2) and foam and cardboard (4%, n = 1) (Table 8).

3.3 Debris abundance, mass and density

Density-abundance (items) of debris from the beaches surveyed across all regions ranged from 0.001 to 0.066 items m^{-2}, with mean density of 0.017 ± 0.016 items m^{-2} for all sites. Density-mass (gm/m^{-2}) ranged between 0.018 – 26.19 gm/m^{-2}, with mean density of 2.06 ± 4.76 gm/m^{-2} (Table 8). Density was not significantly different between the five regions tested by number of items or mass (ANOVA: F = 0.595, d.f. = 4, 34, P = 0.669, ANOVA: F =0.595, d.f. = 4, 34, P = 0.427 (respectively). This was also reflected for item abundance data for each region (all comparisons P = < 0.05). Based on raw mass and abundance data (Fig 3.), Sandhurst beach and West Bay, Kangaroo Island contained the largest number of items primarily due to the collection of small plastic fragments, followed by urban sites Willunga and O'Sullivan Beach from collection of plastic food wrappers and plastic straws. By mass, Black Point on

Table 8. Density, % abundance (items) and mass (gm) (shaded) of major debris categories collected for all sites per region: Kangaroo Island, Gulf St. Vincent West, Gulf St. Vincent East, Lower Fleurieu Peninsula, and Lower Yorke Peninsula, South Australia. Data highlighted is mean ± s.d.

Site	Density (items/m^2)	Density (gm/m^2)	Plastic		Glass and ceramic		Metal		Foam		Rubber		Wood		Material		Paper and cardboard		Composite		Other	
Kangaroo Island																						
American Beach	0.006	0.44	81.7	43.7	9.9	2.0	-	-	2.1	1.0	1.4	0.2	2.8	23.1	2.1	28.1	-	-	-	-	-	-
Bales Bay	0.014	0.19	97.1	71.3	1.0	23.8	-	-	1.7	5.0	0.2	-	-	-	-	-	-	-	-	-	-	-
Cape Gantheaume	0.022	0.36	95.5	67.4	2.0	24.4	0.5	1.0	1.0	2.0	0.7	0.3	-	-	-	-	0.2	1.0	-	-	0.2	1.0
Destrees Bay	0.007	0.21	74.8	46.2	5.4	20.0	10.8	5.4	7.2	6.9	-		1.8	21.5	-	-	-	-	-	-	-	-
Red Banks	0.006	0.77	5.6	-	9.3	12.1	-	-	81.5	0.0	1.9	6.1	-	0.0	1.9	1.4	-	-	-	-	-	-
Rocky Point	0.007	0.12	88.3	21.1	4.9	63.2	1.3	-	4.0	2.6	-		-	0.0	0.4	10.5	-	-	-	-	-	2.6
Rocky River	0.066	14.64	47.1	28.1	-	0.0	-	-	1.3	0.3	0.4	-	51.1	71.6	-	-	-	-	-	-	0.9	-
Sandhurst Beach	0.052	0.71	94.4	58.7	1.6	26.8	0.3	2.2	2.9	5.0	0.5	0.5	0.1	0.6	0.1	0.6	-	-	-	-	0.2	3.4
Sandy Creek Beach	0.032	0.37	96.5	64.3	0.6	10.1	0.8	2.9	1.3	19.0	0.4	0.3	0.4	-	-	-	-	-	-	-	-	-
Vivonne Bay	0.006	0.02	96.6	14.3	0.4	28.6	0.4	-	2.5	57.1	-		-	-	-	-	-	-	-	-	-	-
West Bay	0.024	0.06	98.6	96.5	0.4	0.0	0.2	-	0.5	-	-		0.1	-	0.2	3.5	-	-	-	-	-	-
Point Morrison	0.014	5.48	54.9	2.6	14.4	1.5	19.6	1.0	2.0	-	5.2	0.8	-	-	3.3	3.4	-	-	0.7	90.2	-	-
	0.021 ± 0.02	**1.95 ± 4.26**	**77.6**	**46.7**	**4.5**	**17.7**	**4.2**	**2.5**	**9.0**	**9.9**	**1.3**	**1.4**	**9.4**	**19.5**	**1.3**	**7.9**	**0.2**	**1.0**	**0.7**	**90.2**	**0.4**	**2.3**
Gulf St. Vincent West																						
Black Point	0.016	26.20	71.1	98.2	10.8	0.5	9.3	1.0	0.5	-	3.6	0.3	2.6	0.2	1.5	-	0.5	-	-	-	-	-
Mullowurtie Point	0.005	2.74	70.6	90.2	15.6	1.3	3.7	3.4	1.8	-	1.8	0.5	2.8	2.8	1.8	1.5	1.8	-	-	-	-	-
Point Hicks	0.002	0.17	37.1	24.5	37.9	16.4	12.9	8.8	5.2	3.8	-		3.4	28.9	3.4	17.6	-	-	-	-	-	-
Port Vincent Long Beach	0.009	6.52	28.0	4.5	40.7	3.3	11.9	1.8	6.8	0.3	6.8	55.1	0.8	0.2	4.2	0.9	-	-	0.8	27.1	-	-
Stansbury Back Beach	0.030	4.41	42.2	17.8	40.8	11.9	6.3	1.4	2.9	0.3	2.7	39.8	0.4	0.8	3.6	6.8	0.2	0.2	0.7	0.3	0.2	0.6
Tiddy Widdy Beach	0.007	0.27	12.3	4.2	78.1	42.0	0.7	1.7	3.4	1.7	2.7	0.3	0.7	33.6	1.4	3.4	-	-	0.7	8.4	-	-
Wattle Bay	0.004	0.20	55.6	86.2	1.9	3.4	11.1	3.4	5.6	-	1.9	-	20.4	-	3.7	6.9	-	-	-	-	-	-
	0.012 ± 0.01	**5.79 ± 9.32**	**45.3**	**46.5**	**32.3**	**11.3**	**8.0**	**3.1**	**3.7**	**1.5**	**3.2**	**19.2**	**4.4**	**11.1**	**2.8**	**6.2**	**0.9**	**0.2**	**0.7**	**11.9**	**0.2**	**0.6**
Gulf St. Vincent East																						
Carackalinga	0.003	0.07	67.2	-	28.9	23.1	0.8	3.8	0.8	3.8	-		1.6	61.5	-	-	-	-	0.8	7.7	-	-
Great Sandy Beach	0.023	2.85	9.7	3.3	67.6	47.7	11.9	15.9	0.6	3.3	1.7	2.2	2.2	3.3	3.2	3.1	0.9	-	0.2	0.2	1.9	19.5
Hallet Cove	0.031	1.02	72.1	39.0	1.1	0.7	3.3	23.3	17.6	2.1	2.5	1.2	0.4	0.7	0.4	-	1.8	-	0.4	5.5	0.2	20.5
Morgan's Beach	0.018	0.38	84.6	44.3	2.1	0.0	2.4	1.6	2.8	-	4.2	1.3	2.4	6.6	0.3	1.6	1.0	24.6	-	-	-	-
North Parham	0.008	1.84	48.7	3.5	11.3	14.9	7.0	1.2	0.9	-	9.6	1.5	9.6	55.3	11.3	19.2	0.9	-	-	-	0.9	-
O' Sullivan Beach	0.058	1.00	94.2	91.7	0.6	1.5	0.8	0.8	1.9	0.8	1.3	0.2	0.8	3.0	0.4	0.8	-	-	-	-	-	-
Rapid Bay	0.004	0.15	77.2	71.6	3.7	9.1	10.3	15.8	2.2	-	2.2	0.2	-	-	2.2	-	2.2	-	-	-	-	-
Tennyson	0.005	0.05	91.3	53.8	0.7	15.4	-	-	0.7	7.7	5.1	0.2	-	-	1.4	7.7	-	-	-	-	0.7	-
Willunga Beach	0.016	0.92	91.5	12.8	0.9	9.1	0.5	52.1	3.9	-	2.0	0.1	0.7	24.8	0.4	1.0	0.2	-	-	-	-	-
	0.018 ± 0.018	**0.92 ± 0.93**	**70.7**	**40.0**	**13.0**	**13.5**	**4.6**	**14.3**	**3.5**	**3.5**	**3.6**	**0.9**	**2.5**	**22.2**	**2.5**	**5.6**	**1.2**	**24.6**	**0.5**	**4.4**	**0.9**	**20.0**
Lower Fleurieu Peninsula																						
Lands end	0.025	2.42	51.3	54.7	37.7	30.2	1.0	0.5	3.7	-	4.2	0.7	1.0	9.9	-	-	1.0	0.8	-	-	-	-
Tunkalilla Beach	0.001	0.15	71.0	51.9	3.2	9.6	3.2	1.9	9.7	7.7	3.2	0.2	-	-	3.2	15.4	6.5	9.6	-	-	-	-
Victor Harbour East	0.027	0.66	92.8	7.6	1.2	43.2	1.0	0.8	3.3	-	0.2	0.1	0.8	5.1	0.4	-	0.2	42.4	-	-	-	-
Waitpinga Beach	0.018	0.15	95.6	46.7	0.5	15.6	1.2	2.2	1.4	6.7	0.5	-	0.7	28.9	-	-	-	-	-	-	-	-
	0.018 ± 0.01	**0.85 ± 1.08**	**77.7**	**40.2**	**10.7**	**24.7**	**1.6**	**1.4**	**4.5**	**7.2**	**2.0**	**0.3**	**0.9**	**14.6**	**1.8**	**15.4**	**2.6**	**17.6**	**-**	**-**	**-**	**-**
Lower Yorke Peninsula																						
Bangalee Beach	0.028	0.56	68.2	72.0	19.8	20.7	1.7	1.0	7.0	2.1	2.5	0.2	0.4	-	-	-	-	-	0.4	-	-	-
Cable Bay	0.003	1.86	45.5	-	4.5	0.8	27.3	90.9	-	-	-		4.5	7.6	18.2	0.8	-	-	-	-	-	-
Cape Spencer	0.022	0.26	98.8	79.7	0.2	8.5	-	-	-	-	0.6	0.3	-	-	-	-	0.4	6.8	-	-	-	-
Chinamans A	0.016	0.78	5.9	83.1	84.3	9.1	3.1	0.8	1.2	-	1.2	0.1	1.2	-	3.1	6.2	-	-	-	-	-	-
Chinamans B	0.009	0.23	57.1	18.2	19.0	9.1	4.8	-	7.1	-	4.8	0.1	-	-	-	-	-	-	-	-	7.1	63.6
Kemps Bay	0.006	0.25	72.9	57.5	-	-	-	-	16.5	1.7	2.3	0.3	6.0	27.2	0.9	1.1	-	-	0.5	9.1	0.9	-
	0.014 ± 0.01	**0.66 ± 0.62**	**58.1**	**62.1**	**25.6**	**9.6**	**9.2**	**30.9**	**8.0**	**1.9**	**2.3**	**0.2**	**3.0**	**17.4**	**7.4**	**2.7**	**0.4**	**6.8**	**0.4**	**9.1**	**4.0**	**63.6**

the upper west coast of Gulf St Vincent, was highest polluted beach (301.8 kg). This was principally due to the collection of plastic oyster racks and remnants of disused oyster aquaculture leases, which were also the main contributing item/s to overall mass at Mullowurtie Point situated ~10 km south of Black Point. This result was also reflected in density-mass; Black Point contributing the highest mass of debris (gm) per m^2 (Fig 3.) followed by Rocky River, Kangaroo Island. However, the latter site was ~3.5 times smaller in search area size than Black Point (11788 m^2 vs. 3378 m^2, respectively) (Table 1, 3). While Rocky River showed a lower number of items collected, it contributed the highest density-items / m^{-2} most likely due to the small sample area size and irregularity of debris collection. For other sites exhibiting higher item densities (e.g. Sandhurst beach, Victor Harbor, Sandy Creek), the main contributing items to these were plastic fragments or plastic debris composed of plastic bottle caps and lids, food wrappers, or plastic drinking straws (e.g. O'Sullivan Beach, Willunga Beach) (Fig. 3). There was a significant positive correlation between sample area size and number of items collected (Spearman's r^2 = 0.121, P = < 0.05) (Fig 4.), but item density remained static as site search area size increased (r^2 = 0.090, P > 0.05). However, not all sites with larger search areas produced a higher number of debris items. For example, Point Hicks on western Gulf St. Vincent was the 3rd largest site in search area but produced low number, mass and densities of debris items (Table 8, Fig. 3).

3.4 Regional differences

There were some significant differences observed between debris quantity (items) and type between the 5 regions surveyed (R_{ANOSIM} = 0.35, P = < 0.001). Notably, regions containing higher energy open ocean beaches (LYP, KI, LFP, n = 18) compared to lower energy sheltered beaches (east and west GSV, n = 20) showed a significant difference in their composition (R_{ANOSIM} = 0.18, P = 0.01) (Fig. 5.). Although item abundance and mass were not significantly different, higher energy sites contained a larger number of light debris items compared to lower energy sites where items were fewer but heavier (7428 and 182.8 kg vs. 5175 and 802. 4 kg, respectively). SIMPER analysis identified the main component for the dissimilarity between the two groups was due to the incidence of plastic fragments which were more common at high energy sites compared to low energy sites (i.e. Gulf St. Vincent). Abundance data further indicated lower energy sites have significantly higher composition of packaging debris (plastic food wrappers, bags) compared to high energy sites, probably as a result of their urban localities (χ^2 = 634, d.f. = 1, 179, P = <0.001). East and west GSV regions (EGSV, WGSV) were also significantly different, with the largest dissimilarity between the regions associated with the abundance of glass fragments and oyster racks from upper west coast GSV ($R_{ANOSIM} = 0.39$, $P = < 0.001$ SIMPER, 0.71).

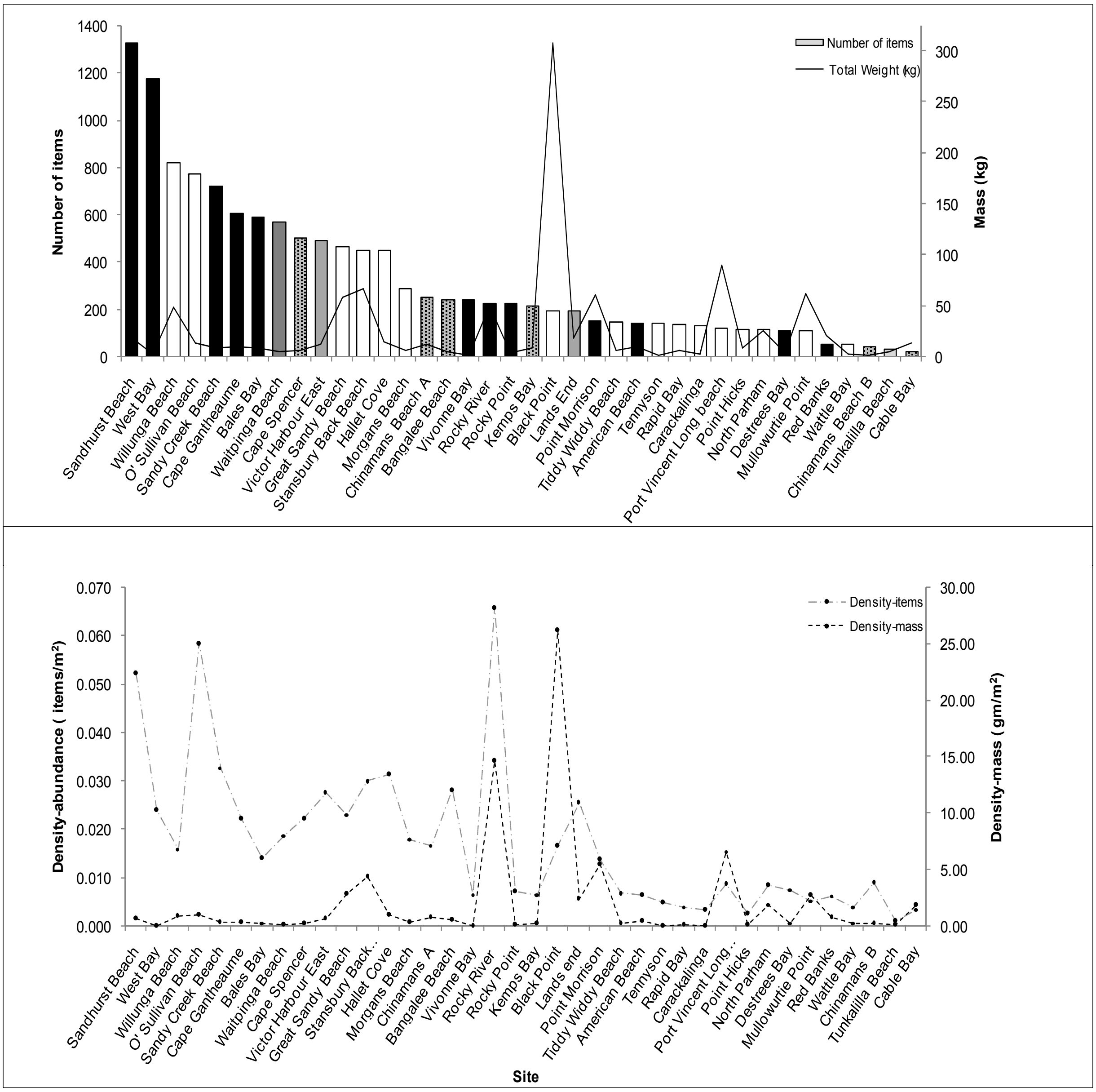


Figure 3. Total item abundance, mass (kg) (upper) and density-abundance-mass plots (lower)of marine debris collected for 38 sites. Sites within regions are Gulf St.Vincent (white bars), lower Yorke Peninsula (hashed bars), lower Fleurieu Peninsula (grey bars) and Kangaroo Island (black bars).

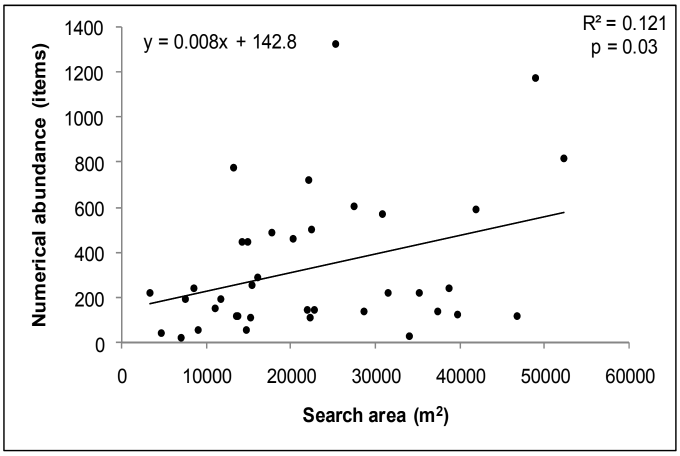


Figure 4.Total abundance (number items) relative to search area (m^2). Data indicates an increase in search area significantly increased the number of items collected ($P < 0.05$) (n = 38 sites).

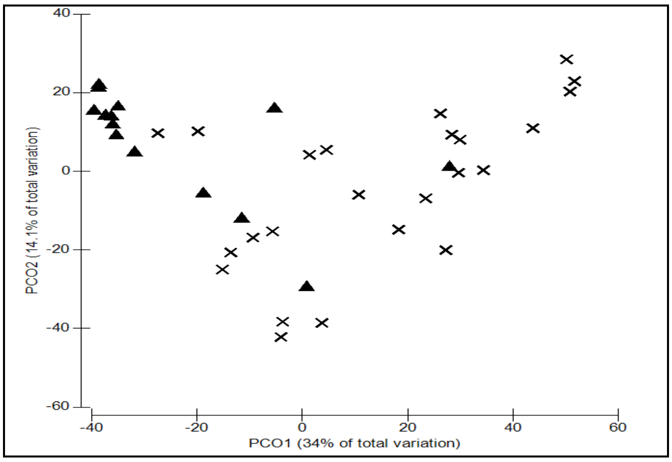


Figure 5. Principal coordinate analysis of debris abundance data collected from high energy open ocean sites (▲) and lower energy (×) beach sites (n = 38). Fragmented plastic pieces were responsible for the dissimilarity and separate group clustering for high energy sites compared to low energy sites ($P < 0.05$).

3.5 Major pollution sources

Debris collected from all sites was categorised by user group to determine the potential terrestrial or marine-based origin. Because classification of debris is often subjective, the terrestrial-marine grouping comprises both debris that may originate from land and marine-based sources. For example, timber (building products) and plastic bottles (containers) are floatable items and can easily transport across water bodies. Overall, there were 6 major contributing groups to debris across all sites (Table 9, 10).

Table 9. Marine debris (number of items and mass (kg)) categorised by major groups. For each group, the major contributing item by *abundance* (number of items) is listed as (%) overall. [1]Marine-based, [2]terrestrial, [1,2]terrestrial-marine based.

Debris group	Number of items	Mass (kg)	Main contributing item/s	Composition (%)
Fragments				
plastic [1]	5325	21.2	small plastic fragments	81.3
glass and ceramic [2]	1156	17.3		
metal [2]	68	27.6		
rubber [2]	1	0.1		
Packaging[1,2]	1976	33.5	Plastic food wrappers	43.9
Fishing & Boating[1]	1461	436.5	Marine rope	61.7
Containers[1,2]	1451	51.4	Plastic bottles and caps	92.0
General housing products[2]	642	51.2	Plastic straws	39.6
Building products[1,2]	291	130.5	Timber	67.8
Smoking[2]	106	0.3	Cigarettes	63.2
Automotive[2]	43	132.5	Tyres	48.7
Firearms[2]	20	-	Gun cartridges	100.0
Transport[2]	19	-	Plastic tickets	100.0
Sanitary[2]	17	0.7	Toothbrushes	76.5
Composite-Electrical[2]	12	81.7	Whitegoods	100.0
Watersports equipment[2]	9	0.5	-	-
Farming products[2]	3	0.1	-	-
Marine research[1]	2	-	-	-
Sex[2]	1	0.1	-	-
Total	**12603**	**985.2**		

These were building products, containers, fishing and boating debris, general housing goods, packaging, and debris fragments comprising plastic, glass and rubber. Of these, marine-based debris constituted the highest amount of debris by number and mass (n = 6788, 457.7 kg), followed by terrestrial-marine based debris (n = 3718, 215.4 kg) and terrestrial debris (n = 2097, 312.1 kg) (Table 9, 10). The major contributor to marine-based debris by number was the presence of marine plastic fragments (n = 5325) followed by commercial and fishing-boating debris predominantly pieces of marine nylon rope (n = 901) and oyster rack and mesh debris (n = 160). Oyster racks also comprised 79 % (343.5 kg) of the overall fisheries related debris collected (436.7 kg) which was the largest identifiable contributing group by mass (Table 9, 11, 12). For the marine-terrestrial group, the highest contributor of pollution resulted from the abundance of plastic containers (91%) followed by plastic packaging (72.4%). The former was dominated by hard plastic bottle lids (72%) and PET bottles (10%), while the latter group predominantly consisted of items of plastic wrappers (43%), plastic bags, and box strapping (~10% both groups).

Table 10. Sites and major categories of debris collected (abundance) for each user group. Data highlighted is mean abundance per region.

Site	Automotive	Building products	Composite materials	Containers	Farming products	Firearms	Fishing & Boating	General housing	Marine research	Fragments	Packaging	Paint products	Sanitary S	ex	Smoking	Transport	Watersports equipment
Kangaroo Island																	
American Beach		9		10			15	5		84	19						
Bales Bay				62			205	8		261	49		2				
Cape Gantheaume		1		84			74	17		405	23	1	1				
Destrees Bay		2		43			28	1		25	12						
Point Morrison	7	8	1	19	1	1	10	8		71	27						
Red Banks	1			1				2		4	46						
Rocky Point		5		19			24	6		135	32	1			1		
Rocky River		115		17			32	11		37	10		1				
Sandhurst Beach	4			138			167	17		931	51		6		9		
Sandy Creek Beach				124			132	15		436	4		4		4		
Vivonne Bay		1		9			17	3		196	10		1		1		
West Bay		1		80		2	169	15		870	32				4		
	4.0	**17.8**	**1.0**	**50.5**	**1.0**	**1.5**	**79.4**	**9.0**	**-**	**287.9**	**26.3**	**1.0**	**2.5**	**-**	**3.8**	-	-
Lower Yorke Peninsula																	
Bangalee Beach		2	1	28			21	11		147	29				3		
Cable Bay		1		3			1	4		12	1						
Cape Spencer				36			27	4		430	3		1				
Chinamans A		2		11			5	9		218	5				2		3
Chinamans B				3			2	5		8	23						1
	-	**1.7**	**1.0**	**16.2**	**-**	**-**	**11.2**	**6.6**	**-**	**163.0**	**12.2**		**1.0**	**-**	**2.5**	**-**	**2.0**
Gulf St. Vincent West																	
Kemps Bay		15	1	13			41	7	1	75	58	1			5		1
Black Point	2	10		14			126	7		29	6						
Mullowurtie Point		4		3			64	4		26	8						
Point Hicks		6		4			8	7		70	21						
Port Vincent Long Beach	5	1	1	19			13	9		52	18						
Stansbury Back Beach	6	4	3	32		11	31	23		220	117				1		
Tiddy Widdy Beach		2	1	7			6	7		110	13						
	4.3	**6.0**	**1.5**	**13.1**	**-**	**11.0**	**41.3**	**9.1**	**1.0**	**83.1**	**34.4**	**1.0**	**-**	**-**	**3.0**	**-**	**1.0**
Gulf St. Vincent East																	
Carackalinga		2	1	10			7	18		64	26						
Great Sandy Beach	2	25	1	35			7	34		314	41				4		
Hallet Cove		8	2	118		1	16	43		56	201				3		
Morgans Beach	8	6		63		1	29	15		89	70				5		
North Parham		14		24	2	1	11	24	1	9	27	1		1			
O' Sullivan Beach		8		153			12	124		114	351		1		1	10	
Rapid Bay	1	3		18			24	17		42	27				4		
Tennyson	1	1		37			2	36		37	22				2		
Wattle ay B		10		7		1	7	9		4	16						
Willunga Beach	2	10		97		1	32	87		124	448				7	9	2
	2.8	**8.7**	**1.3**	**56.2**	**2.0**	**1.0**	**14.7**	**40.7**	**1.0**	**85.3**	**122.9**	**1.0**	**1.0**	**1.0**	**3.7**	**9.5**	**2.0**
Lower Fleurieu Peninsula																	
Lands end		4		35		1	22	10		85	34						
Tunkalilla Beach				7			6	3		3	11						1
Victor Harbour East		6		15			15	13		351	58				30		
Waitpinga Beach		5		53			53	4		406	27				20		1
	-	**5.0**	**-**	**27.5**	**-**	**1.0**	**24.0**	**7.5**	**-**	**211.3**	**32.5**	**-**	**-**	**-**	**25.0**	**-**	**1.0**

The quantity of plastic packaging and containers collected was significantly higher for East GSV compared to West GSV and LYP (ANOVA: F =3.315, d.f. = 1, 32, P = 0.007, F = 1.432, d.f. = 1, 28, P = 0.002, respectively) but similar to KI and LFP (all comparisons P > 0.05). When site location was also considered (urban vs. remote) the combined abundance of containers and packaging was surprisingly similar between remote and urban sites (all comparisons P > 0.05), but the amount of fishing related items were significantly higher at remote sites compared to urban sites (Mann Whitney U= 11.0, d.f. = 1, 16, P = 0.027). The raw abundance data further indicated plastic food-wrappers and food packaging are more common sources of debris at urban sites than remote sites. Plastic drink bottles and plastic lids were also more common at remote sites compared to urban sites (Table 11).

Table 11. Summary comparisons of item abundance for the most common debris items collected from four of the six major debris user groups for urban (n = 12) and remote sites (n = 26). Figures highlighted are means.

Major group	Remote	Urban
Fishing & Boating	**1283**	**178**
Rope pieces	804	97
Anchor rope	2	0
Fishing traps and pots *	162	1
Bait baskets, crates & trays	121	4
Foam buoys	47	11
Fishing monofilament line	23	27
Plastic fishing floats and buoys	35	10
Fishing net	28	0
Plastic fish measuring devices	0	10
Fishing related (sinkers, lures, hooks, etc.)	47	11
Plastic burley buckets	1	5
Mesh bags (vegetable, oyster nets & mussel bags)	5	0
Oyster aquaculture	8	2
Containers	**969**	**598**
plastic bottle caps and lids	655	431
bottles (plastic, glass)	250	97
drums	12	6
aluminium cans	52	64
Packaging	**500**	**1261**
food wrappers	69	781
foam food packaging	188	169
plastic bags	116	158
fast-food and takeaway	20	121
strapping	96	27
corks	11	5
Fragments	**5302**	**1248**
plastic	4526	800
glass	728	428
metal	48	20

3.6 Fishing, boating and aquaculture debris

Commercial, recreational and vessel-based fishing debris consisted approximately 12 % of the overall number of debris items collected across all sites and represented the largest group by mass (44% of overall mass) (Table 12). This amount is likely an underestimate, as a number of items that were recorded could not be collected due to their size and mass, but also because of their location and inability to be removed. There were three major examples of these (Appendix 3): 1) a single ~50 kg commercial buoy was recorded from Bales Bay, Kangaroo Island, 2) an estimated 200-250 kg of commercial boating anchor rope was recorded at Mullowurtie Point, North West GSV that could not be removed from rocks, 3) a bundle of box strapping was recorded off at Mullowurtie Point, North West GSV. Two records over the sampling period recorded large quantities of commercial rope and net. The first (unrecorded weight) was collected at West bay, Kangaroo Island and contained a deceased juvenile Australian sea lion. This was reported and a necropsy performed by SA Museum (report attached). The second was the collection of a large quantity (~3 t) of commercial rope off Cape Hart, Kangaroo Island (Appendix 3). The rope was described as 4 strand 16 mm white and green also containing a length of fisheries long line. The source of the rope is undetermined but possibly is of overseas fishery origin.

Of the debris related to fishing and-boating collected, three user groups could be identified; Commercial, recreational and commercial-recreational which included both groups as the origin of the debris is uncertain (Table 12). Plastic strapping was included as an unknown group because while its origin is unknown, it is known to be used in commercial fishing bait boxes but also used in packaging for commercial transport and packaging purposes. Commercial-recreational debris was the largest group by abundance (n = 938, 59.2 %), frequency of sites and second largest by mass (55.7 kg, 12.8 %). This was predominantly from the collection of rope fragments (n = 901, 57% of overall debris). By mass, commercial aquaculture debris was the highest contributor to pollution contributing 86 % (377.5 kg) of total debris retained. This resulted predominantly from the collection of disused oyster racks (n = 134), oyster rack mesh inners (n= 27) and nylon tubing typical of oyster leases from two sites (Appendix 3), representing 78.7% (343.5 kg) by mass of all fishing debris, and 35% of the total amount of fisheries related debris collected by mass. Recreational fishing and boating debris comprised discarded lures, sinkers, hooks and monofilament fishing line. These items made up 88% (n = 116) of the overall recreational debris recovered.

Table 12. Numerical abundance (NA), frequency of occurrence (FOO) and mass (kg) of fishing debris collected across 38 sites. *denotes the largest group by mass (kg). † Origin unknown.

Debris category and item	Potential Origin	NA		FOO		Mass (kg)	
		No.	%	No.	%	kg	%
Fishing & Boating							
Rope pieces	Commercial and Recreational	901	56.9	34	89	46.4	10.6
Anchor rope	Commercial	2	0.1	2	5	10.1	2.3
Fishing traps and pots *	Commercial	163	10.3	5	13	343.5	78.7
Bait baskets, crates & trays	Commercial	125	7.9	16	42	7.8	1.8
Foam buoys	Commercial	58	3.7	22	58	2.3	0.5
Fishing monofilament line	Recreational	50	3.2	17	45	0.2	0.0
Plastic fishing floats and buoys	Commercial and Recreational	37	2.3	11	29	9.3	2.1
Fishing net	Commercial	28	1.8	10	26	5.3	1.2
Plastic fish measuring devices	Recreational	10	0.6	3	8	0.1	0.0
Fishing related (sinkers, lures, hooks, etc.)	Recreational	66	4.2	26	68	1.6	0.4
Plastic burley buckets	Recreational	6	0.4	5	13	1.4	0.3
Mesh bags (vegetable, oyster nets & mussel bags)	Commercial	5	0.3	5	13	7.1	1.6
Oyster aquaculture	Commercial	10	0.6	4	11	1.4	0.3
		1461	92.2			**436.4**	99.9
Packaging†							
Strapping	Unknown	123	7.8	23	61	0.3	0.1
		123	7.8			**0.3**	0.1
Total		**1584**	**100**			**436.7**	**100**

3.7 Marine debris and impact to harm marine species and ecological communities

Debris collected across 38 sites were categorised to determine their potential to cause harm to marine species in the South Australian regions surveyed (Table 13). In total, 10 major litter groups were identified, comprising 62 % (n = 7786) of the overall debris items collected by number and 10 % (99.9 kg) of the overall by mass. All groups comprised hard or soft plastic. Six groups were identified as having potential to cause harm through ingestion. Of these, plastic fragments (64%), bottle caps and lids (13%) and marine rope (12%) were the largest contributors in abundance. Seven groups were identified as having potential to cause harm through entanglement. Of these, marine rope (12%), plastic bags (3%) and strapping (2%) were main contributors by abundance. While trawl netting was collected, most were small fragments, with the exception of one 2.1 kg piece collected from Tunkalilla Beach, lower Fleurieu Peninsula. Three groups (plastic bags, marine rope, monofilament fishing line) were identified to potentially cause harm either directly through entanglement or ingestion. In most cases, monofilament fishing line was collected in small bundles rather than long lengths, but this could suggest the line was initially at length prior to its collection with the potential to cause entanglement. Additionally to these data, ~ 343.5 kg (n= ~100) oyster racks were collected from 2 sites from North West GSV (Appendix 3). Oyster racks probably do not directly cause entanglement and are not ingestible. However, they pose significant risk to localised intertidal and inshore ecological communities and were reported to have trapped intertidal fauna. Most racks collected had also shown signs of significant decomposition into smaller plastic fragments which could be ingested by some marine wildlife. Furthermore, lengths of plastic coated nylon were collected within NW GSV have the potential to cause entanglement. These were found in bundled lengths at 2 sites in NW GSV.

Table 13. Marine debris with potential to cause harm to marine vertebrates either by ingestion or entanglement within the South Australian regions surveyed. * Ingestion, † entanglement.

Potential hazard	NA		FOO		Total Mass (kg)
	No. items	%	No. Sites	%	
Fragmented plastic pieces (small)*	4990	64	32	84	12.9
Plastic bottle caps & lids*	1041	13	33	87	7.7
Marine rope and fragments of marine rope*†	903	12	36	95	56.5
Fragmented plastic pieces (large)*	331	4	15	39	8.0
Plastic bags (opaque & clear)* †	272	3	28	74	8.1
Plastic strapping †	123	2	23	61	0.3
Monofilament fishing line* †	50	1	17	45	0.2
Fishing lures †	47	1	16	42	0.9
Fishing net †	28	0	10	26	5.3
Drink package rings †	1	0	1	3	0.0
Total	**7786**	**100**			**99.9**

3.8 Fragmented plastic sampling

In total, 95 pieces of plastic fragments were recovered from190 m^2 of sifted surface sand (0.5 pieces / m^2). These were only represented across 7 sites (18 %) with 31 sites not recovering any fragmented plastic debris. The largest number of fragments (n = 76) were recovered from 4 sites (West bay (n = 29), Waitpinga beach (n = 27), Victor Harbor East (n = 20) and Cape Gantheaume (n = 11).

3.9 Validation and effectiveness of litter surveys

Based on the diversity of litter types collected across the GSV bioregion, the number of sites used was representative of the potential litter that may exist on the beaches within GSV and validated our survey techniques.

The litter types collected exhibited a sigmoidal curve exhibiting an asymptote of which the Gompertz function showed reasonable fit with r^2 value of 0.989 (Fig. 6). Based on the Gompertz function, the mean number of sites required to sample 95% of the asymptotic number of litter items identified was 22.5 sites, which was less than the number of sites assessed (n = 38).While a larger data set can provide better regional and local resolution to debris deposition, this result suggests 23 sites could be selected in confidence of covering 95% of all litter types recovered (refer to Section 4.6 for discussion).

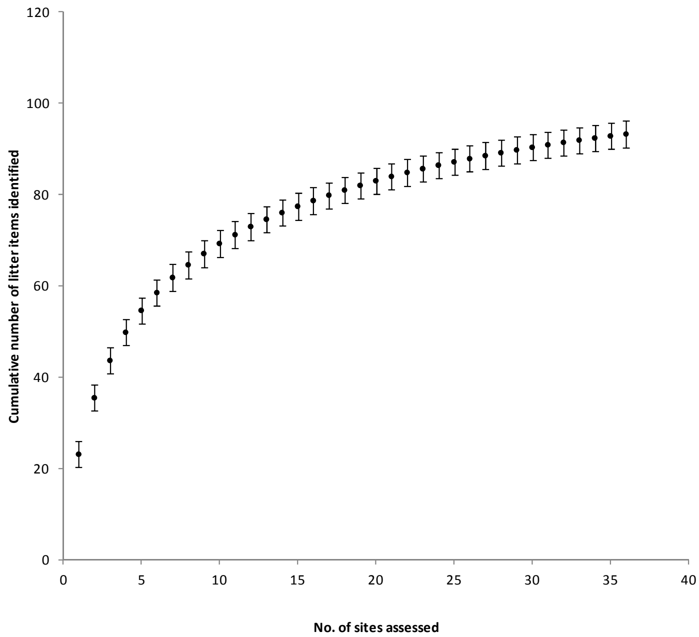


Figure 6. Mean and standard deviation of the asymptotic number of sites required to sample 95% of the litter types sampled from the marine debris surveys. The respective number of sites required to sample 95% of the asymptotic number of litter types identified was 22.5 sites.

3.10 Ingestion of plastics by the Short-tailed shearwater (Puffinis tenuirostris).

In total 23 deceased birds were collected for analysis. Based on discriminant function scores from head-bill measurements (described in Section 1.6), 16 birds were identified as female and 7 male. Based on the necropsy results, 61% of birds were emaciated, 30% showed fair body condition (containing some muscle reserve), and 2 birds were classified in good condition. Body mass of the birds ranged from 350.5 - 592.8 gm with a mean body mass of 487.09 ± 65.0 gm. This indicated most birds were in poor - starving condition based on short-tailed shearwater body condition index (Baduini et al. 2001.) (Table 14). Digestive tracts of the birds collected were empty of food remains except for four birds which contained in total 2 eye lenses, squid suction cups cephalopod beak, 2 pieces of quartizite and a piece of black pumice. In total, 56 pieces of marine debris were found in 70% (n = 16) of digestive tracts of birds collected with a mean of 2 ± 2.9 plastic pieces per bird. Plastics found in the digestive tract of birds ranged between 1 – 12 pieces / bird and consisted of small hard plastic pieces (n = 47), silicone pellets (n = 8) and rubber (n = 1). The debris pieces ranged in size and were significantly longer than wide (long axis, mean 7.05 ± 3.45 mm, 2.0 – 21.0mm; short axis, mean 5.26 ± 2.01 mm, 2.0 – 14.0 mm; Wilcoxon signed-ranked test: Z = -3.856, P = < 0.001).

Table 14. Morphometrics and stomach contents of Short-tailed shearwater (*Puffinis tenuirostris*) collected from Goolwa beach, October 2010.

Sex	Discriminant sex score	Bird weight (gm/wet weight)	Beak length	Beak depth	Head+bill length	Tarsus length	Stomach contents	Plastic fragments	Plastic type
F	-1.68	350.5	31.5	11	81	59	-	0	-
F	-1.93	525.84	33	11.1	80.1	60.09	-	2	hard plastic
F	-1.73	480.5	31.5	11.1	80.5	59.9	-	1	hard plastic
F	-1.98	468.3	30	11.1	80	61.1	-	0	-
F	-0.30	427.4	34.5	11.1	83.4	60	-	1	hard plastic
F	-4.19	455.17	31.9	10.1	79.5	59.5	+	2	silicone pellets
F	0.14	504.6	35.5	11.1	84.3	59.8	-	2	hard plastic
F	-0.70	520.6	31.4	11.1	82.6	59.8	-	1	hard plastic
F	-2.57	543.9	30.1	11.1	78.8	59.7	-	6	hard plastic
F	-5.37	397.68	21.2	9.5	79.5	72.8	-	0	-
F	-6.67	506.34	18.1	12.1	66.5	60.1	-	3	hard plastic
F	-4.24	528.7	31.9	10.2	79	60	-	2	silicone pellets
F	-3.55	368.4	34	10.1	80.8	57.5	-	5	silicone pellets, rubber cap
M	0.68	401.91	31.1	12.2	81	59.8	-	4	hard plastic
M	1.27	553.45	31.5	12	83	57	+	2	hard plastic
M	1.80	484.1	31	13	80.1	55.5	-	0	-
F	-0.21	-	34.1	12	80	51	-	0	-
F	-4.20	592.8	31.5	11	75.9	53	+	12	hard plastic
M	2.50	557.9	32.1	12	85.5	56		7	hard plastic
M	0.92	492.6	32.9	12.1	81.9	60.05	+	4	hard plastic
M	0.04	500.5	32.1	12	80.5	60.09	-	0	-
F	-1.14	567.87	32	11.5	80.1	60	-	0	-
-	-	487.10	-	-	-	-	-	2	hard plastic

3.11 Gross pollutant trap (GPT) and trash rack (TR) debris recovery.

GPT and TR intercepted approximately 1853.6 tonnes of organic and inorganic debris over the 2 year reporting period (2009-2011). Between years, the amount of debris collected was not significantly different, although overall recovery in 2010-11 was lower than 2009-10 (679.1 and 1174.5 t, mean: 67.9 ± 34.4 and 97.9 ± 73.9 t, respectively) (Wilcoxon signed rank test: Z = -0.866, P = 0.386) (Fig. 7). The overall lower quantity of debris intercepted in 2010-11 possibly reflects the absence of data for November –December periods as cleaning of debris traps was not significantly different between years (T-test: t =0.605, d.f. = 1, 9, P = 0.560). Combined data for GPT and TR over the reporting period (2009-2011) showed the highest levels of terrestrial debris intercepted during winter (June-August) although Spring collections were similarly high compared to winter except there was an absence of data for November – December periods (mean ± s.d: 107.1 ± 81.8 and 100.2 ± 69.6 t, respectively). Excluding 2010-2011, the amount of debris recovered during 2009-2010 was not significantly different to the previous 5 year of GPT and TR data (all comparisons P = > 0.05).Due to the large volumes of debris recovered, differentiation between the organic and inorganic components could not be determined.

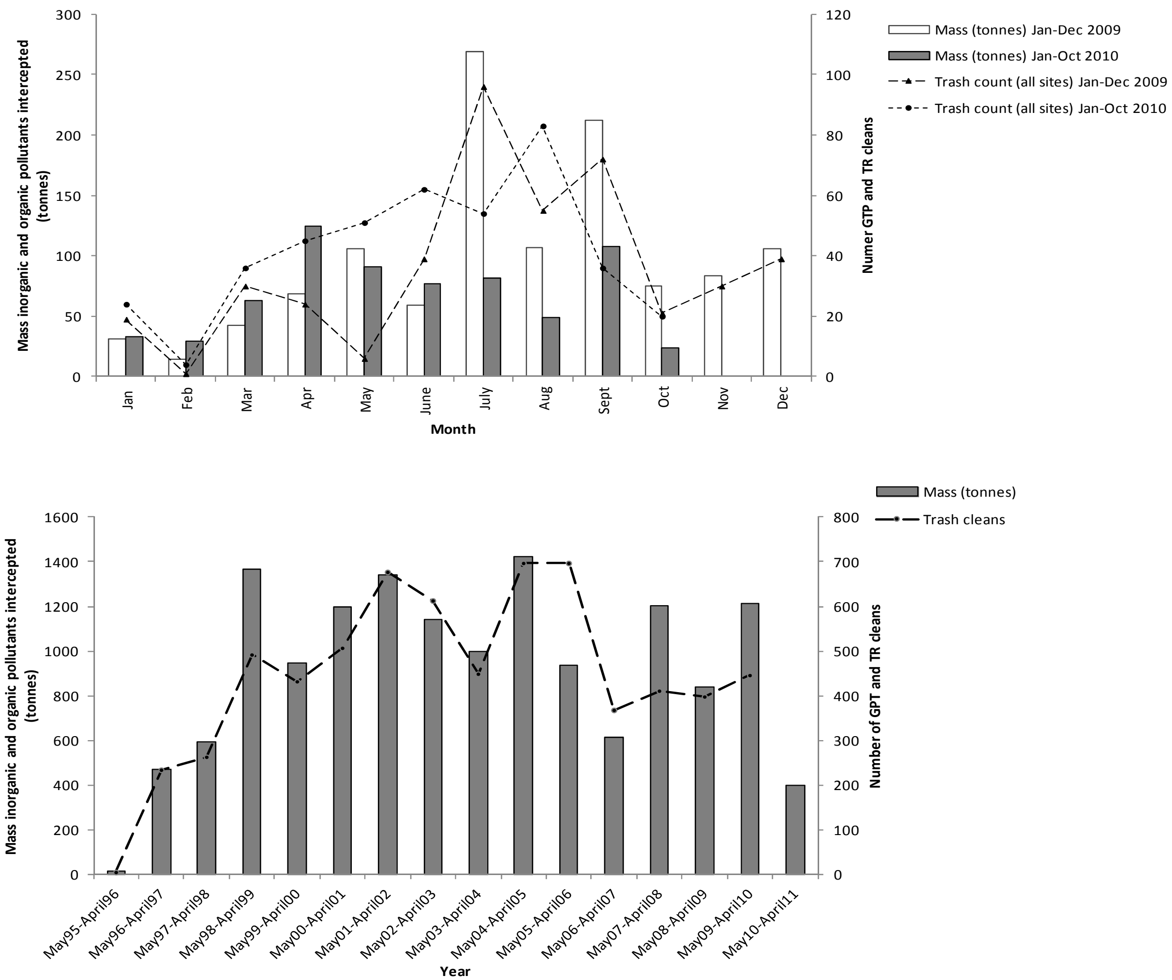


Figure 7. Amount (tonnes) of inorganic and organic pollutants recovered from Gross pollutant trap (GPT) and Trash rack (TR) monthly mass (tonnes) Jan-Dec 2009-2010 (upper) and annual mass (tonnes) from historical data May - April 1995 - April 2011 (lower). Reporting period of the Marine Debris Threat Abatement Plan (TAP), January 2009 - October 2010.

Discussion

Marine debris and its harmful effects on marine wildlife and ecological systems is a matter of national and international importance. This study aimed to investigate and identify the knowledge gaps of the potential sources of marine debris that are likely or could potentially impact marine wildlife and ecological communities within the Gulf St. Vincent bioregion. Of the 985 kg and 12,603 items of marine debris recovered, the survey results identified 10 major debris categories that could be potentially harmful either directly through ingestion or entanglement to wildlife, and further identified a number of sources of debris that should be mitigated to reduce their impact on coastal and marine ecological systems. While it more than likely a large proportion of debris enters GSV and surrounding waters from terrestrial discharge, circulation models of the GSV bioregion (Bye, 1976; Middleton and Bye, 2007; Bye and Kämpf, 2008) further suggest debris deposition could originate in-part from westerly inflows through the Investigator Strait and the Southern Ocean. With the exception of two sites (Tiddy Widdy and O'Sullivan Beach), we believe these are the first quantitative marine debris surveys to be conducted at each site and as such, the data that is presented here (standing crop) corresponds to debris that has accumulated potentially over a number of years. While this provides historical and current representation of the amount and types of debris at each site, it is imperative that continual temporal annual or biennial monitoring be established to assess the actual rate of oceanic litter accumulation (Ribic et al. 1992; Cheshire et al. 2009).

4.1 Marine debris in the GSV bioregion.

Our surveys were conducted over the austral winter, when hydrological circulation surrounding and within the GSV bioregion tends to be maximised (Middleton and Bye, 2007). The austral winter further coincides with higher rainfall events, which increases nutrient inflows and higher debris influx rates into the Gulf St. Vincent system from land (Fig. 7) (GPT data, *this study*). The results from our surveys indicate a wide range of debris accumulates along the coastal habitats across the GSV bioregion. Debris types were predominantly composed of plastic; with the highest proportions from recovery of fragments, packaging, containers, and fishing related debris which originates from both terrestrial and marine based sources. The most commonly encountered debris type by number across the entire GSV bioregion were hard-polymer plastic fragments, which were collected in the highest proportions from 4 of the 5 regions surveyed. The only exception being east GSV region, where debris was dominated by plastic food packaging (wrappers) presumably associated with the proximity to metropolitan Adelaide. The total amount of debris collected relative to their density (item abundance and mass per unit area) showed overall, no significant differences between the regions; the mean amount of debris ranging 0.014 items m^{-2} in the lower Yorke Peninsula region to 0.021 items m^{-2} on Kangaroo Island with a mean density across the GSV bioregion of 0.017 items m^{-2} (Table 8). The most polluted sites within the GSV bioregion based on item densities were Rocky River (KI), O'Sullivan Beach (GSVE), Sandhurst Beach (KI), Hallett Cove (GSVE) and Sandy Creek (KI). These sites showed also high litter abundances but low overall mass predominantly because their compositions contained a large percent of light weight plastic debris. The only exception was Rocky River, which comprised the highest density and mass attributable to driftwood, but its highest ranking was also because it contained the smallest search area (3392.9 m^2). Conversely, Willunga Beach (GSVE) produced the third highest abundance of debris but showed lower density because it was the largest site surveyed (52434.9 m^2). The item mean densities recorded for GSV bioregion are lower than reported mean densities elsewhere in Australia; for example Cable Bay, Western Australia (0.5 items $m^{-2)}$, south, central and north Sydney beaches (0.1), are comparable to Fog Bay, NSW (0.11 x 10^{-3}) (Frost and Cullen, 1997; Cunningham and Wilson, 2003; Foster-Smith et al. 2007), but globally significantly lower (summarised in Hilal and Najjar, 2009).

In terms of regional weight, debris ranged from a mean of 0.66 gm m^{-2} in lower Yorke Peninsula region and peaked at 5.8 gm m^{-2} within west GSV region with a mean density across the GSV bioregion of 2.06 gm m^{-2}(Table 8). Five sites (Black Point (GSVW), Point Morrison (KI), Rocky River (KI), Port Vincent (GSVW), Stansbury (GSVW)) showed mean mass densities above 4 gm m^{-2}. This was predominantly related to single-based category items. For example, a major contributor to mass at Stansbury and Port Vincent were car tyres, while Point Morrison's debris by mass was dominated by a single refrigerator. Black Point on the upper west coast of GSV indicated by far, the highest mass at 26.2 gm m^{-2}. This significant high anomaly was predominantly related to the large collection of plastic oyster baskets possibly from active but likely redundant oyster aquaculture sites known to occur within the region. Within South Australia, the mean mass densities expressed per region presented here are comparable to those recorded from biennial surveys of marine litter on Kangaroo Island (1.6 - 2.4 gm m^{-2}) but higher than the standing crop density estimated by Edyvane et al. (2004) for Anxious Bay in 1991 (0.15 gm m^{-2}). However, as we extrapolated the beach area size of Anxious Bay with Arc GIS and Edyvane et al. (2004) only presented data as kg / km, our interpretation of their mass density value could be an underestimate, and may be closer to what we observed in this study.

4.2 General trends

Some interesting patterns also emerged from this study. We found that the majority of debris that congregates around urban sites (n = 12) is most likely terrestrial-based in its origin. This was supported by the higher occurrence and abundances of packaging associated with common use food items and general housing products (Table 11) that were observed on the beaches of east GSV. O'Sullivan Beach, Hallett Cove and Willunga Beach comprised 50% of all packaging and 40% of household products, with plastic food wrappers and fast- food plastic drinking straws most commonly encountered debris. Given Eastern GSV has two significant estuarine systems (Port River, Onkaparinga River), a large river outlet (Torrens River), subsidiary creeks, and large number of storm-water drains, these are possible vectors of the debris transport from terrestrial systems. Interestingly though, the number of containers, which largely comprised plastic PET bottles and hard-polymer lids from PET bottles, were found in greater abundance at remote sites than urban sites. Three possible theories could explain this phenomenon; 1) plastic bottles and lids are easily transported by wind and ocean currents out of the gulf and deposited at higher energy remote sites, 2) some items are transoceanic debris originating from elsewhere, and 3) urban sites are more accessible to beach-goers than remote sites and given the State's 'money for bottles' scheme, more bottles are collected and recycled.

4.3 Fishing, boating and aquaculture related debris

Fishing, boating and aquaculture related debris showed some differences in its distribution across the survey regions. By count, relative to identifiable recreational and commercial debris, the most common occurring debris types were marine rope fragments but the origin of these could not be determined. These were distributed across all sites, however, higher abundances of rope were recorded in GSV and KI, with open beaches of KI indicating the highest overall abundance than the other four regions sampled (GSVE, GSVW, LYP, LFP). The GSV bioregion and surrounding waters are both significantly utilised by commercial and recreational fishers and vessels, as is marine rope, thus the source of its origin is unclear. Nonetheless, it is possible given the strong oceanographic conditions and extent of the south east, GAB trawl fisheries, international fisheries and international shipping that operate in waters that include KI and the Southern Ocean, some of this debris is possibly commercial in origin. Where fisheries–related debris could be identified to specific fisheries or aquaculture, we found that highest contributors to pollution were related to the commercial oyster aquaculture industry that currently operate or contain redundant sites in the NW of GSV. This was the highest contributor by mass (~345 kg) and by number (n = 134) represented largely by lockable and mesh style oyster racks (Appendix 3). Under the South Australian Aquaculture Act, 2001, Aquaculture Regulations 2005, it is a requirement for aquaculture in state waters that '*farming structures used for aquaculture are securely fixed or moored in place so as to remain wholly within the licence area; and* (B) *anchored in a manner that minimises the impact on the benthos; and* (ii) *maintained in good working condition* (Division 2, section 17 1(b)), and '*a licensee must ensure that if a farming structure used for aquaculture, or any equipment used to secure, anchor or mark the position of the structure, is blown, washed or swept off the licence area, the structure or equipment is recovered as soon as practicable* (Division 2, section 17 (2)). As this was one of the most significant results of the surveys, this matter has been raised with Department of Primary Industries and Resources of South Australia (PIRSA).

4.4 Impacts on wildlife and biodiversity from ingestion of marine debris

Within the ten categories likely to threaten marine species (Table 13), 97% of the items identified (n = 7587) could pose significant risk through direct ingestion or could be potentially ingested after natural or mechanical fragmentation (large plastic fragments). Potentially ingestible items were dominated by small hard-polymer plastic pieces, hard-polymer plastic bottle caps and lids, marine nylon rope fragments and plastic bags. Nylon rope and plastic fragments are either oceanic or locally marine-based in origin. Plastic bottle caps and bags could also originate from sea, but given the proximity of gulf waters to South Australia's largest urban centre, it is likely a large proportion of these originate from land. This was supported by the fact that eastern GSV beaches (n = 9), representing 25 % of all beaches surveyed, produced nearly 50% of plastic bottle caps and 60% of the overall number of bags collected. However, excluding these, ingestible items were predominantly associated with higher energy southerly facing beaches rather than the passive beaches of GSV and northern Kangaroo Island. In fact, 16 of the 18 beaches classified as high energy, accounted for 84% of the total amount of plastic fragments recovered. The only passive sites that showed higher recovery of plastic pieces were Willunga and O' Sullivan beaches located within south eastern GSV region. These sites also contained the highest proportion of plastic bags and some of the highest overall debris abundances (Fig. 3). Both of these sites are westerly facing; however, their northerly limits are both punctuated with a NW facing headland and extensive marina rock-wall (respectively). Given that plastic fragments were common at these sites concurrently with large proportions of other debris, suggests these structures could possibly influence hydrological movement with water exiting the gulf, subsequently leading to greater litter deposition.

The circumstances of ingestion of litter by wildlife such as cetaceans, marine reptiles and seabirds are reasonably clear. Debris are either mistakenly ingested as a result of indiscriminate feeding behaviour, visual misidentification for prey, through indirect consumption, or naïve foraging, while physical effects can range from internal trauma, digestive blockages, and indirectly can potentially suppress fitness by reducing stomach volumes meant for adsorption of prey (Mroskovsky, 2009; Denuncio et al. 2011). For marine mammals inhabiting the GSV bioregion, there is no evidence of litter consumption or litter ingestion-related deaths based on 441 necropsies (328 cetacean, 113 pinniped) performed by the South Australian Museum (Kemper et al. 2005, Kemper and Tomo, 2011). This is probably because pinnipeds and odontocete cetaceans are highly mobile, active foragers that visually identify and consume fast moving prey and in the latter group, non-preferred objects such as litter are unlikely consumed due to echolocation capabilities. Less prey selective species, such as endangered itinerant leatherback turtle, *Dermochelys coriacea*, and migratory Short-tailed shearwater, (*Ardenna tenuirostris*) that frequent waters of the GSV bioregion are known to consume marine debris (Mroskovsky, 2009; Carey, 2011). Mrosovsky (2009) for example, indicated that *D. coriacea* indiscriminately consume a range of plastic debris assumingly mistaken as jellyfish that include proportionally, plastic bags, fishing line, balloons and cigarette wrappings. They further suggest based on historical necropsy reports these items are likely responsible anthropogenic causes of death in this species.

This study also confirms the ingestion of marine debris by Short-tailed shearwaters. Our necropsy results revealed from the 23 birds analysed, 70% contained between 1 - 12 pieces of fragmented hard-polymer plastic or silicone based debris within the gastrointestinal tract (Table 14). However, as a highly migratory species and because the age demographic of the specimens are unknown, it is unclear whether these debris items were recently consumed within waters of GSV bioregion, within distant southern oceanic or Antarctic waters, or along their 15,000 km migratory route from southern Australia to feeding grounds in the northern hemisphere (Baduini et al. 2001). Even if the weight of the specimens was slightly underestimated, it is likely the majority of birds died of starvation given the low recovery of prey remains contained within their stomachs. While low numbers of ingested plastic debris in shearwaters are considered unlikely to cause high levels of direct mortality in adult Procellariiformes (see Carey, 2011), indirect effects facilitating reduction in body condition from either adults provisioning plastic to chicks, or the accumulation of Persistent Organic Pollutants (POPs) through plastic ingestion are well documented.

4.5 Impacts on wildlife and biodiversity from entanglement by marine debris

Within the ten categories likely to threaten marine species (Table 13), 15% of the items identified (n = 1224) could pose significant risk through direct entanglement. Items that could potentially lead to entanglement were dominated by plastic bags, box strapping and to some degree monofilament fishing line, and fishing nets. Of these items, 60% of plastic bags recovered were accumulated on low energy eastern beaches of GSV and as previously mentioned are probably associated with metropolitan usage or translocated into the gulf though urban water discharge. Lengths of box strapping and trawl net were more directly associated with higher energy open beaches; particularly Kangaroo Island's south facing beaches where the direct influence of the Southern Ocean is met. This is a reasonable expectation given the activity of regional commercial fisheries within its surrounding waters (Knight and Tsolos, 2009) and international fisheries operating in the waters of the Southern Ocean. Debris such as trawl net and box strapping are known entangling material of pinnipeds, particularly fur seals that often target productive upwelling and convergence zones where fishing debris also accumulates (Page et al. 2004; Arnould and Croxall, 1995). This is true for New Zealand fur seals and Australian sea lions that breed on Kangaroo Island, which target the rich foraging grounds within and off the continental shelf. These have been recorded to interact and become entangled in marine debris such as plastic bags, bait strapping, fragments of trawl net, and monofilament fishing line (Page et al. 2004). Similarly, *D. coriacea* in Southern Australian waters are also susceptible to rope entanglement in pot fisheries and mooring lines (Bone 1998). Given the large number of recreational fishers that utilise the GSV bioregion (Jones, 2009), it was surprising to reveal such low quantities of recreational-fishing debris in particular monofilament line, which was collected predominantly from GSV beaches. While the length of monofilament line was not quantified directly in this study, its general composition consisted of small tangled bundles (Peters pers. comm.), which suggests it was either discarded *in situ*, or was once at length and became tangled from the turbulent hydrological nature of the gulf. Nonetheless, the amounts recorded here are more than likely a gross underestimate, as monofilament line is a common benthic-related fishing debris item (Hess et al. 1999), and likely to be ensnared within the sea grass beds and rocky substrates of the GSV bioregion. Finally, there were two significant records of threats associated with the collection of rope debris within the TAP GSV survey period. These included a collection of bundled rope that contained a deceased juvenile Australian sea lion, and ~ 3 tonnes of rope collected off Cape Hart, Kangaroo Island (Kemper and Tomo, 2011). Marine rope, is the third most common material found to entangle Australian sea lions and fourth of New Zealand fur seals off Kangaroo Island (Page et al. 2004), while 'ghost' and active rope buoy lines, are known entanglement risks for leatherback turtles and cetaceans within GSV bioregion (Bone, 1998; Kemper and Tomo, 2011).

4.6 Effectiveness of surveys in the Gulf St. Vincent bioregion

To assess the effectiveness of our surveys, we estimated the number of sites required to be sampled to cover the 95% asymptotic range of the total number and types of litter items collected across the GSV bioregion. As a result, the number of surveys conducted easily covered the 95% asymptotic range of all litter items identified, which was reached at ~23 sites. Future studies of marine debris within the GSV bioregion could use this estimate to determine the minimum number of sites required to represent litter composition within GSV.

Conclusions and further development

The GSV marine bioregion is a unique ecosystem. The area is utilised by commercial and recreational fishers, boating and shipping. The surrounding terrestrial regions sustain the highest population centre of ~ 1.2 million people (Australian Bureau of Statistics (ABS), 2010). The debris surveys conducted here reflect standing crop of marine and terrestrial-based debris associated from a broad range of user groups and potential sources. The debris surveys are representative of macro pollutants historically and currently accumulated, however, there is no clear differentiation given the structural longevity of many litter items, of the rate litter currently accumulates on beaches within the GSV bioregion surveyed.

Directly, the GSV bioregion would benefit from continuation of marine debris surveys across the same spatial scale as has been currently conducted in this study. These would provide on an annual or biennial basis, temporal data on the current accumulation rates and most recent sources pollution. Furthermore, standardised protocols such as those outlined in the International Marine Debris Survey Guidelines developed by the United Nations Environment Program (UNEP, 2009) and employed in the current study, are a feasible method to beach-based marine debris surveys. Their broad application at a national level would facilitate a coordinated and strategic plan to quantify current levels of marine debris data, enabling comparison at local, regional, statewide and international scales.

A range of studies and improvements have been undertaken with Australian Government support to improve waste reception facilities and industry awareness of marine debris matters. In the 1990's the Australian Government's previous Australian and New Zealand Environment and Conservation Council (ANZECC) produced a range of investigations to reduce impacts from shipping and provision of waste reception facilities in ports (1995), while the South Australian Environment Protection Authority (EPA) also produced code of practice for vessel and facility management (EPA, 2008) and 'Materials Handling on Wharves' (EPA, 2007). Historically also, targeted funding through the Australian Government Coast and Clean Seas program of the Natural Heritage Trust and previous Coastal Action Program 'Marine Waste Reception Facilities Program' facilitated the identification, funding and provision of adequate disposal facilities in ports, marinas and boat harbours. The work by various Oceanwatch and SeaNet Extension Officers in South Australia has also contributed to fisheries extension and awareness of the marine debris issue in commercial fisheries (van der Geest, 2004; Oceanwatch, 2007). Nationally, Oceanwatch has also reviewed the feasibility of reducing plastics in the Australian seafood industry (Oceanwatch, 2007). Recommendations included surveys of plastic usage and volumes in the industry, trials of alternative products across the entire supply chain, scoping recycling of waste fishing net and line and reduction of volume of polystyrene boxes. Whilst the commercial fishing sector has taken part in a range of initiatives, there is arguably a need to maintain awareness relating to recreational boating and fishing activities in the region.

Finally, as a party to the MARPOL Convention, Australia is required to ensure the provision of adequate port waste reception facilities for oily wastes, noxious liquid substances, sewage, garbage, ozone-depleting substances and exhaust gas cleaning residues. The International Maritime Organisation (IMO) has developed guidelines for ensuring the adequacy of waste reception facilities including an audit procedure. Since 2006, the Australian Maritime Safety Authority and Ports Australia have conducted trial audits based on the IMO guidelines in some Australian states. The Ports Australia Environment and Sustainability Working Group have endorsed a framework for AMSA to continue these audits as a series of voluntary "gap analyses".

The recommendations and findings of many of these investigations have been incorporated into the Australian Government's 2009 Threat Abatement Plan for the impacts of marine debris on vertebrate marine life. The Plan outlines three key objectives with approaches to:

- Improve waste management practices on land and at sea
- Raise public awareness and improve education campaigns about the prevention of

littering on land and at sea

- Facilitate implementation of wildlife research and recovery actions

The Australian Government's Marine Debris Threat Abatement Plan identifies lead responsibility for many of these approaches to Australian, state and territory governments. The Marine Debris in Gulf St. Vincent study has attempted to undertake actions at a local level across Natural Resource Management regions, to gauge the extent of the issue in the GSV bioregion and qualify the amount and sources scientifically to help better formulate future awareness and mitigation approaches that may be undertaken by Natural Resource Management bodies and state agencies.

In spite of the good work undertaken and continued community interest demonstrated by involvement in Clean Up events and support for projects such as the current study, marine debris continues to pose a threat to marine wildlife in the region. Whilst arguably more investigation and monitoring can be undertaken, there is need to ensure that a coordinated national approach to awareness and mitigation action is continued, particularly with regards to ensuring on-going provision of waste management facilities at boating facilities and ports are continued.

The local community support for the project and enthusiastic volunteer effort is a reflection that there is community will to address global issues at a local level. Local and regional communities however need support and coordination to successfully undertake and maintain their involvement in initiatives such as this. The support of the Australian Government and regional Natural Resources Management bodies, state agencies local government and non-government organisations was instrumental in implementing this project. There is a need to ensure that national and state environmental priorities and funding program targets allow for on-going support of local and regional implementation of the Threat Abatement Plan.

RECOMMENDATIONS

- Continuation of marine debris surveys at the same spatial scale to determine current and future accumulation and potential changes in sources of pollution to the GSV bioregion.
- Nationally standardise marine debris sampling protocols so datasets are comparable in order to develop a national coordinated strategic plan to mitigate harmful effects of marine debris.
- Support consistent, long-term monitoring, investigation, recording and management of data on vertebrate marine life harmed and killed by the physical and chemical impacts of marine debris; including continued monitoring of marine mammal mortalities for the Gulf St Vincent Bioregion and support for adequate archiving of data and specimens to ensure long term availability.

- Continued efforts to improve waste management practices on land and at sea, particularly through regional and local review and improvement of port, boating hub and beach (and catchment) waste and recycling facilities; awareness of best practice waste management for vessels, improving solid pollutant (litter) control strategies in waterways.

- Develop national and statewide working groups or networks to address key objectives and outcomes of the *Threat Abatement Plan for the impacts of marine debris on vertebrate marine life* at local, cross-regional and state levels and facilitate action at regional and local levels.

- Develop a Southern Australian Marine Debris Guide to identify potential sources of debris recovered within the Southern Ocean, similar to that produced for Northern Australia.

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Appendices

Appendix 1. Summary of marine and coastal species of GSV, Investigator Strait, Backstairs Passage, Encounter Bay and surrounding waters of Kangaroo Island. Conservation status is based on Australian Commonwealth Environment Protection and Biodiversity Conservation Act (EPBC, 1999) (DEWHA, 2009) EPBC Act.

Common name	Genus -species	EPBC Status
Birds		
Common Sandpiper	*Actitis hypoleucos*	
Red-necked Stint	*Calidris ruficollis*	
Little Penguin	*Eudyptula minor*	
Blue Petrel	*Halobaena caerulea*	Vulnerable
Soft-plumaged Petrel	*Pterodroma mollis*	Vulnerable
Fork-tailed Swift	*Apus pacificus*	
Great Egret, White Egret	*Ardea alba*	
Fleshy-footed shearwater	*Ardenna carneipes*	
Ruddy Turnstone	*Arenaria interpres*	
Sharp-tailed Sandpiper	*Calidris acuminata*	
Sanderling	*Calidris alba*	
Red Knot, Knot	*Calidris canutus*	
Curlew Sandpiper	*Calidris ferruginea*	
Pectoral Sandpiper	*Calidris melanotos*	
Long-toed Stint	*Calidris subminuta*	
Great Knot	*Calidris tenuirostris*	
Great Skua	*Catharacta skua*	
Double-banded Plover	*Charadrius bicinctus*	
Greater Sand Plover, Large Sand Plover	*Charadrius leschenaultii*	
Lesser Sand Plover, Mongolian Plover	*Charadrius mongolus*	
Red-capped Plover	*Charadrius ruficapillus*	
Oriental Plover, Oriental Dotterel	*Charadrius veredus*	
Amsterdam Albatross	*Diomedea amsterdamensis*	Endangered
Tristan Albatross	*Diomedea dabbenena*	Endangered
Southern Royal Albatross	*Diomedea epomophora (sensu stricto)*	Vulnerable
Wandering Albatross	*Diomedea exulans (sensu lato)*	Vulnerable
Gibson's Albatross	*Diomedea gibsoni*	Vulnerable
Northern Royal Albatross	*Diomedea sanfordi*	Endangered
Latham's Snipe, Japanese Snipe	*Gallinago hardwickii*	
Swinhoe's Snipe	*Gallinago megala*	
Pin-tailed Snipe	*Gallinago stenura*	
White-bellied Sea-Eagle	*Haliaeetus leucogaster*	

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Common name	Genus -species	EPBC Status
Birds		
Grey-tailed Tattler	*Heteroscelus brevipes*	
Black-winged Stilt	*Himantopus himantopus*	
White-throated Needletail	*Hirundapus caudacutus*	
Silver Gull	*Larus novaehollandiae*	
Pacific Gull	*Larus pacificus*	
Broad-billed Sandpiper	*Limicola falcinellus*	
Bar-tailed Godwit	*Limosa lapponica*	
Black-tailed Godwit	*Limosa limosa*	
Southern Giant-Petrel	*Macronectes giganteus*	Endangered
Northern Giant-Petrel	*Macronectes halli*	Vulnerable
Rainbow Bee-eater	*Merops ornatus*	
Osprey	*Pandion haliaetus*	
Red-necked Phalarope	*Phalaropus lobatus*	
Ruff (Reeve)	*Philomachus pugnax*	
Pacific Golden Plover	*Pluvialis fulva*	
Grey Plover	*Pluvialis squatarola*	
Short-tailed shearwater	*Puffinis tenuirostris*	
Fluttering shearwater	*Puffinus gavia*	
Red-necked Avocet	*Recurvirostra novaehollandiae*	
Painted Snipe	*Rostratula benghalensis s. lat.*	Vulnerable
Little Tern	*Sterna albifrons*	
Crested Tern	*Sterna bergii*	
Caspian Tern	*Sterna caspia*	
Sooty Tern	*Sterna fuscata*	
Fairy Tern	*Sterna nereis*	
Buller's Albatross	*Thalassarche bulleri*	Vulnerable
Shy Albatross, Tasmanian Shy Albatross	*Thalassarche cauta (sensu stricto)*	Vulnerable
Grey-headed Albatross	*Thalassarche chrysostoma*	Endangered
Campbell Albatross	*Thalassarche impavida*	Vulnerable
Black-browed Albatross	*Thalassarche melanophris*	Vulnerable
Salvin's Albatross	*Thalassarche salvini*	Vulnerable
Hooded Plover	*Thinornis rubricollis*	
Hooded Plover (eastern)	*Thinornis rubricollis rubricollis*	Threatened
Wood Sandpiper	*Tringa glareola*	
Marsh Sandpiper, Little Greenshank	*Tringa stagnatilis*	
Terek Sandpiper	*Xenus cinereus*	

Appendix 1. Summary of marine and coastal species of GSV, Investigator Strait, Backstairs Passage, Encounter Bay and surrounding waters of Kangaroo Island. Conservation status is based on Australian Commonwealth Environment Protection and Biodiversity Conservation Act (EPBC, 1999) (DEWHA, 2009) EPBC Act.

Common name	Genus -species	EPBC Status
Birds		
Common Sandpiper	*Actitis hypoleucos*	
Red-necked Stint	*Calidris ruficollis*	
Little Penguin	*Eudyptula minor*	
Blue Petrel	*Halobaena caerulea*	Vulnerable
Soft-plumaged Petrel	*Pterodroma mollis*	Vulnerable
Fork-tailed Swift	*Apus pacificus*	
Great Egret, White Egret	*Ardea alba*	
Fleshy-footed shearwater	*Ardenna carneipes*	
Ruddy Turnstone	*Arenaria interpres*	
Sharp-tailed Sandpiper	*Calidris acuminata*	
Sanderling	*Calidris alba*	
Red Knot, Knot	*Calidris canutus*	
Curlew Sandpiper	*Calidris ferruginea*	
Pectoral Sandpiper	*Calidris melanotos*	
Long-toed Stint	*Calidris subminuta*	
Great Knot	*Calidris tenuirostris*	
Great Skua	*Catharacta skua*	
Double-banded Plover	*Charadrius bicinctus*	
Greater Sand Plover, Large Sand Plover	*Charadrius leschenaultii*	
Lesser Sand Plover, Mongolian Plover	*Charadrius mongolus*	
Red-capped Plover	*Charadrius ruficapillus*	
Oriental Plover, Oriental Dotterel	*Charadrius veredus*	
Amsterdam Albatross	*Diomedea amsterdamensis*	Endangered
Tristan Albatross	*Diomedea dabbenena*	Endangered
Southern Royal Albatross	*Diomedea epomophora (sensu stricto)*	Vulnerable
Wandering Albatross	*Diomedea exulans (sensu lato)*	Vulnerable
Gibson's Albatross	*Diomedea gibsoni*	Vulnerable
Northern Royal Albatross	*Diomedea sanfordi*	Endangered
Latham's Snipe, Japanese Snipe	*Gallinago hardwickii*	
Swinhoe's Snipe	*Gallinago megala*	
Pin-tailed Snipe	*Gallinago stenura*	
White-bellied Sea-Eagle	*Haliaeetus leucogaster*	

Appendix 1. Summary of marine and coastal species of GSV, Investigator Strait, Backstairs Passage, Encounter Bay and surrounding waters of Kangaroo Island. Conservation status is based on Australian Commonwealth Environment Protection and Biodiversity Conservation Act (EPBC, 1999) (DEWHA, 2009) EPBC Act.

Common name	Genus -species	EPBC Status
Birds		
Grey-tailed Tattler	*Heteroscelus brevipes*	
Black-winged Stilt	*Himantopus himantopus*	
White-throated Needletail	*Hirundapus caudacutus*	
Silver Gull	*Larus novaehollandiae*	
Pacific Gull	*Larus pacificus*	
Broad-billed Sandpiper	*Limicola falcinellus*	
Bar-tailed Godwit	*Limosa lapponica*	
Black-tailed Godwit	*Limosa limosa*	
Southern Giant-Petrel	*Macronectes giganteus*	Endangered
Northern Giant-Petrel	*Macronectes halli*	Vulnerable
Rainbow Bee-eater	*Merops ornatus*	
Osprey	*Pandion haliaetus*	
Red-necked Phalarope	*Phalaropus lobatus*	
Ruff (Reeve)	*Philomachus pugnax*	
Pacific Golden Plover	*Pluvialis fulva*	
Grey Plover	*Pluvialis squatarola*	
Short-tailed shearwater	*Puffinis tenuirostris*	
Fluttering shearwater	*Puffinus gavia*	
Red-necked Avocet	*Recurvirostra novaehollandiae*	
Painted Snipe	*Rostratula benghalensis s. lat.*	Vulnerable
Little Tern	*Sterna albifrons*	
Crested Tern	*Sterna bergii*	
Caspian Tern	*Sterna caspia*	
Sooty Tern	*Sterna fuscata*	
Fairy Tern	*Sterna nereis*	
Buller's Albatross	*Thalassarche bulleri*	Vulnerable
Shy Albatross, Tasmanian Shy Albatross	*Thalassarche cauta (sensu stricto)*	Vulnerable
Grey-headed Albatross	*Thalassarche chrysostoma*	Endangered
Campbell Albatross	*Thalassarche impavida*	Vulnerable
Black-browed Albatross	*Thalassarche melanophris*	Vulnerable
Salvin's Albatross	*Thalassarche salvini*	Vulnerable
Hooded Plover	*Thinornis rubricollis*	
Hooded Plover (eastern)	*Thinornis rubricollis rubricollis*	Threatened
Wood Sandpiper	*Tringa glareola*	
Marsh Sandpiper, Little Greenshank	*Tringa stagnatilis*	
Terek Sandpiper	*Xenus cinereus*	

Appendix 1. Summary of marine and coastal species of GSV, Investigator Strait, Backstairs Passage, Encounter Bay and surrounding waters of Kangaroo Island. Conservation status is based on Australian Commonwealth Environment Protection and Biodiversity Conservation Act (EPBC, 1999) (DEWHA, 2009) EPBC Act.

Common name	Genus -species	EPBC Status
Pinnipeds		
New Zealand Fur-seal	*Arctocephalus forsteri*	
Australian Australo-African Fur-seal	*Arctocephalus pusillus*	
Australian Sea-lion	*Neophoca cinerea*	Vulnerable
Reptiles		
Loggerhead Turtle	*Caretta caretta*	Endangered
Green Turtle	*Chelonia mydas*	Vulnerable
Leatherback Turtle, Leathery Turtle	*Dermochelys coriacea*	Endangered
Cetaceans		
Minke Whale	*Balaenoptera acutorostrata*	
Pygmy Right Whale	*Caperea marginata*	
Bryde's Whale	*Balaenoptera edeni*	
Blue Whale	*Balaenoptera musculus*	
Common Dophin, Short-beaked	*Delphinus delphis*	
Southern Right Whale	*Eubalaena australis*	Endangered
Risso's Dolphin, Grampus	*Grampus griseus*	
Dusky Dolphin	*Lagenorhynchus obscurus*	
Humpback Whale	*Megaptera novaeangliae*	Vulnerable
Killer Whale, Orca	*Orcinus orca*	
Indian-Pacific Bottlenose dolphin	*Tursiops aduncus*	
Bottlenose Dolphin	*Tursiops truncatus* s. str.	
Sharks		
Great White Shark	*Carcharodon carcharias*	Vulnerable
Shortfin Mako, Mako Shark	*Isurus oxyrinchus*	

Appendix 2. Beach parameters used for marine debris survey site selection, Gulf St. Vincent and Fleurieu Peninsula, South Australia.

Beach identification	GSVEZ1B	GSVEZ1B	GSVEZ2A	GSVEZ2D	GSVEZ2B	GSVEZ3C	GSVEZ3A	GSVEZ3B	GSVEZ3C	GSVEZ3D	FP1	FP2	FP4
Common name	North Parham	Great Sandy beach	Tennyson	Hallet Cove	O' Sullivans beach	Willunga	Carackalinga	Rapid bay	Morgans beach	Lands End Cape Jervois	Tunkalilla beach	Waitpinga beach	Victor Harbor East
Latitude	34°24'20.63"S	34°27'46.22"S	34°52'45.99"S	35° 3'46.72"S	35° 7'25.49"S	35°14'55.74"S	35°26'15.05"S	35°31'22.48"S	35°35'47.86"S	35°37'15.68"S	35°38'16.65"S	35°38'5.13"S	35°32'26.75"S
Longitude	138°14'53.29"E	138°15'37.24"E	138°28'55.27"E	138°30'5.19"E	138°28'7.08"E	138°27'43.66"E	138°18'48.16"E	138°11'41.56"E	138° 6'11.96"E	138° 5'44.83"E	138°18'15.24"E	138°29'59.70"E	138°38'28.52"E
Geographical													
Direction wind current	SW/W/NW	W	SW	W	W	WWSW	WSW	WSW	WSW	SW	SW	SW	SW
Direction ocean current	NW	NW	NW	SW	SW	SW	SW	SW	SW	SENW	SW	S	W
Aspect	W	SW	W	W	W	W	W	NW	NW		S	SW	S
Beach curvature/profile													
linear (L), concave (CA), convex (CO), sinsoidal/tierral (S/T)	LC	LC	L	L	L	LC	LC	LC	LC	C	L	C	LC
Beach length(m)	10000+	600	5000	1500	1500	550	500	1200	800	500	5000	3200	2000+
Nearest river	epehmeral creek	Tidal creek	Torrens river+Port riv	ephemeral creek L	ephemeral creek -Chris	Onkaparinga River	ephemeral creek	Yattagolinga ephemer	ephemeral creek	ephemeral creek	ephemeral creek	Waitpinga ephemeral	hindmarsh river mouth
distance(m)	4000	100	6500	2600	500	10000	100	500	400	500	500	500	1000
direction	S	N	SN	S	S	N	N	S	N	N	N+S	W	W
input direct indirect	indirect	direct	indirect	indirect	direct	indirect	direct	Direct	indirect	indirect	direct	direct if flowing	direct
Geomorphological													
Sand(S) gravel(G) shingle(Sh) pebble beach(PB) Rock(R)	S	S	S	G	S	S	S	S	S	RS	S	S	S
Nourished by offshore sands, rather than by nearby rivers contributing land-bas	Y	Y	Y	N	Y	Y	N	FW creek sth	Y	Y	Y	Y	Y
Landward limit	veg salt pan	veg	Dunes	Cliffs	Dunes	cliffs	rock and low veg	sand flats and rock	dunes/rock	dunes/rock	grass	sand	sand rockflats
Having a uniform sediment compartment, at least 5 km long, with minimal longshor	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Rear beach can be described easily and rubbish removed easily	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Beach wide at low tide(m)	<30	30	50	30	40	30-40	30	30	35	50	60	30	30
Beach gradient													
Moderate to low (15-45 degree slope) beach gradients.	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Small tidal range	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Tidal mud flats/large tide flats-dangerous tides and debris shunting	tide flats	tide flats	N	N	N	N	N	N	N	N	N	N	N
Bathymetry													
Direct Offshore bathymetry (m)	5	5	5	5	5	5	5	5	5	5	5	5	5
Offhsore bathymetry characteristic gradual(G) Steep(S)(5-30m)	G	G	G	G	G	S	G	S	S	S	S	S	S
Offshore structures													
No dense subtidal seagrass(SG), algal growth, reef structures(R) offshore, unv	SG, sand		SG RF U	SG RF U	SG R U	RF SG	SG RF	SG,RF	RF		RF+S	n	RF
Clear access to the sea (not blocked by breakwaters or jetties)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Ecological impact													
No endangered/threatened species nesting on beach-councils DEH						Y	Y		Y	Y	Y	Y	Y
Sensitive beach vegetation									Ydunes				
Social Impacts													
Remote from human settlements, seldom visited by tourists, and without easy ac	Y	Y	N	N	N	N	N	N	N	Y	Y	Y	N
Nearest township	Parham	Webb Beach	Tennyson	Hallet Cove		Willunga	Normanville south	Rapid bay	Cape Jervois	Cape Jervois	Cape Jervois	Victor Harbour	Victor Harbour
distance(km)	2	2	1	1	1	2	2		1	2	18000	14000	1500
direction	S	N	E	S	E/N	N	N	N	N	N	W	E	W
Fisheries													
Nearby inshore fisheries, Marine fishing areas(MFA)		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Marine scale(MS)	MS(36 35)	MS(36 35)	MS(43,46)	MS(44A,43)	MS(44A,43)	MS(44A,43)	MS(43,44A)	MS(43,44A)	MS(43,44A)	MS(43,44A)	MS44B	MS44	MS44
Blue Crab(BC)	BC(37 11 38)	BC(37 11 38)	BC(57 48 34)	BC(65,57)	BC(65,57)	BC(73,81)	BC(88)	BC(88)	BC(88)	BC(88)			
Crayfish(CR)						CR(43,44)	CR(44)	CR(44)	CR(44)	CR(44)	CR(44)	CR(44)	CR(44)
Shark(SH)													
ABALone(AB)				AB(25A)	AB(25A)	AB(25A)	AB(25A)	AB(25A)	AB(25A)	AB(25A)	AB(25A)	AB(25B)	AB(25C)
Prawn(PR)			PR(50 49)	PR(75,65,64,50)	PR(75,65,64,50)	PR(71,72,73,74,75)	PR(71,72,73,74,75)	PR(71,72,73,74,75)	PR(71,72,73,74,75)	PR(71,72,73,74,75)			
Sardine(SD)	SD(35)	SD(36 35)	SD(43,46)	SD(44A,43)	SD(44A,43)	SD(44A,43)	SD(44A)	SD(44A)	SD(44A)	SD(44A)	SD44B	SD(44B)	SD(45)
Nearby anchorages	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y
Cultural Impacts							N	N	N	N			N
Not on aborgincal land or involve cultural heritage sites-council agreements			N	N	N	N	N	N	Y(burial sites)		N	N	N
Economic													
Within reach of a refuse centre													
Within council locations (state council region)	Mallala	Mallala	Charles Stuart	Onkaparinga	Onkaparinga	Onkaparinga	Yankalilla	Yankalilla	Yankalilla	Yankalilla	Yankalilla	Yankalilla	Victor Harbour
Site access													
Access year round.	N		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Access 4WD(4) or 2WD(2)	4	4	2	2	2	2	2	2	2+4	2	2	2	2
Subjective													
Not previously used for litter surveys	N	N	N	N	N	N	N	N	N	N	N		
Can be sampled any time of year/periodically			Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Estimated visits per year(in 10n)													
Main beach usage(swimming(S), fishing(F), boating(B), recreational (R)		R	FBRS	R	RFS	RFS	R	R	RFS	RFS	RFS	RFS	RF
Boat access	N	N	N	N	Y	N	N	Y	N	N	N	N	N
Anchorages	N	N	N	N	Y	N	N	Y	N	N	N	N	N
Remote	Y	Y	N	N	N	N	N	N	N	Y	Y	Y	N
Comments													
Access coordinates	34°24'18.93"S	34°27'29.23"S	34°53'13.20"S	35° 3'46.72"S	35° 7'23.73"S	35°14'52.94"S	TBA	TBA	TBA	TBA	TBA	TBA	35°32'28.95"S
Access coordinates	138°19'24.50"E	138°21'43.45"E	138°29'12.17"E	138°30'5.19"E	138°28'37.84"E	138°28'7.04"E	TBA	TBA	TBA	TBA	TBA	TBA	138°38'16.21"E
Road type	Dirt road	Dirt road	Main road	Main road	Main road	Main road	Main road	Main road	Main road	Main road	Farm property	Main road	Main road
Beach access	2wd	4wd-2wd	2wd	2wd	2wd	2wd	2wd	2wd	2wd	2wd	4wd	2wd	2wd
Information to get to site	Drive along the A1 Hwy	Drive along the A1 Hwy	Travel North via		Travel South via the	Travel down toward							Travel south down
JPG Image for site	Y		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Search area mapping for site	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
GE-Path coordinates in excel based on 500m length	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Appendix 2. Beach parameters used for marine debris survey site selection, Gulf St. Vincent and Yorke Peninsula, South Australia.

Beach identification	GSVWZ1A	GSVWZ1B	GSVWZ1C	GSVWZ2B	GSVWZ2C G	SVWZ3A	GSVWZ3B
Common name	Tiddy w iddy	Mullow urtie Point	Black point South	Long beach PV	South Stansbury	Point Hicks	Wattle bay
Latitude	34°23'52.48"S	34°31'15.52"S	34°38'3.40"S	34°50'32.07"S	34°55'25.36"S	35° 2'37.37"S	35° 8'6.55"S
Longitude	137°56'46.69"E	137°53'8.48"E	137°54'1.61"E	137°49'5.68"E	137°47'23.11"E	137°45'37.61"E	137°42'59.87"E
Geographical							
Direction w ind current	W	W	W	W	W	SW	SW
Direction ocean current	SW	SW	SW	SW	SW	SW	SW
Aspect	SE	SW	SE	SE	SE	SE	SE
Beach curvature/profile							
linear (L), concave (CA), convex (CO), sinsoidal/tierral (S/T)	LCO	C	LC	CO	L	CO	L
Beach length(m)	500	450	500+	600	600	500	500+
Nearest river	tidal creek	tidal creek	ephemeral creek				
distance(m)	3	5000	2000				
Input	indirect	indirect	direct				
Geomorphological							
Sand(S) gravel(G) shingle(Sh) pebble beach(PB)	S G	S	S	S	S	SR	S
Nourished y ffshore ands,oather han y earby riversb ontributing andsbased ediments s	Y	Y	Y	Y	Y	Y	Y
Landw ard limit	dunes/flats	dunes	dunes	dunes	cliffs	vegetated dune	vegetated dunes
Having a uniform sediment compartment, at least 5 km long, w ith minimal longshore drift of sand.	Y	Y	Y	Y	Y	Y	Y
Rear each an e escribed easilyd nd ubbish emaved easily r	Y	Y	Y	N	?	Y	Y
Beach w ide at low tide(m)	40	20	10	20	20	30	30
Beach gradient							
Moderate to low (15-45 degree slope) beach gradients.	low	low	low	low	low	low	low
Small tidal range	N	Y	Y	Y	Y	Y	Y
Tidal ud flats/large ide flats-dangerous tides nd ebris hunting d s	sand lat	N	N	sand	sand	Sand + ock	sand r
Bathymetry							
Direct Offshore bathymetry (m)	5	5	5	5	5	5	5
Offhsore bathymetry characteristic gradual(G) Steep(S)(5-30m)	G	G	G	G	G	G	G
Offshore structures							
No dense subtidal seagrass(SG), algal grow th, reef structures(R) offshore, unvegetated soft bottom (U)	SG R	SG(2km)	SG	SG	SG	SG R	SG
Clear access to the sea (not blocked by breakw aters or jetties)	Y	Y	Y	Y	Y	Y	Y
Ecological impact							
No endangered/threatened species nesting on beach-councils DEH							
Sensitive beach vegetation	N	N	N				
Social Impacts							
Remote rom human ettlements, seldom isited y ourists, nd without asy ccess o e otora ehicles m	Y v	Y	Y	Y	Y	N	N
Nearest township	Tiddy Widdy	Pine point	Black point	Port Vincent	Stansbury	Coobow ie	Sultana Point
distance(km)	2	3	1.6	10	2.5	3	4.4
direction	S	N	N	N	N	W	NE
Fisheries							
Nearby inshore isheries, Marine ishing areas(MFA)	Y	Y	Y	Y	Y	Y	Y
Marine scale(MS)	MS 34 35	MS 34	MS 34	MS 34	MS 34	MS 40C 40D	MS 40C 40D
Blue Crab(BC)	BC 1 3 5 8	BC 1 3 5 8	BC 1 3 5 8	BC 28 22 42	BC22 42 28	BC 49 58	BC 49 58
Crayfish(CR)	CR 34	CR 34	CR 34	CR 34	CR 34	CR 40	CR 40
Shark(SH)							
ABALone(AB)		AB 22B	AB 22B	AB 24C 24B	AB 24C 24B	AB 24D 24E	AB 24D 24E
Praw n(PR)	PR 1 2	PR 2 3	AB 22B	PR 10 11 23	PR 10 11 23	PR 23 25 26	PR 23 25 26
Sardine(SD)	SD 34 35	SD 34	AB 22B	SD 34	SD 34	SD 30C 40D	SD 30C 40D
Nearby anchorages		Pine point	AB 22B	Port Vincent	Stansbury	Coobow ie	Sultana Point
Cultural Impacts							
Not on aborgincal land or involve cultural heritage sites-council agreements							
Economic							
Within reach of a refuse centre	Y	Y	Y	Y	Y	Y	Y
Within council locations (state council region)	Yorke Peninsula	Yorke Peninsula	Yorke Peninsula	Yorke Peninsula	Yorke Peninsula	Yorke Peninsula	Yorke Peninsula
Site access							
Access year round.	Y	Y	Y	Y	Y	Y	Y
Access 4WD(4) or 2WD(2)	2	2 4	2 4	2	2	2	2
Subjective							
Not reviously sedpor itter urveys l s	N	N	N	N	N	N	N
Can be ampled ny ime f ear periodically	Y	Y	Y	Y	Y	Y	Y
Estimated visits per year(in 10n)							
Main each sage(swimming(S), ishing(F), boating(B), recreational (R)	R	RF	RF	R	R	R	R
Boat access	N	N	N	N	N	N	Y
Anchorages	N	N	N	N	N	N	N
Remote	Y	Y	Y	Y	N	N	Y
Comments							
Access coordinates	34°23'50.37"S	34°31'18.31"S	34°37'9.78"S	34°50'29.12"S	34°55'45.24"S	35° 2'39.52"S	35° 8'4.26"S
Access coordinates	137°56'38.82"E	137°52'46.76"E	137°54'12.20"E	137°48'59.50"E	137°47'9.42"E	137°45'24.54"E	137°42'59.67"E
Road type	Dirt road	Track	Road access	Road access	Council land	Road access	Road access
Beach access	direct	Farm access	TBA	direct	direct	Road access	Road access
Additonal information	Travel south dow n the B86 Yorke	Travel south on the B86 York Valley Hw y	Travel south along B88 Yorke Valley Hw y.	Travel south dow n Yorke Valley Hw y	Travel south along B88	Travel south dow n Yorke	Head south to Edithburgh via
JPG Image for site	Y	Y	Y	Y	Y	Y	Y
Search area mapping for site	Y	Y	Y	Y	Y	Y	Y
GE-Path oordinates in xcel ased n e00m length o 5 l	Y	Y	Y	Y	Y	Y	Y

Beach identification	YP1	YP2	YP3	YP4	YP5	YP6
Common name	Kemps Bay	Bangalee beach	Chinaman's A	Chinaman's B	Cable Bay	Cape Spencer
Latitude	35° 8'36.68"S	35°14'27.37"S	35°17'13.07"S	35°17'16.40"S	35°17'14.49"S	35°17'51.70"S
Longitude	137°36'24.30"E	137° 8'10.99"E	136°54'54.82"E	136°54'53.44"E	136°53'51.45"E	136°52'53.45"E
Geographical						
Direction w ind current	SW	SW	SW	SW	SW	SW
Direction ocean current	SW	SW	SW	SW	SW	SW
Aspect	SW	SW	SE	SW	SE	SW
Beach curvature/profile						
linear (L), concave (CA), convex (CO), sinsoidal/tierral (S/T)	L	C	C	L	C	C
Beach length(m)	500+	450	734	318	1384	500
Nearest river						
distance(m)						
Input						
Geomorphological						
Sand(S) gravel(G) shingle(Sh) pebble beach(PB)	S	S	SR	SR	SR	S
Nourished y ffshore ands,oather han y earby riversb ontributing andsbased ediments s	Y	Y	Y	Y	Y	Y
Landw ard limit	bluffs	dunes	cliff	cliff	cliff	dunes
Having a uniform sediment compartment, at least 5 km long, w ith minimal longshore drift of sand.	Y	Y				Y
Rear each an e escribed easilyd nd ubbish emaved easily r	Y	Y	Y	Y	Y	Y
Beach w ide at low tide(m)	30	20	25	15	10	40
Beach gradient						
Moderate to low (15-45 degree slope) beach gradients.	low	moderate	low	low	low	moderate
Small tidal range	Y	N	Y	Y	Y	Y
Tidal ud flats/large ide flats-dangerous tides nd ebris hunting d s	N	N	N	N	N	N
Bathymetry						
Direct Offshore bathymetry (m)	5	5	5	5	5	5
Offhsore bathymetry characteristic gradual(G) Steep(S)(5-30m)	G	S	G	G	G	S
Offshore structures						
No dense subtidal seagrass(SG), algal grow th, reef structures(R) offshore, unvegetated soft bottom (U)	SG	R R	R	R	R	R
Clear access to the sea (not blocked by breakw aters or jetties)	Y	Y				Y
Ecological impact						
No endangered/threatened species nesting on beach-councils DEH						
Sensitive beach vegetation						
Social Impacts						
Remote rom human ettlements, seldom isited y ourists, nd without asy ccess o e otora ehicles m	Y	Y	Y	Y	Y	Y
Nearest township	Port Morow ie	Marion Bay	Stenhouse Bay	Stenhouse Bay	Stenhouse Bay	Stenhouse Bay
distance(km)	9	15	5	5	5	7
direction	W	W	NE	NE	NE	NE
Fisheries						
Nearby inshore isheries, Marine ishing areas(MFA)	Y	Y	Y	Y	Y	Y
Marine scale(MS)	MS 40B	MS 40B	MS 40B	MS 40B	MS 40B	MS 40A
Blue Crab(BC)	BC 66 74	BC 66 74	BC 66 74	BC 66 74	BC 66 74	
Crayfish(CR)	CR 40	CR 40	CR 40	CR 40	CR 40	CR 40
Shark(SH)						
ABALone(AB)	AB 24F	AB 24F	AB 24F	AB 24F	AB 24F	AB 23C
Praw n(PR)	PR 112 113 120	PR 112 113 120	PR 112 113 120	PR 112 113 120	PR 112 113 120	PR 117
Sardine(SD)	SD 40B	SD 40B	SD 40B	SD 40B	SD 40B	SD 40A
Nearby anchorages	Port Morow ie	Stenhouse Bay	Stenhouse Bay	Stenhouse Bay	Stenhouse Bay	Stenhouse Bay
Cultural Impacts						
Not on aborgincal land or involve cultural heritage sites-council agreements						
Economic						
Within reach of a refuse centre	Y	Y	Y	Y	Y	Y
Within council locations (state council region)	Yorke Peninsula	Yorke Peninsula	Yorke Peninsula	Yorke Peninsula	Yorke Peninsula	Yorke Peninsula
Site access						
Access year round.	Y	Y	Y	Y	Y	Y
Access 4WD(4) or 2WD(2)	2	2	2	2	2	2
Subjective						
Not reviously sedpor itter urveys l s	N		N	N	N	N
Can be ampled ny ime f ear periodically	Y	Y	Y	Y	Y	Y
Estimated visits per year(in 10n)						
Main each sage(swimming(S), ishing(F), boating(B), recreational (R)	R	R	R	R	R	R
Boat access	N	N	N	N	N	N
Anchorages	N	N	N	N	N	N
Remote	Y	Y	Y	Y	Y	Y
Comments						
Access coordinates	35° 8'40.72"S	35°13'48.80"S	35°17'13.07"S	35°17'16.40"S	35°17'14.49"S	35°17'10.32"S
Access coordinates	137°36'34.44"E	137° 7'29.14"E	136°54'54.82"E	136°54'53.44"E	136°53'51.45"E	136°53'53.93"E
Road type	Road access	Road access	Road access	Road access	Road access	Road access
Beach access	Road access	Road access	Road access	Road access	Road access	Road access
Additonal information	Head south to Yorketow n via	Access is via Hillocks Drive				Travel to Innes National Park via
JPG Image for site	Y	Y	Y	Y	Y	Y
Search area mapping for site	Y	Y	Y	Y	Y	Y
GE-Path oordinates in xcel ased n e00m length o 5 l	Y	Y	Y	Y	Y	Y

Appendix 3. Commercial and recreational fishing debris. Oyster rack marine debris North West GSV.

(Photo courtesy: AMLRNRMB)

Appendix 3. Commercial and recreational fishing debris. Rope debris Mullowurtie Point, North West GSV.

(Photo courtesy: AMLRNRMB)

Appendix 3. Commercial and recreational fishing debris. Commercial buoy, Bales Bay, Kangaroo Island

(Photo Courtesy: KI NRM)

Appendix 3. Commercial and recreational fishing debris. Plastic strapping. Mullowurtie Point, North West GSV.

(Photo courtesy: AMLRNRMB)

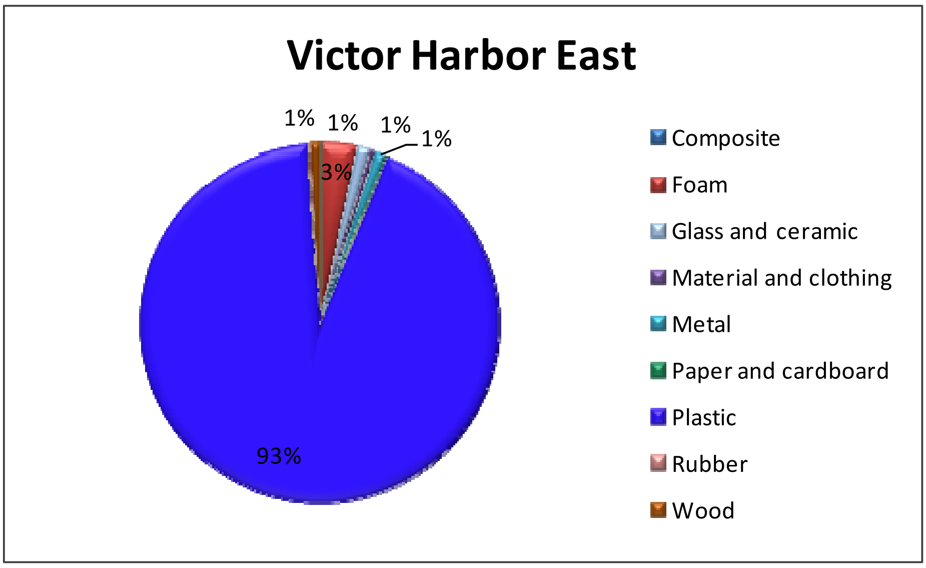
Appendix 3. Commercial and recreational fishing debris. Commercial rope recovered off Cape Hart, Kangaroo Island.

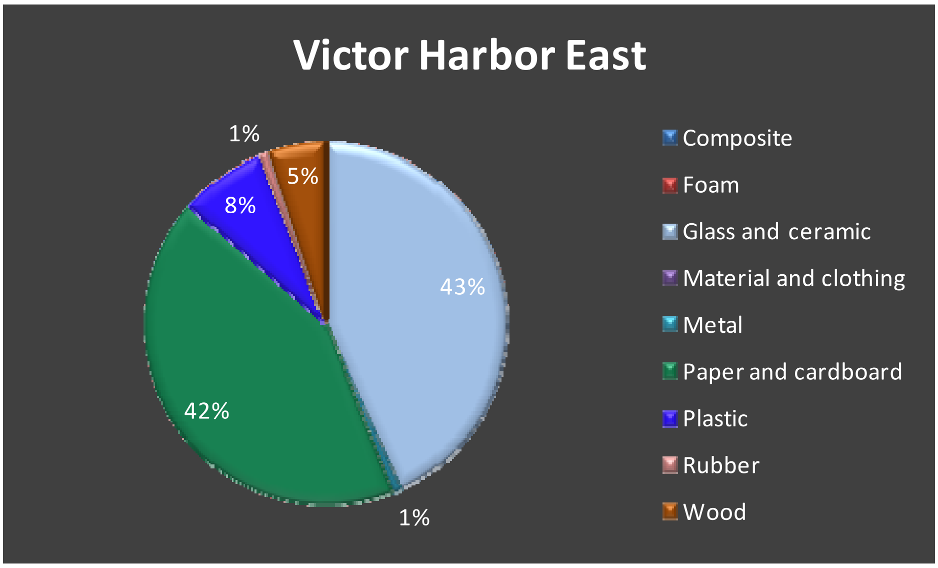
(Photo courtesy: KI NRMB)

Appendix 4. Collection-sort and weigh facilities for marine debris disposal and recycling.

Weigh station location	Name	Address	Hours of trading	Contact number	Area for sorting	Additional Information
Mallala	Mallala Waste Depot Resource Recovery Facility	Lime rock rd., Lower Light, SA 5501	9:00 am - 1:00pm (Thursday) 9:00 pm - 1:00pm (Saturday) 1:00 am - 4: 00 pm (Sunday)	If contact required after hours please call Lewis Richer (manager) **0428400111**	Storage shed on site	Debris to be recycled/discarded at site.
Victor Harbor	City of Victor Harbor Landfill	Dump rd. off Jagger Rd, Victor Harbor SA 5211	10:00 am - 4:00 pm (Monday - Sunday)	None	Allocated corner in generator shed	Debris to be recycled/discarded at site.
Yankalilla	Yankalilla Waste Dump	Lot 2 Victor Harbor Road Victor Harbor Rd (opposite Doctors Hill Rd.) Yankalilla SA 5203	9:00 am - 1:00 pm (Monday - Thursday) 12:00 am - 4:00 pm (Sunday)	Yankalilla manager Wayne **0409 674 982**	Shipping container on site	Debris to be recycled/discarded at site.
Port Vincent	Port Vincent Depot	Wauraltee Rd, Port Vincent SA 5581	9:00 am - 5:00pm (Monday - Sunday)	Please contact Nick Hoskins 2 days prior to arrival to pick up key for site **0419 817 975**	Locked shed	Bag debris and leave on site for removal.
Hillocks Drive	Hillocks Drive, Lower Yorke Peninsula	South Coast Rd, Warooka SA 5577	9:00 am - 2:00 pm (Thurs - Mon) Otherwise by appointment only.	Please contact Pam Bennet prior to arrival.**Hillocks drive: 8854 4002**	Storage shed on site. Enter via main house at driveway.	Bag debris and leave on site for removal.

Appendix 5. Summary data of marine debris represented as percent abundance (number items) (upper) and mass (kg) (lower) for major debris categories per site.





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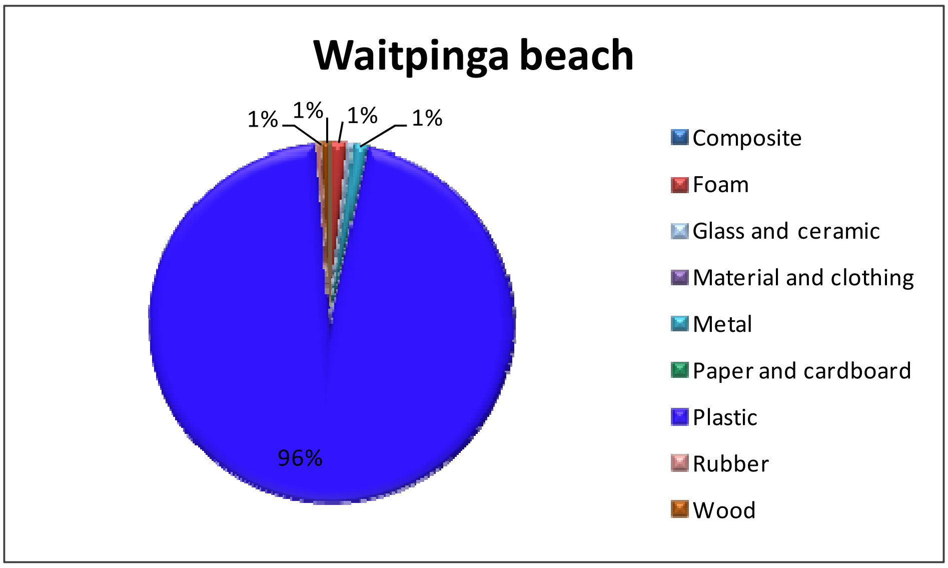

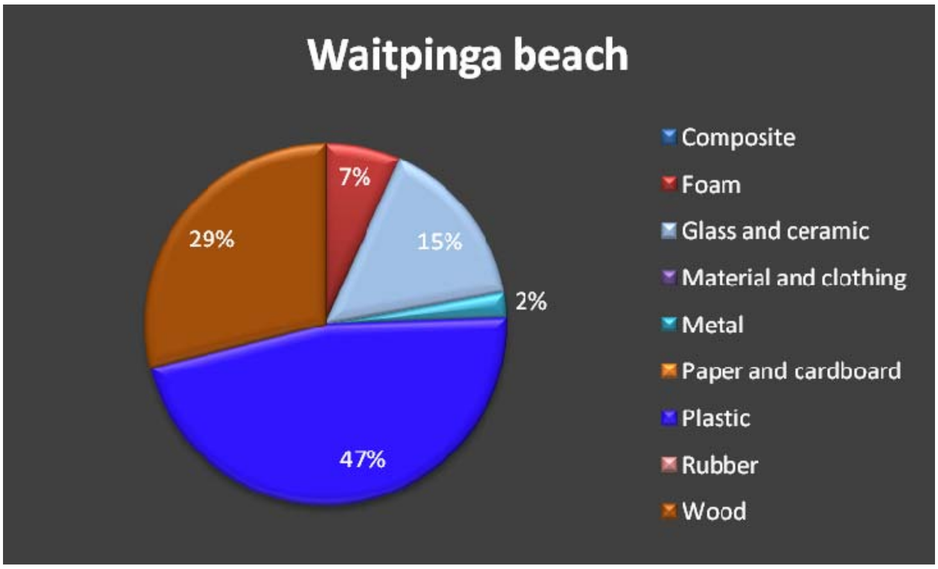

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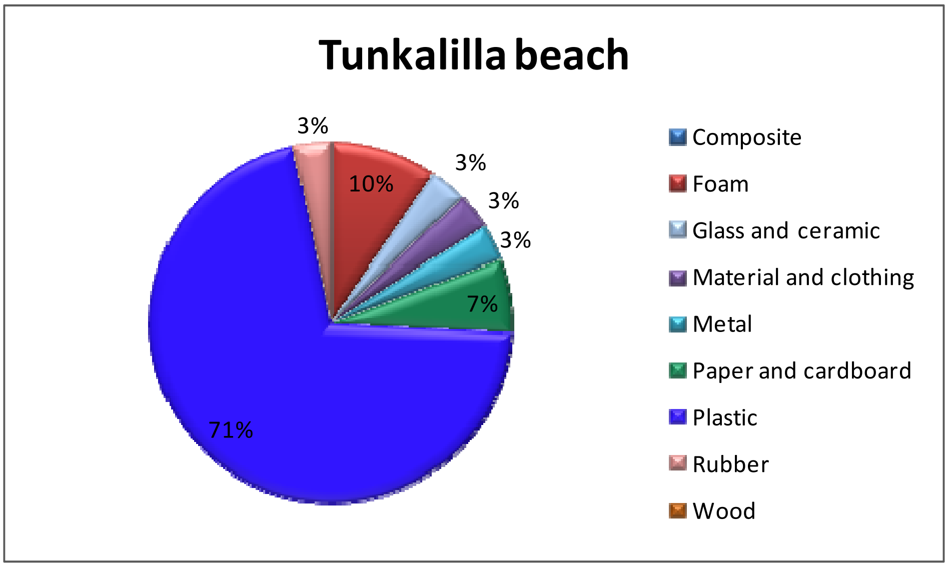

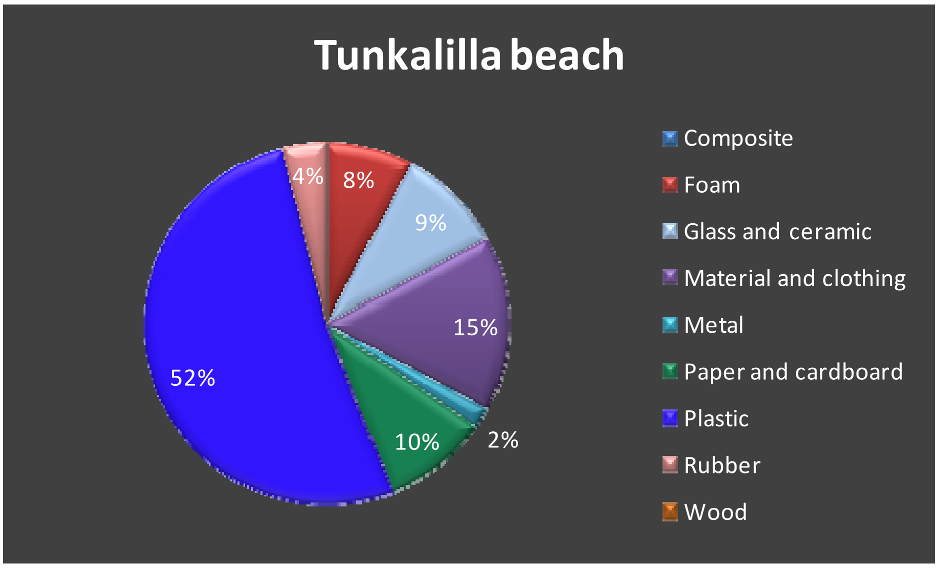

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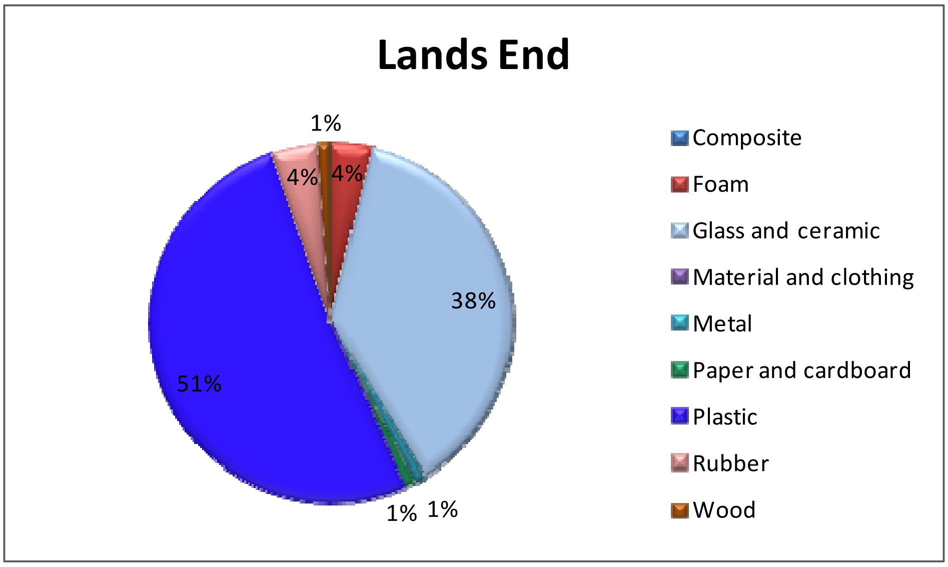

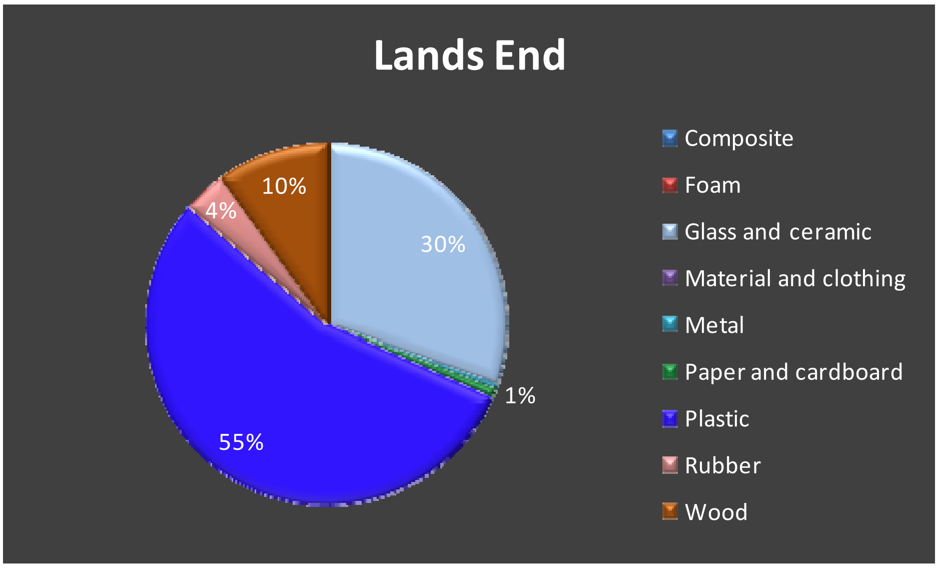

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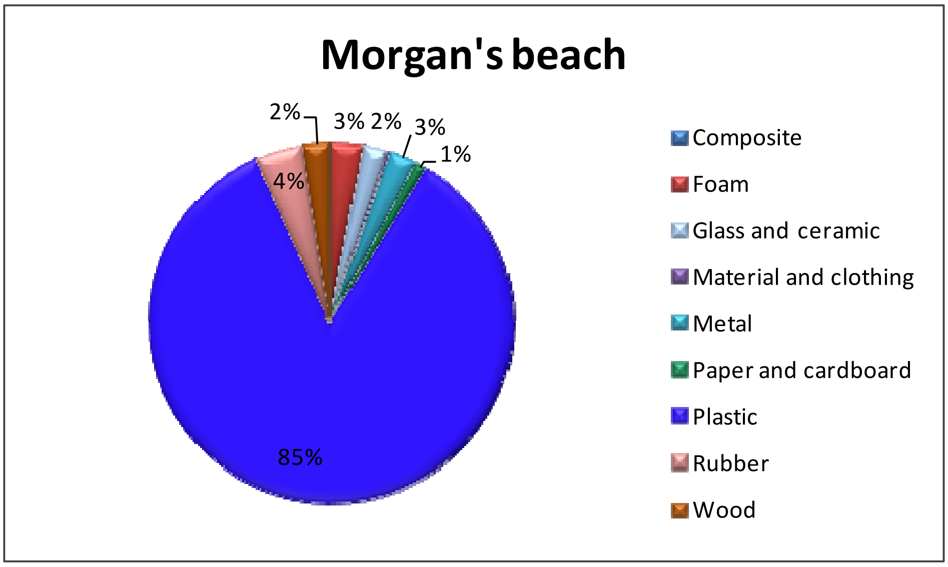

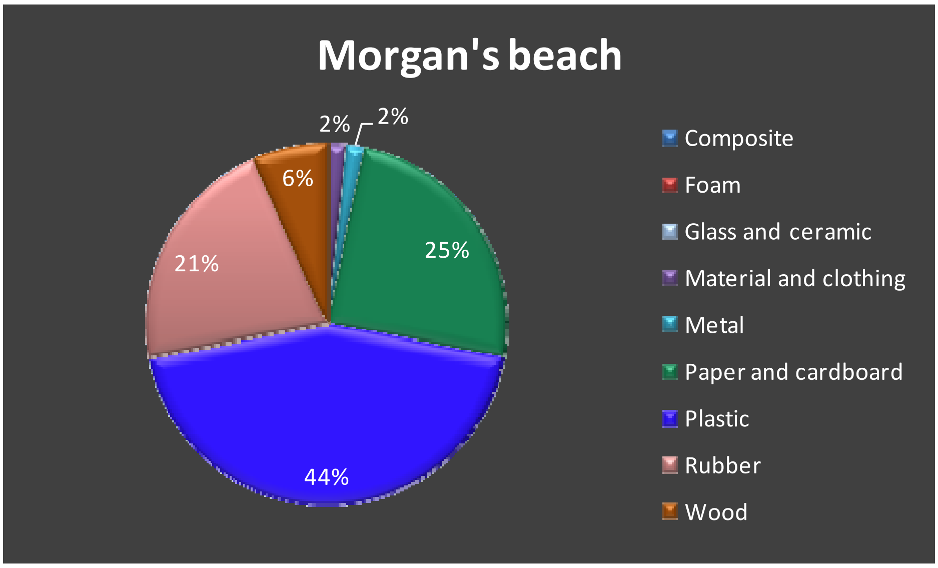

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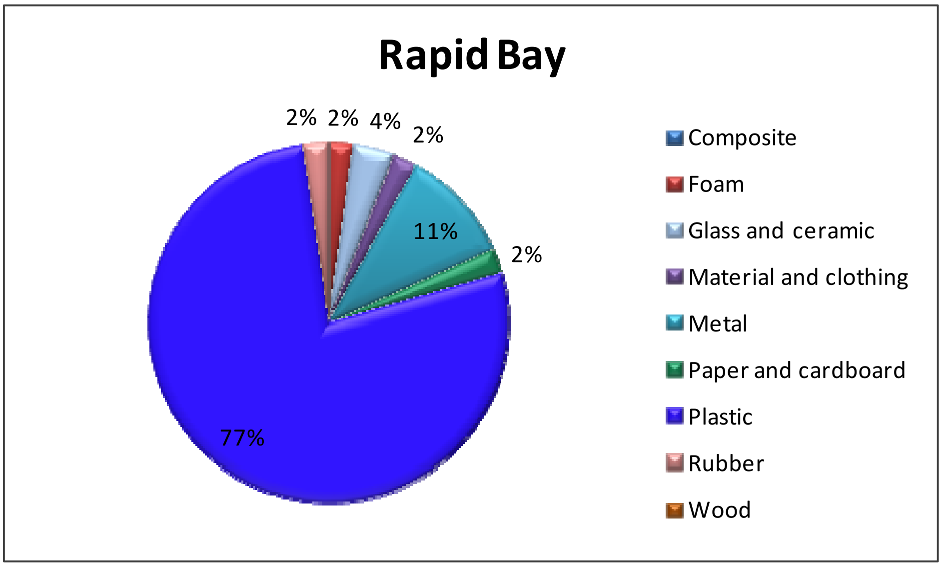

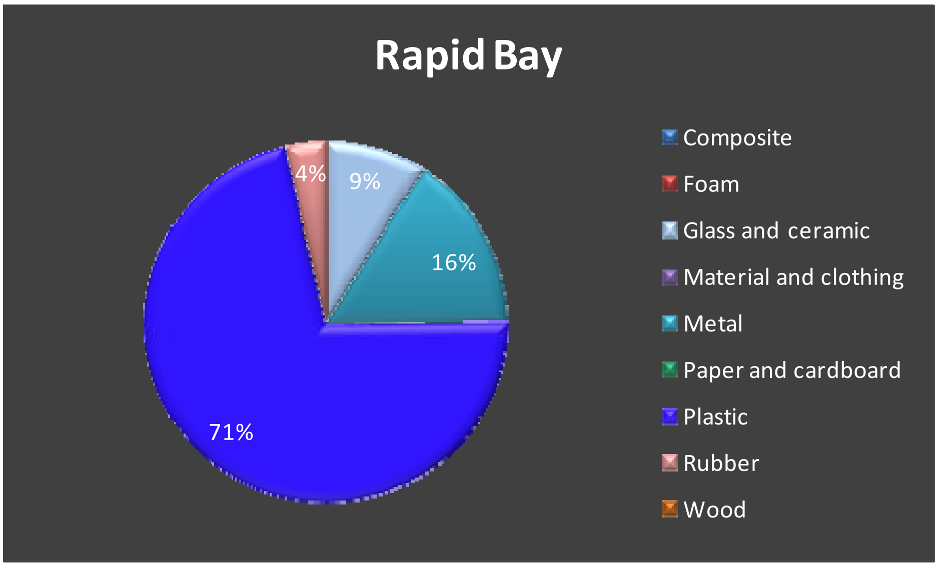

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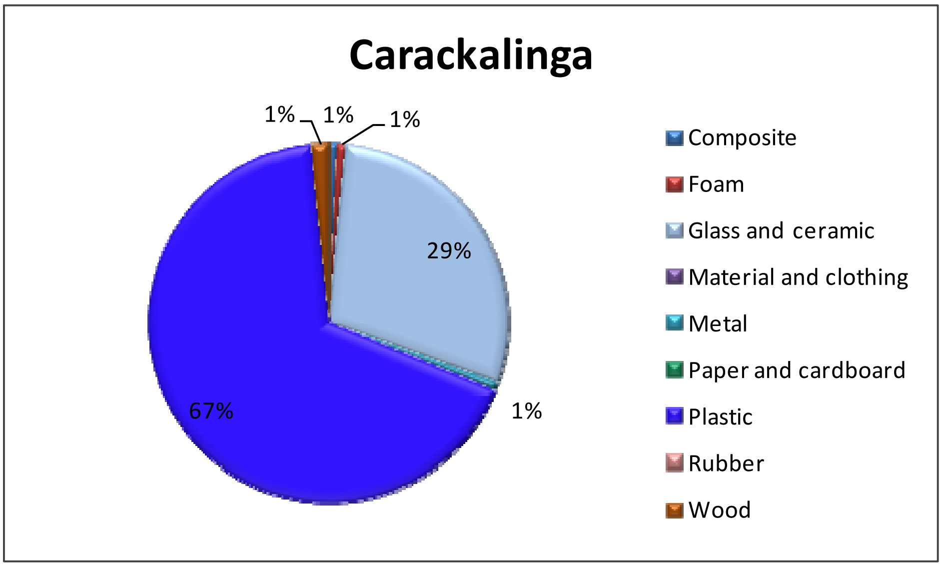

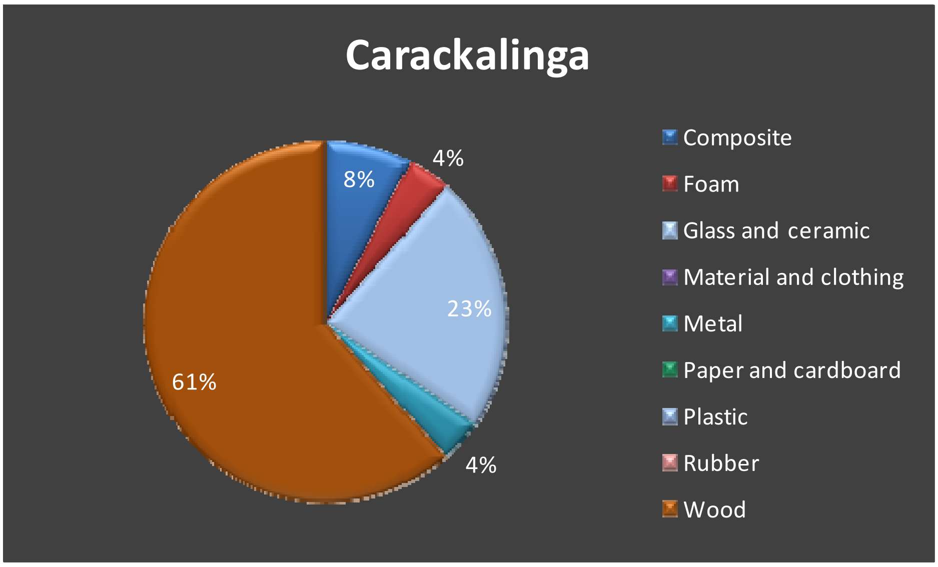

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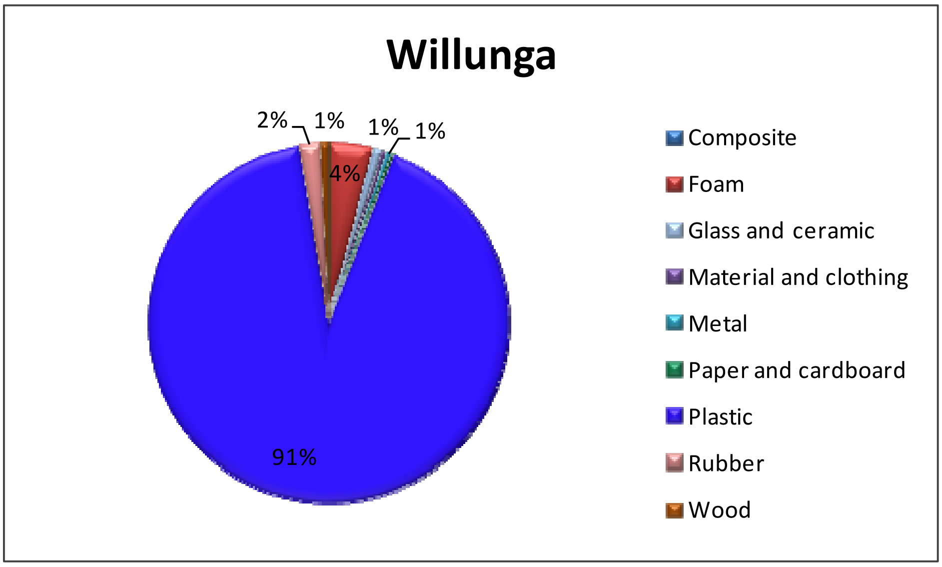

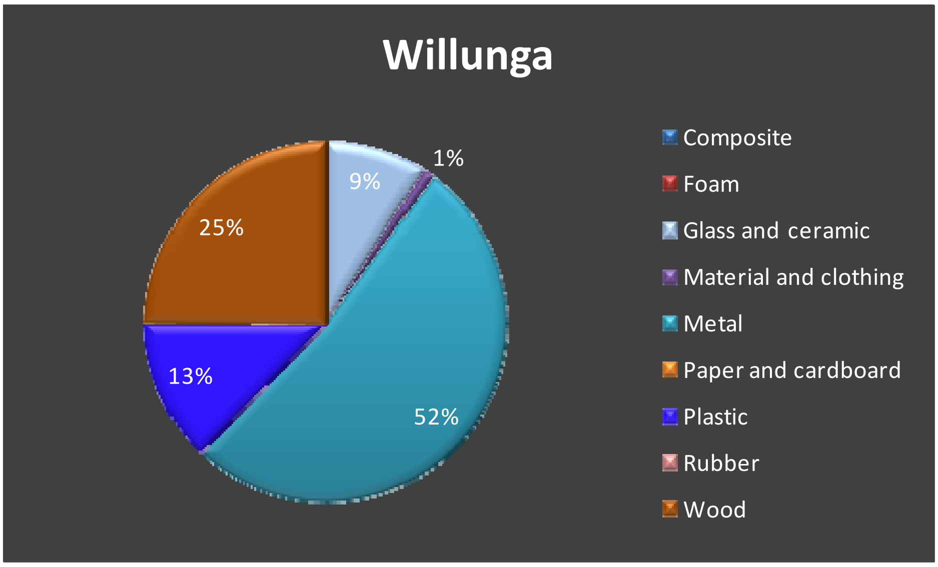

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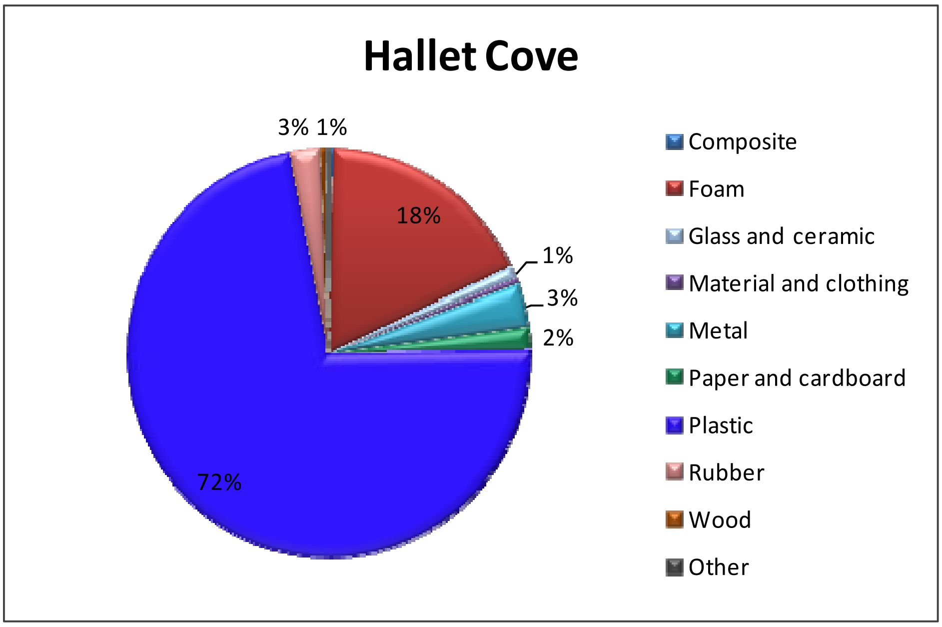

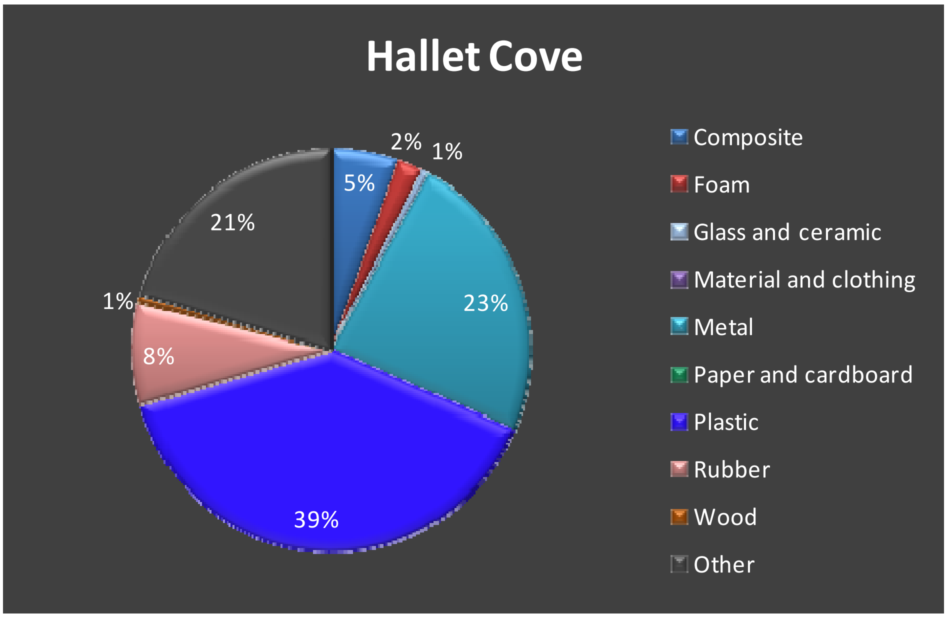

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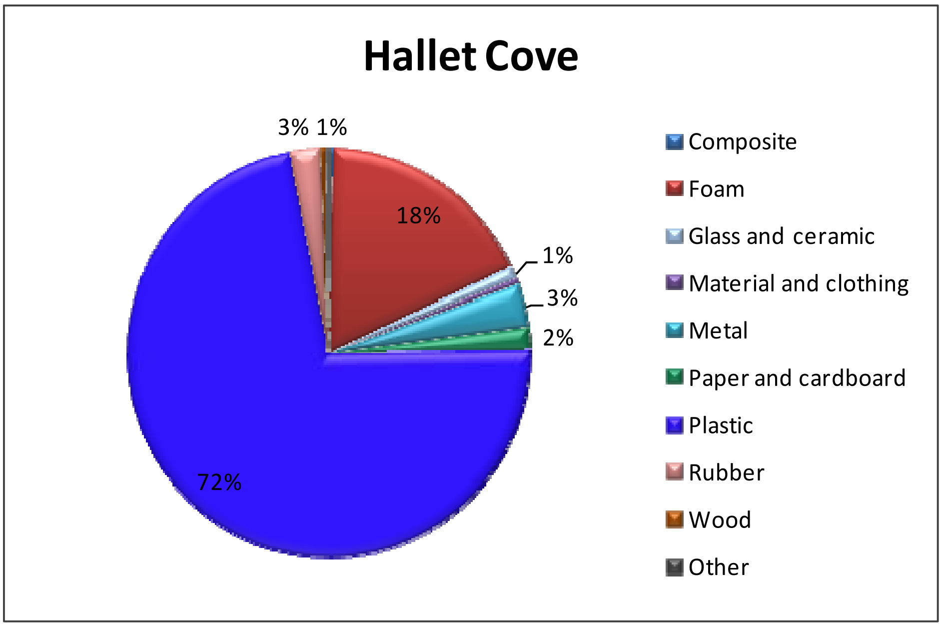

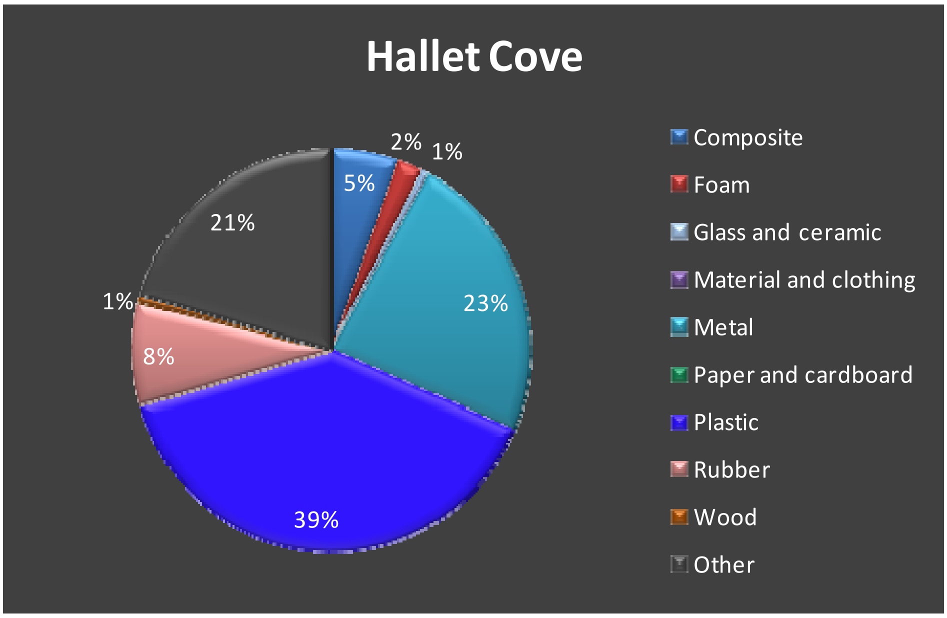

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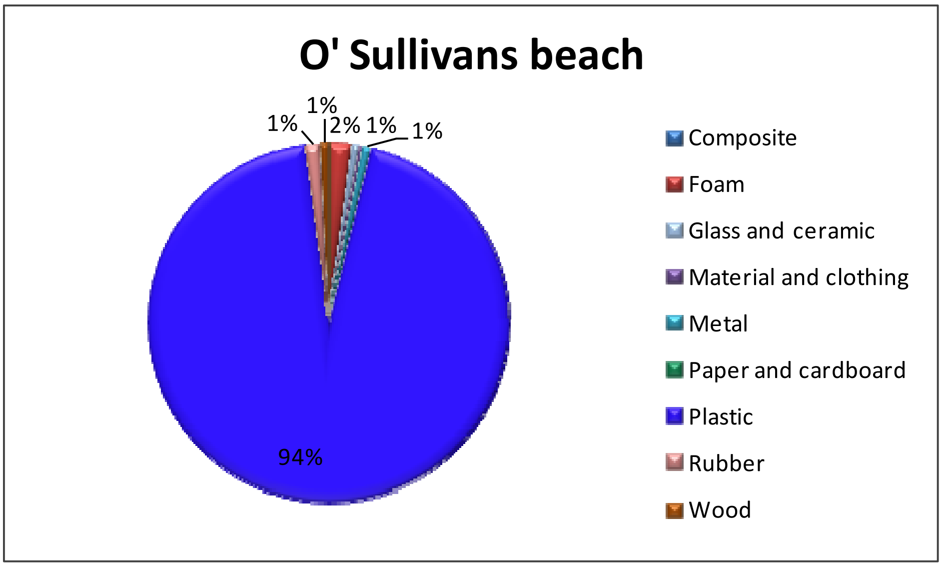

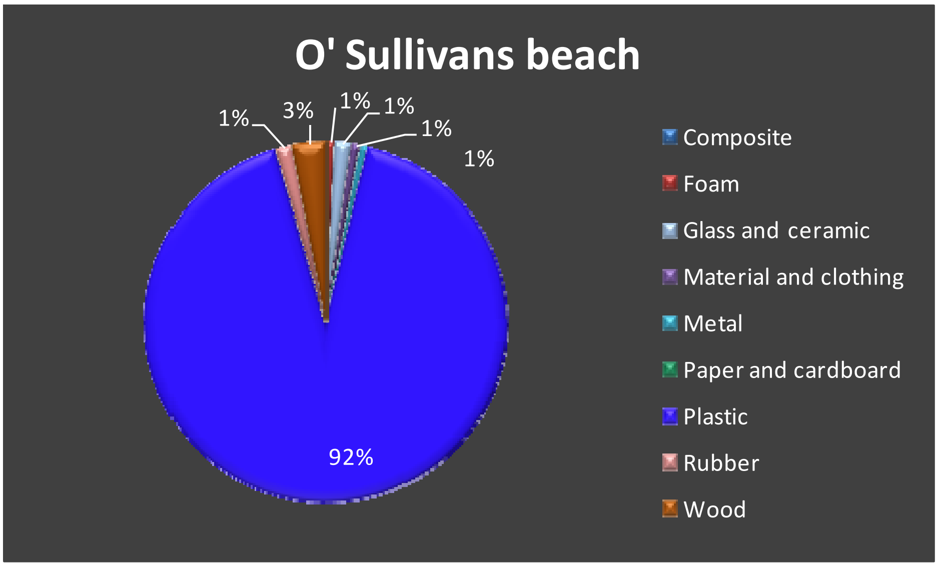

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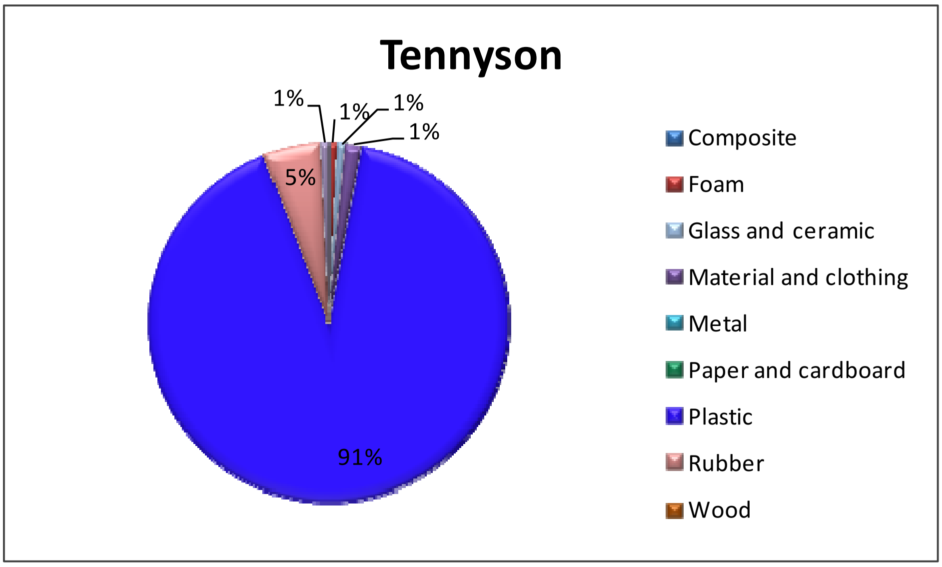

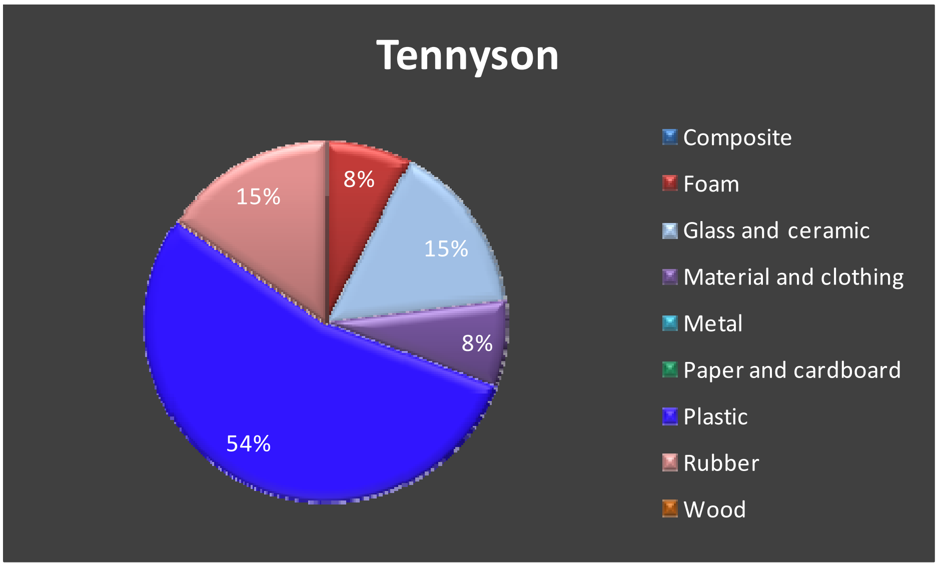

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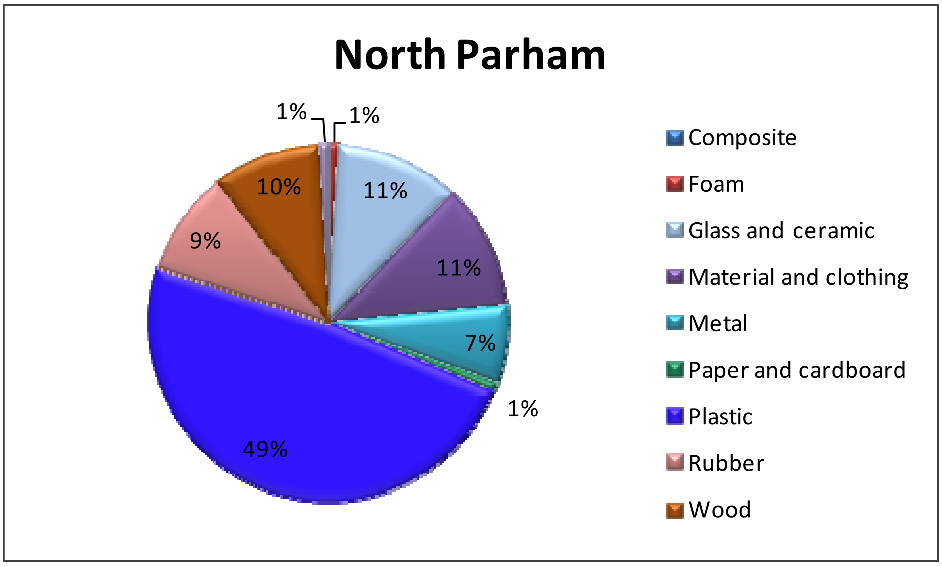

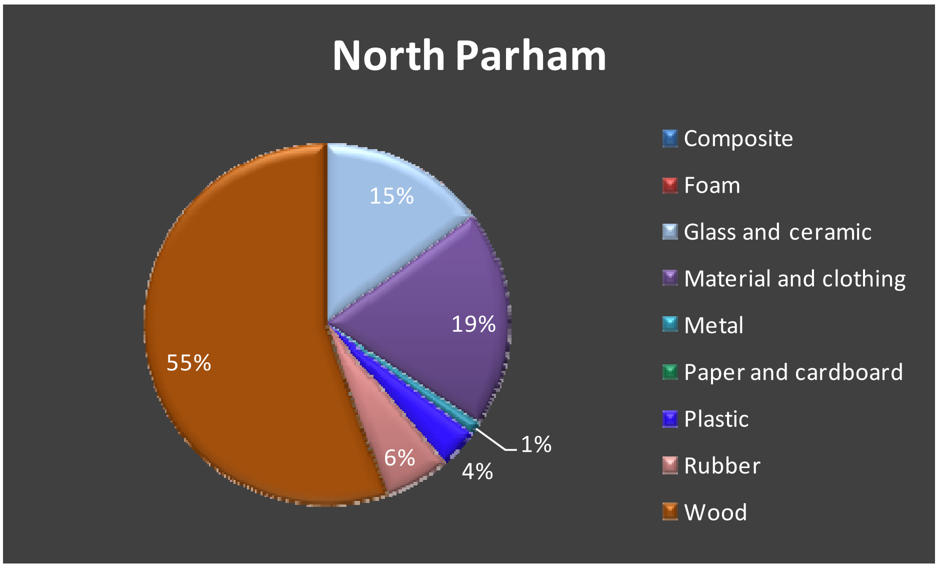

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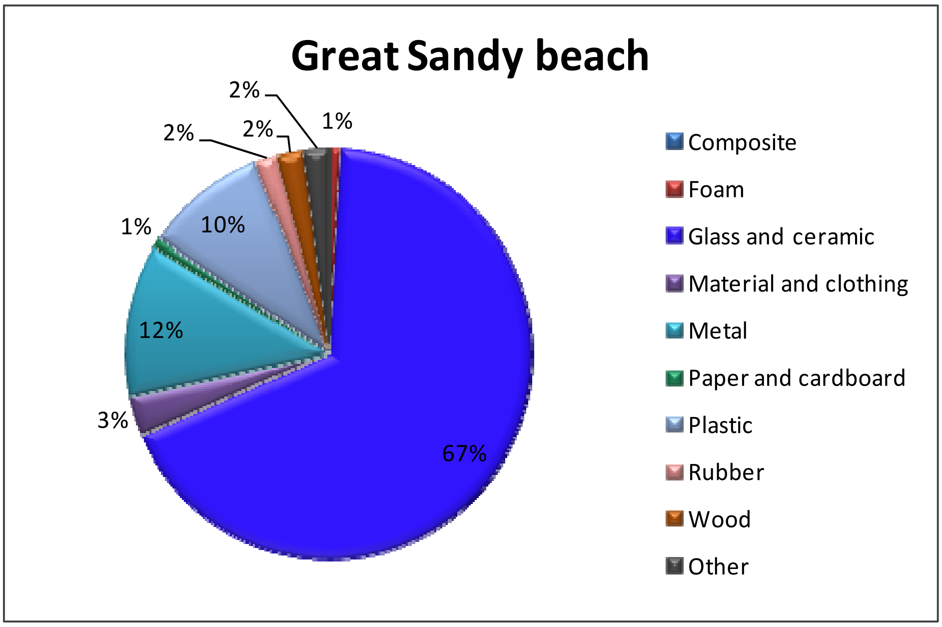

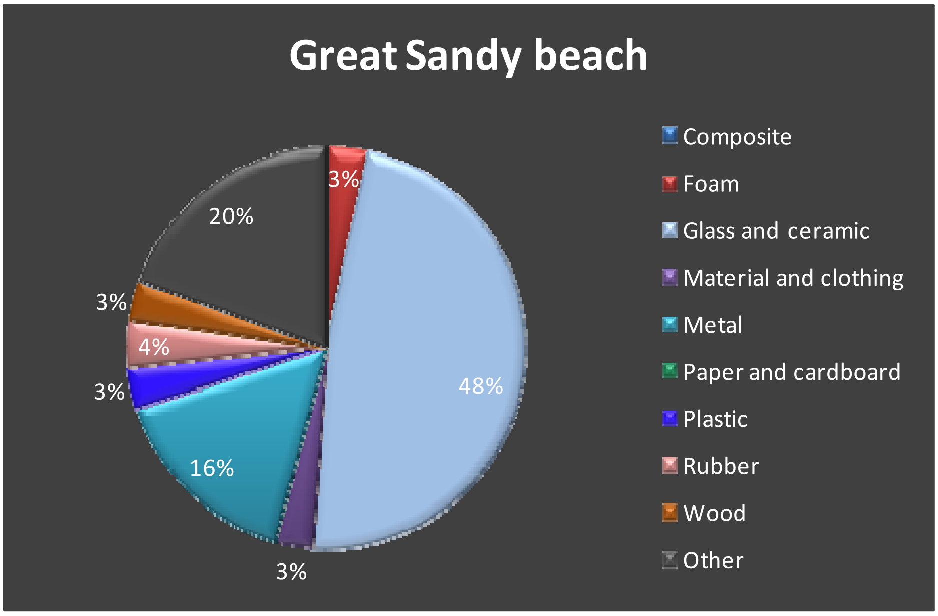

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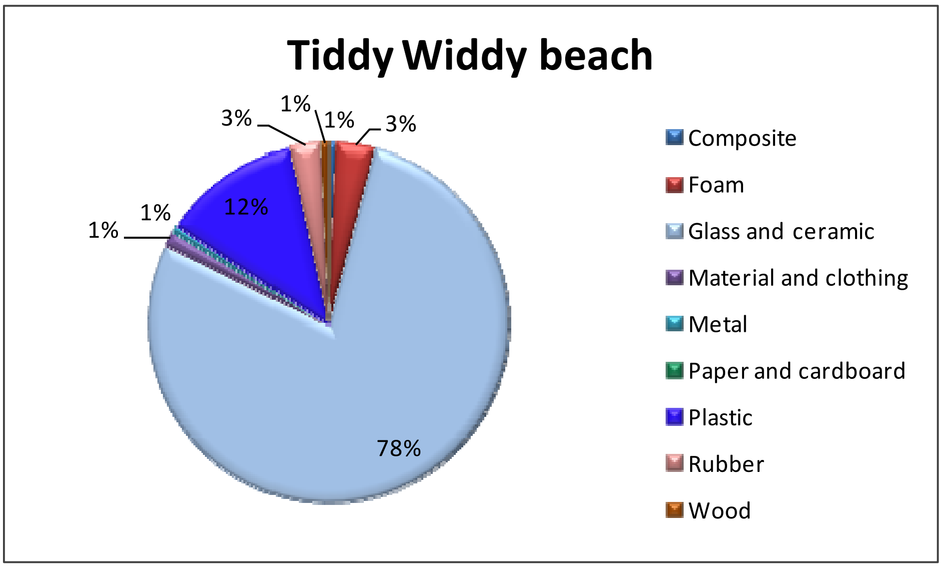

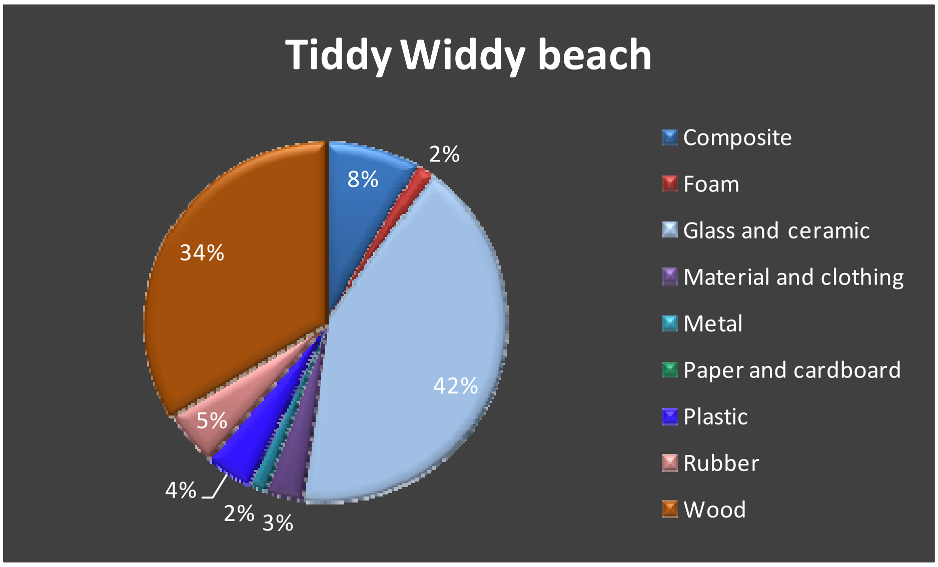

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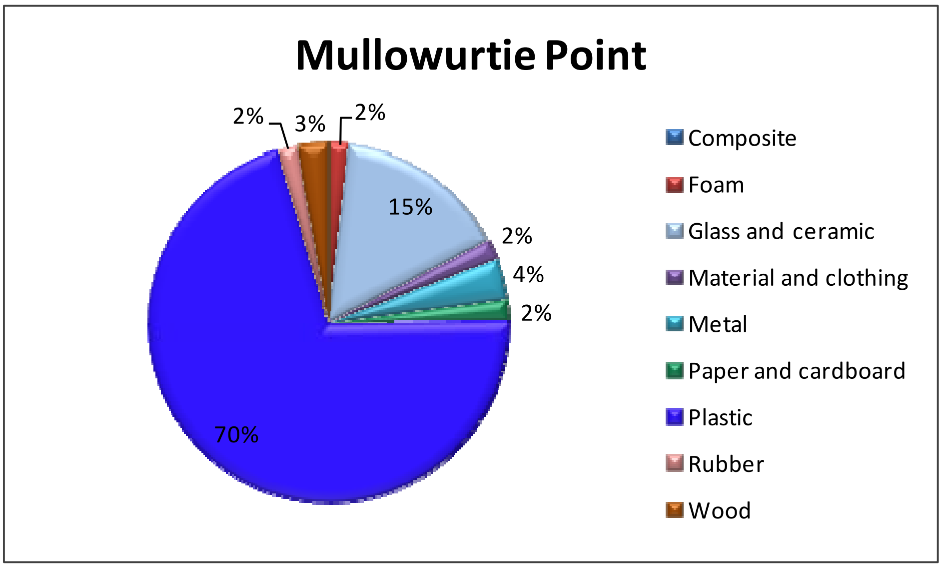

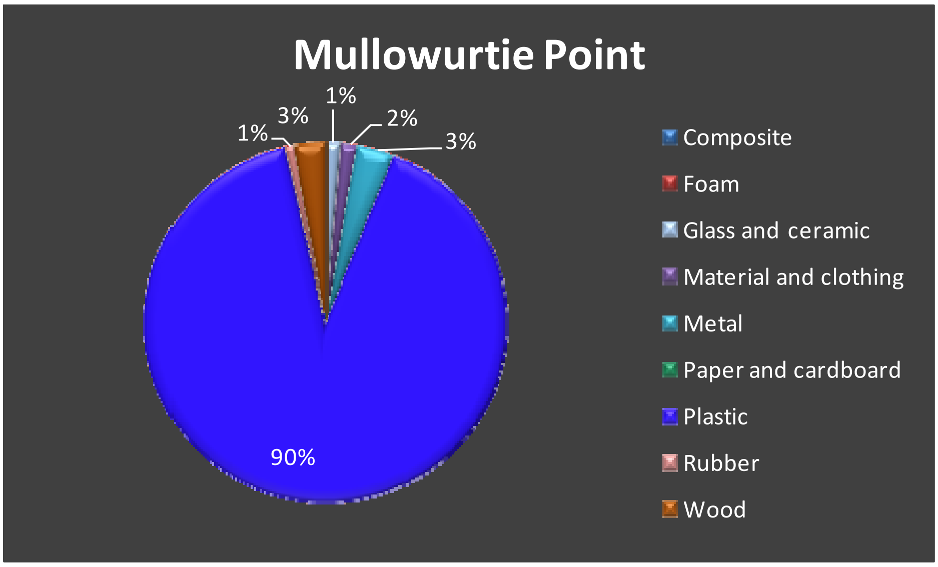

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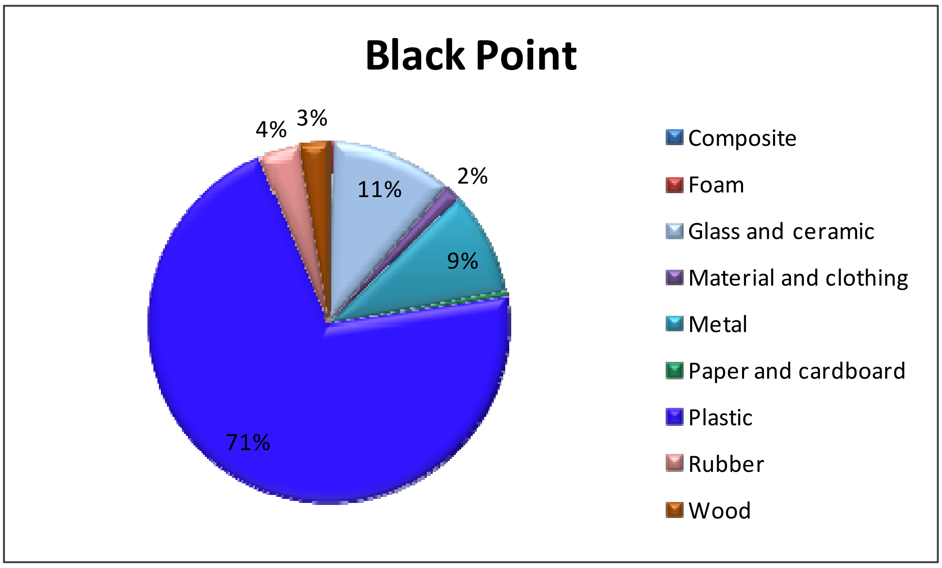

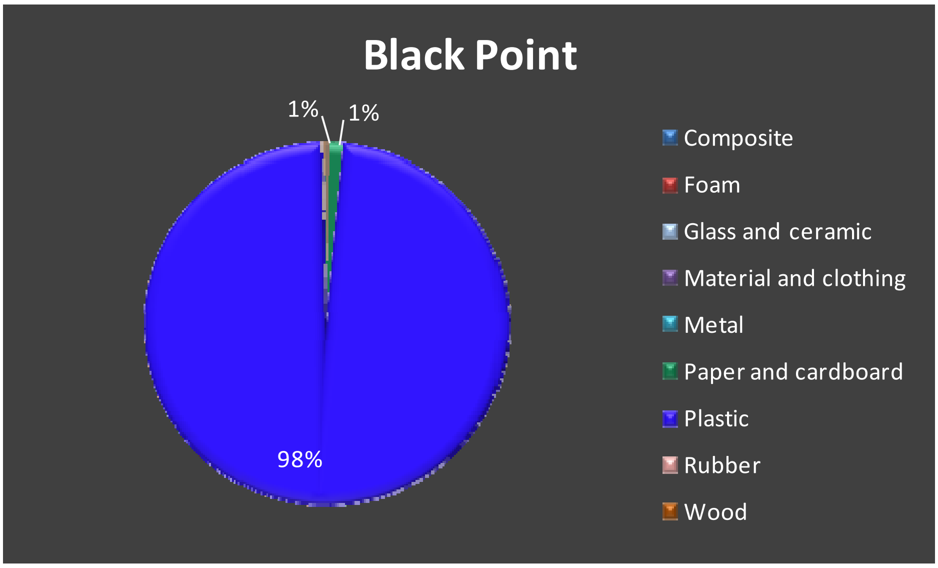

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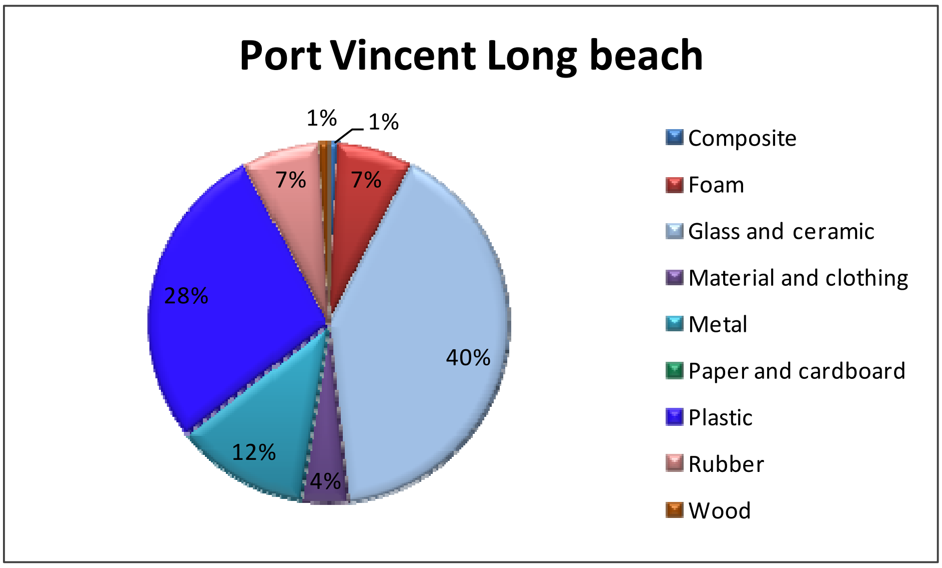

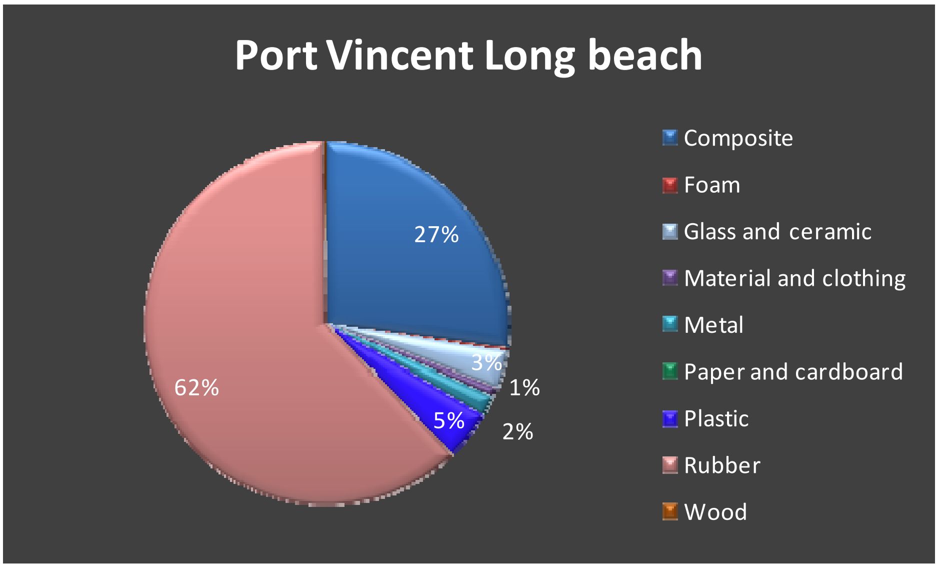

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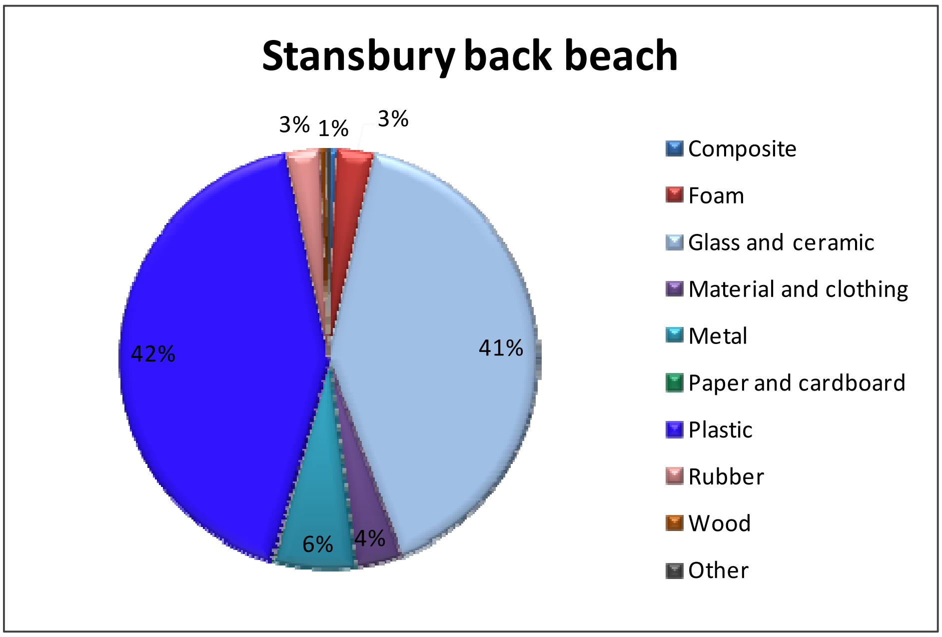

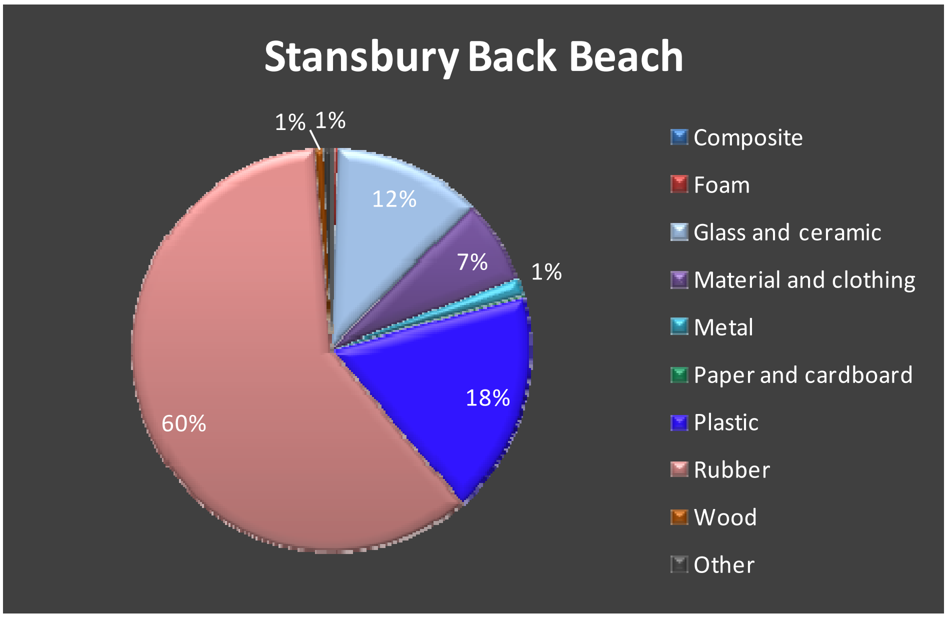

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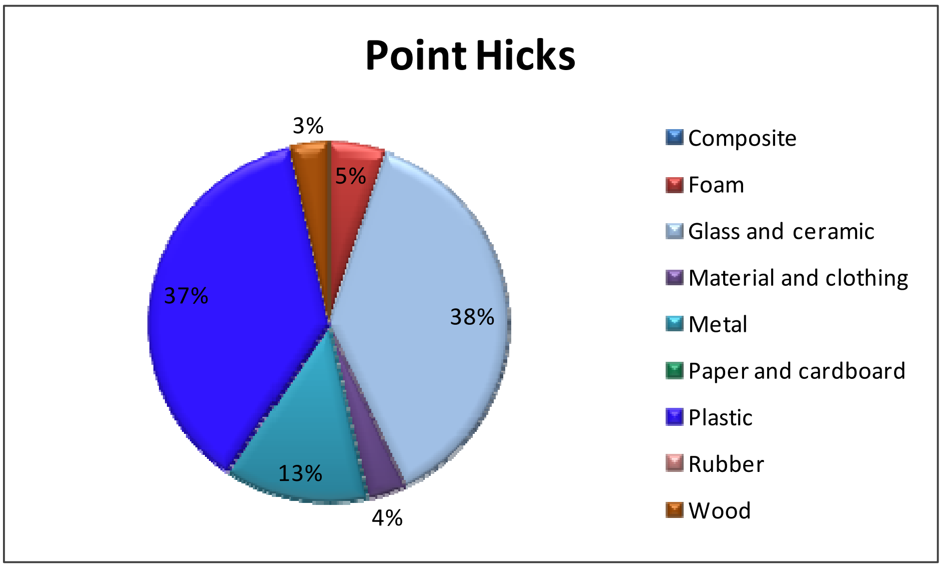

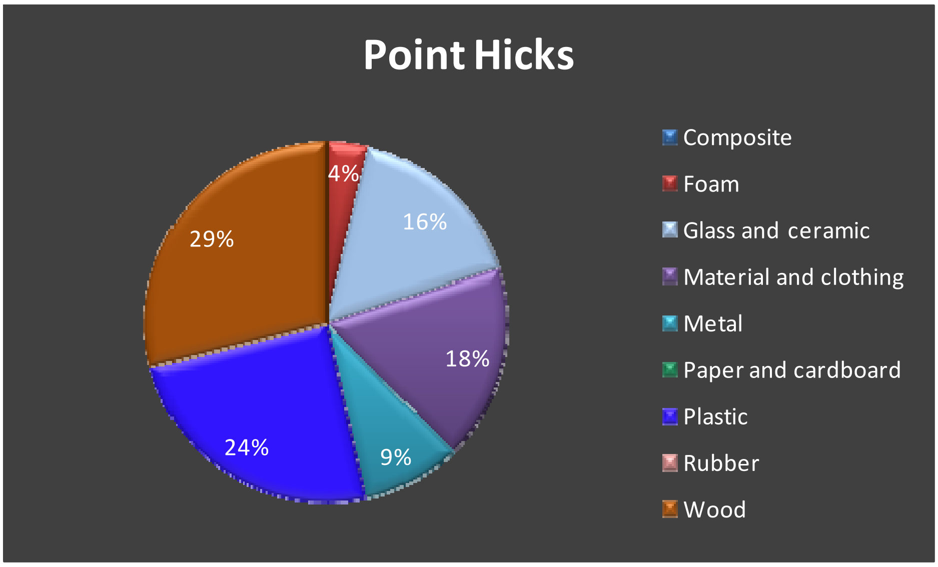

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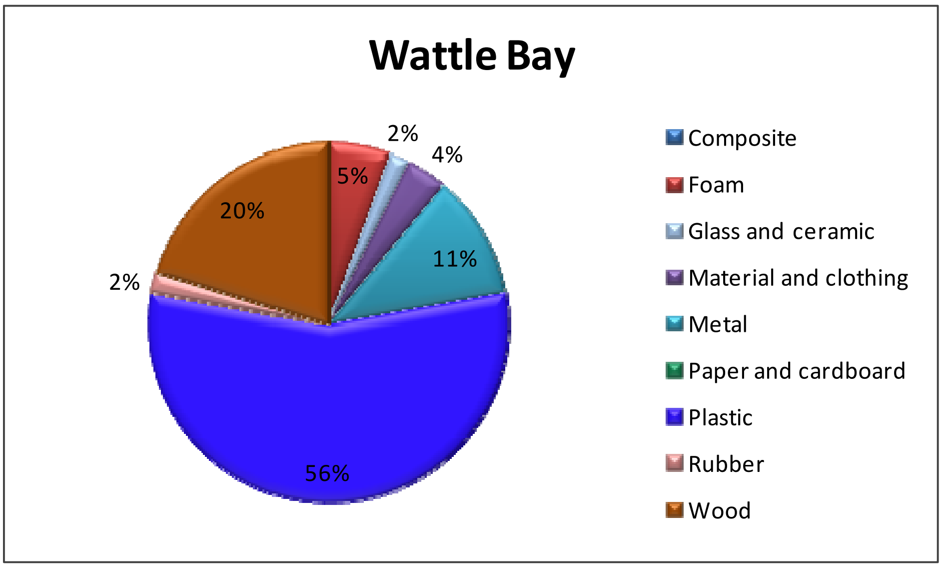

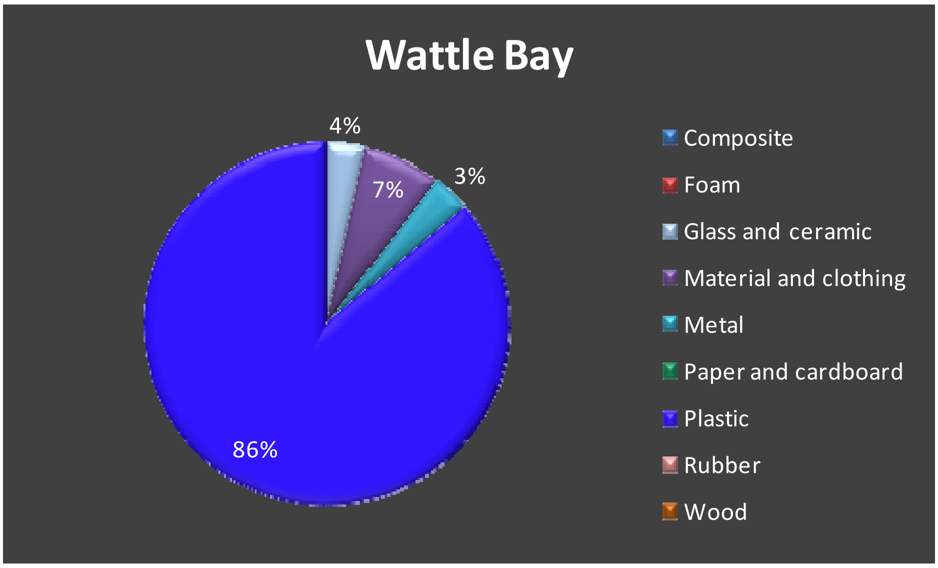

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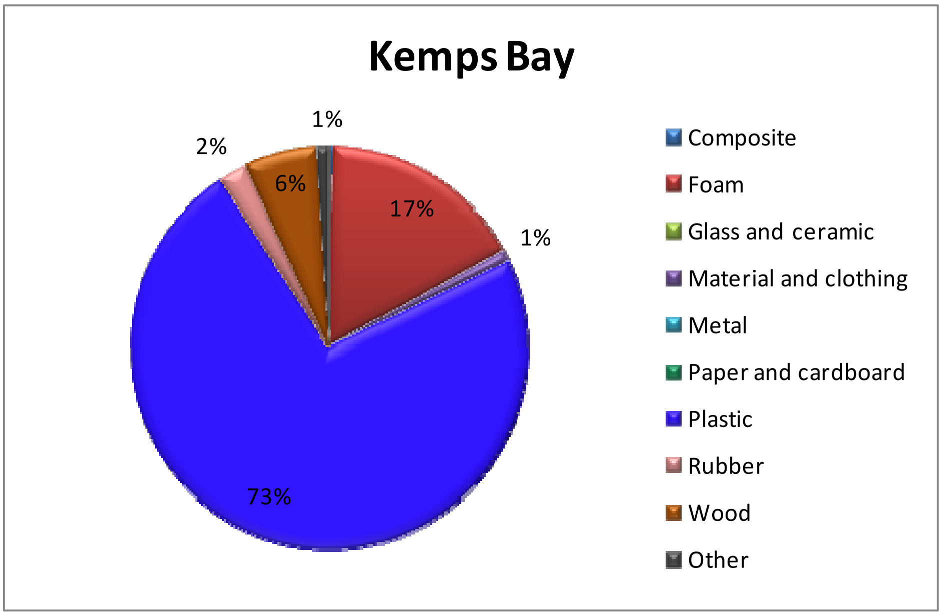

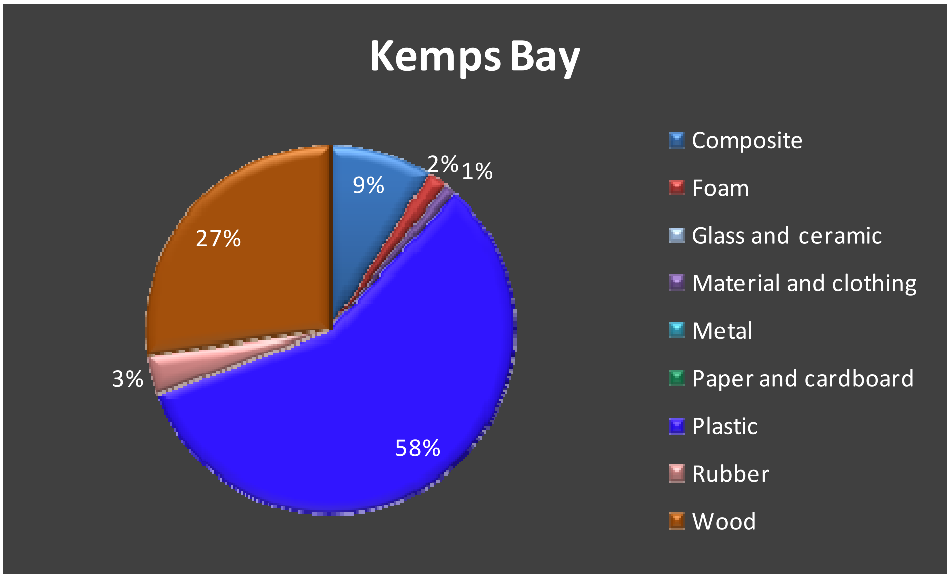

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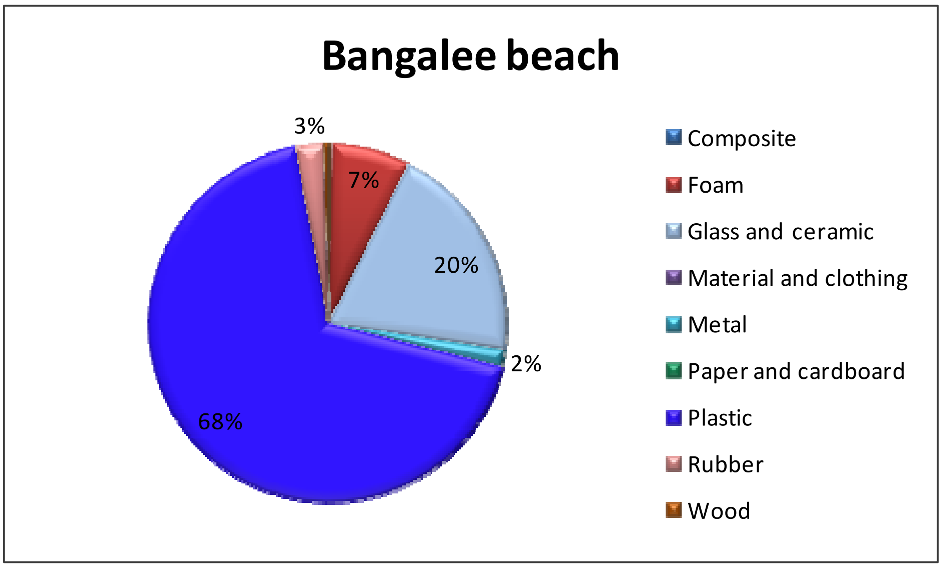

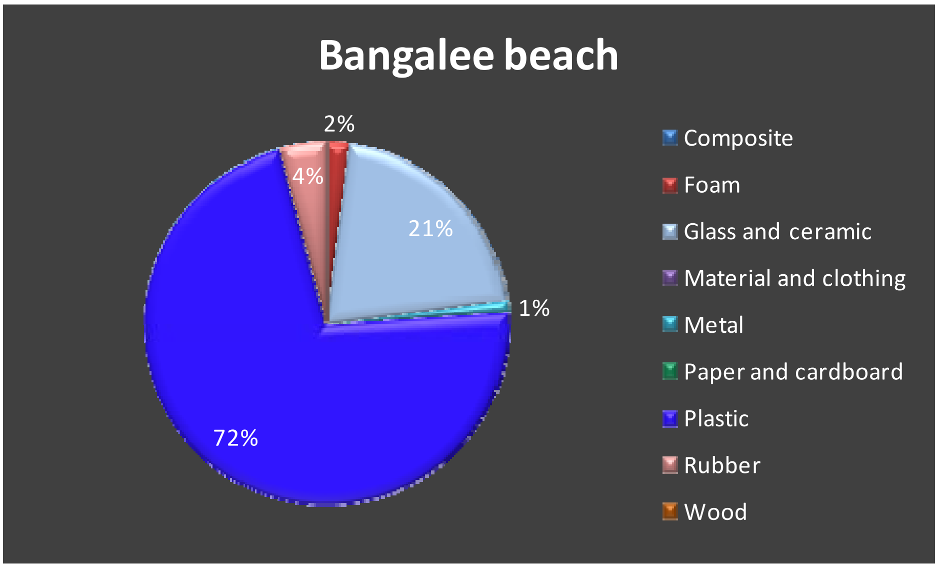

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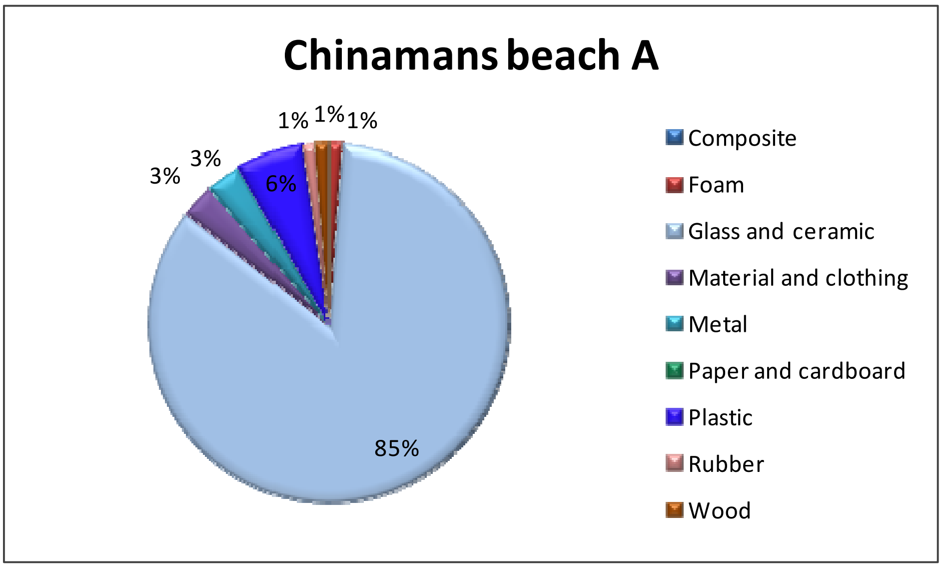

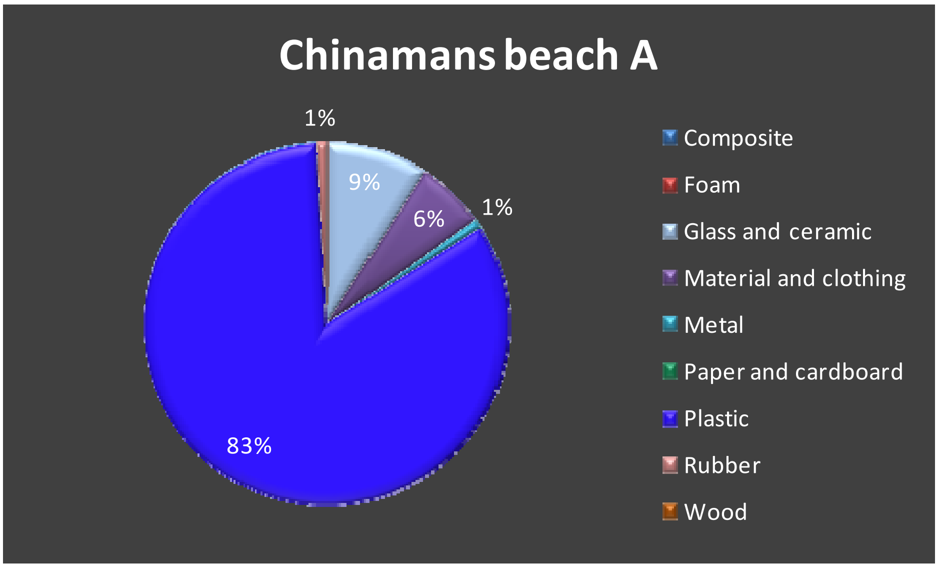

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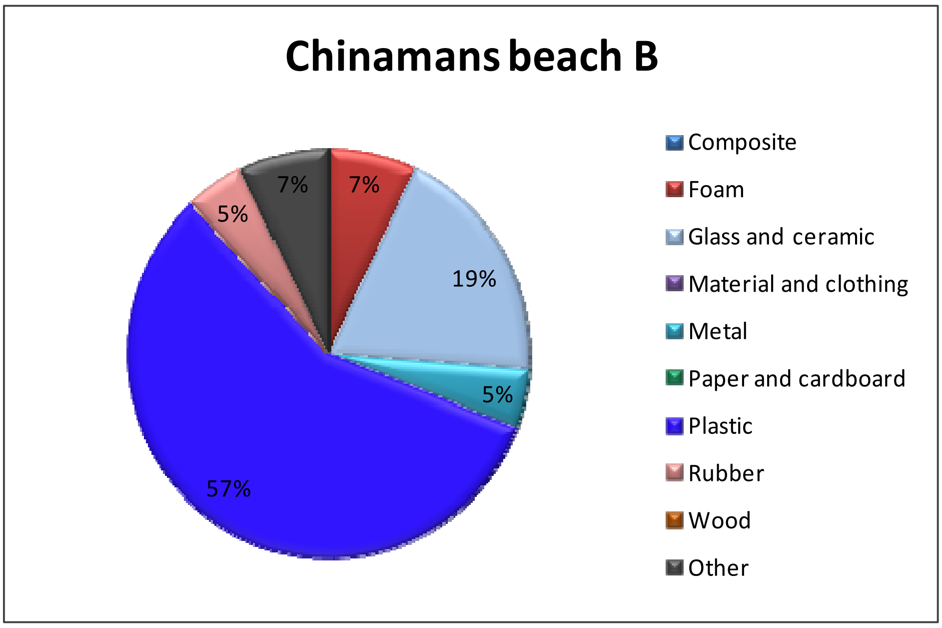

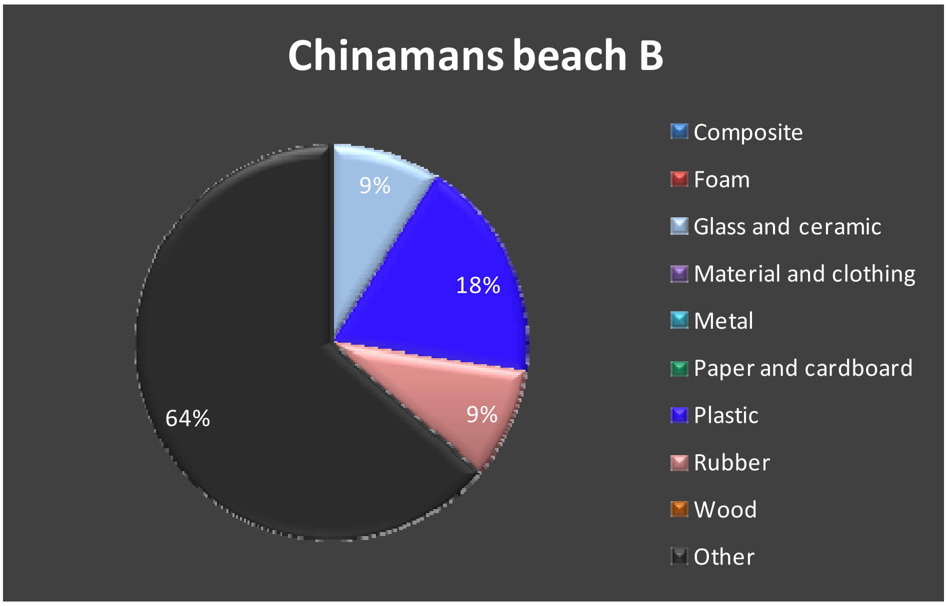

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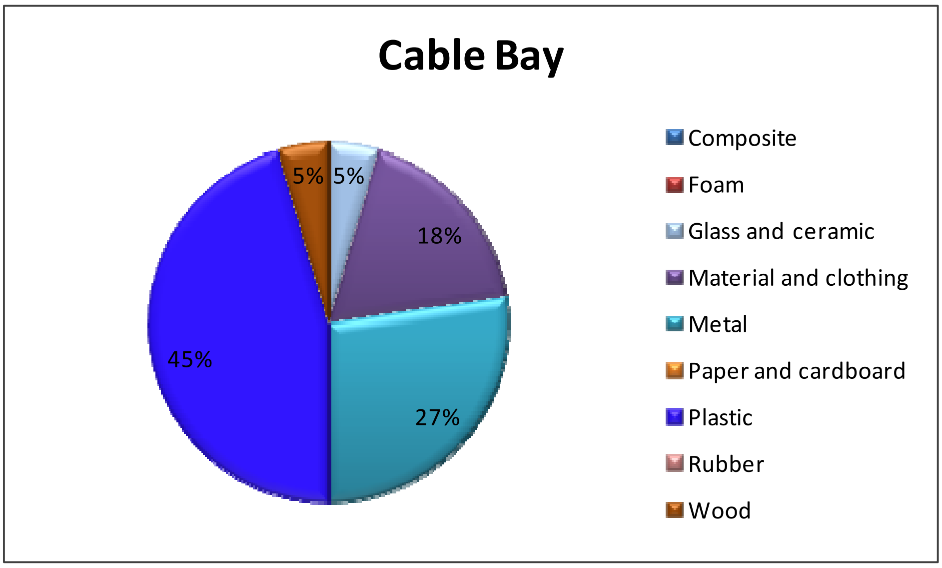
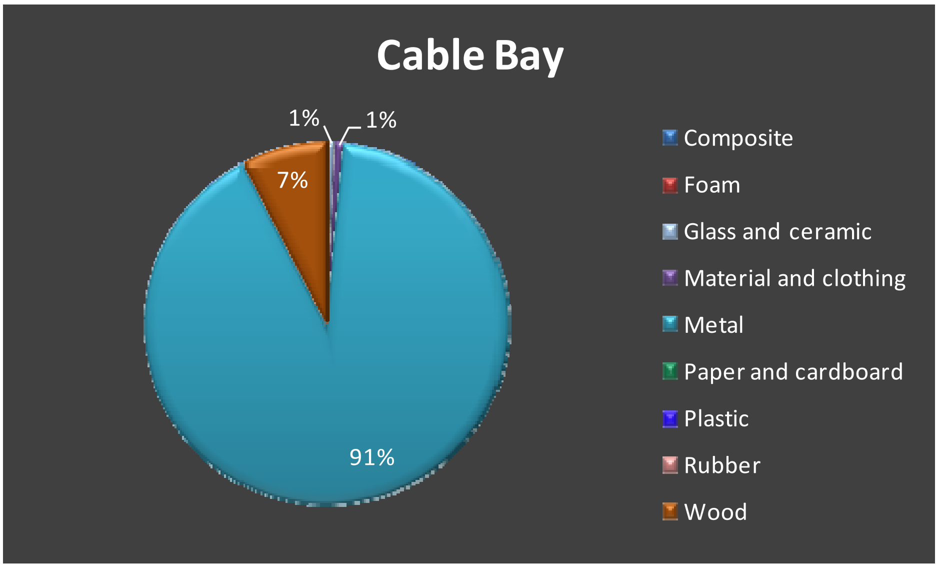
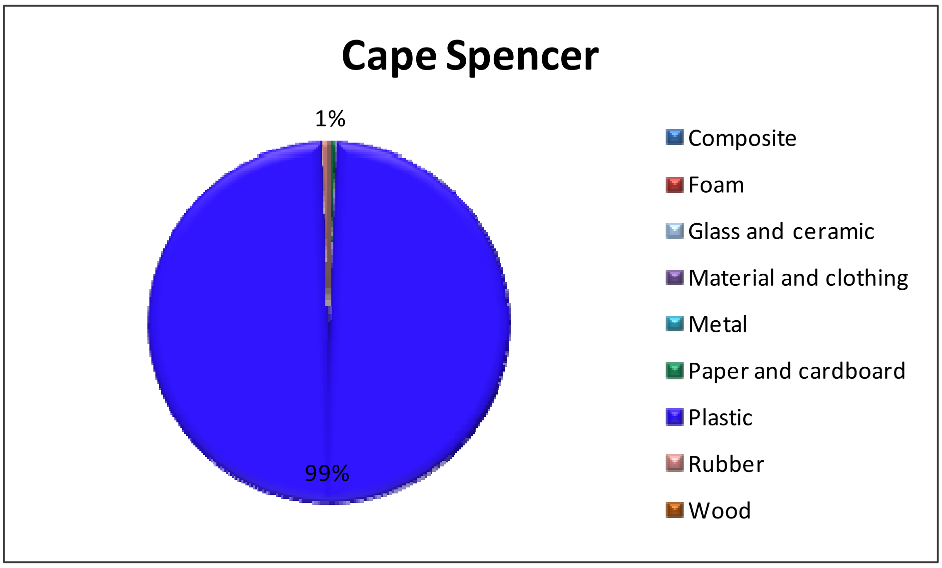
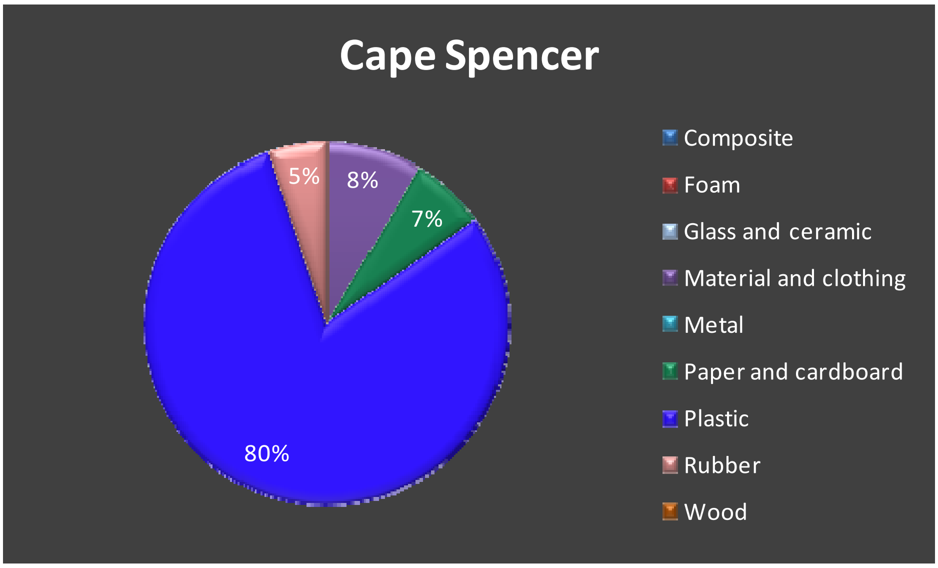


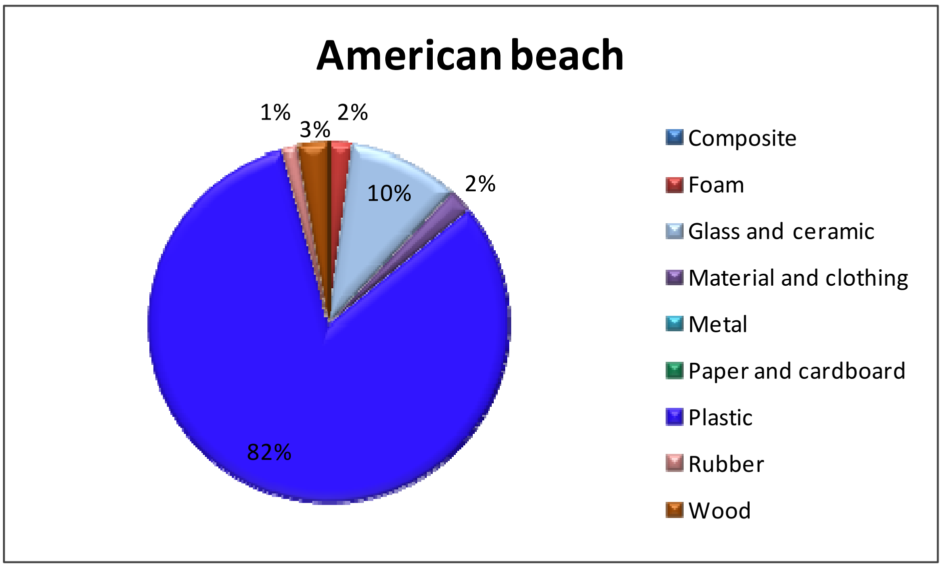


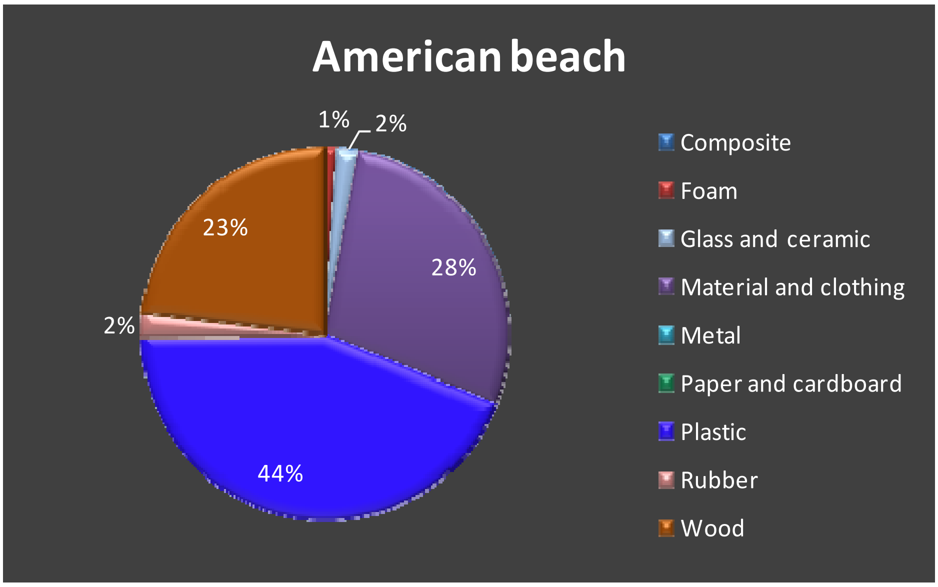
Appendix 5. Summary data of marine debris represented as percent abundance (number items) (upper) and mass (kg) (lower) for major debris categories per site.



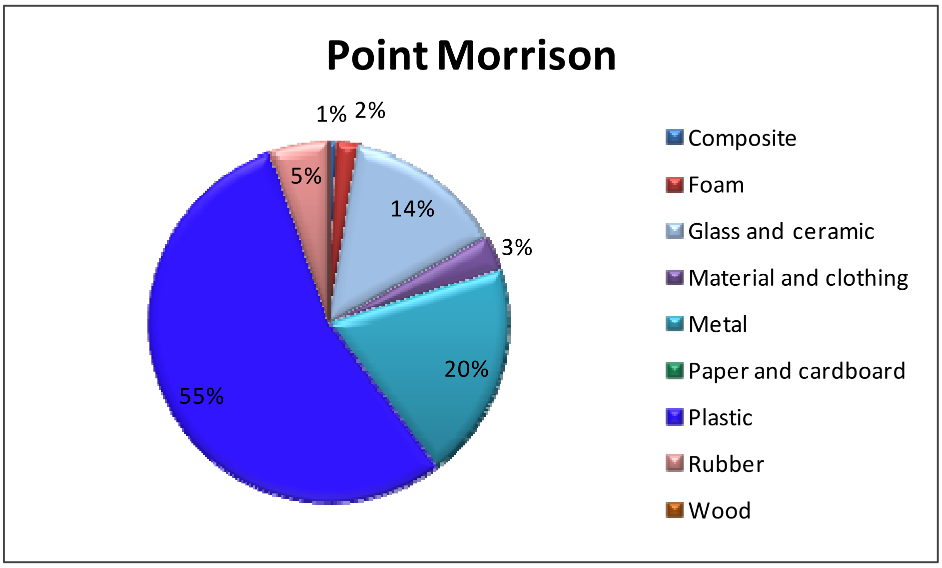


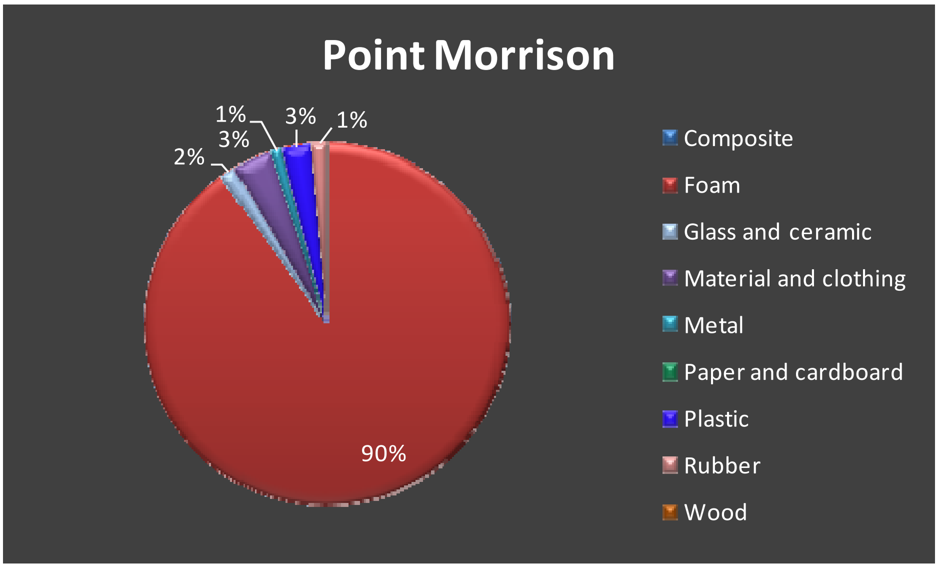
Appendix 5. Summary data of marine debris represented as percent abundance (number items) (upper) and mass (kg) (lower) for major debris categories per site.



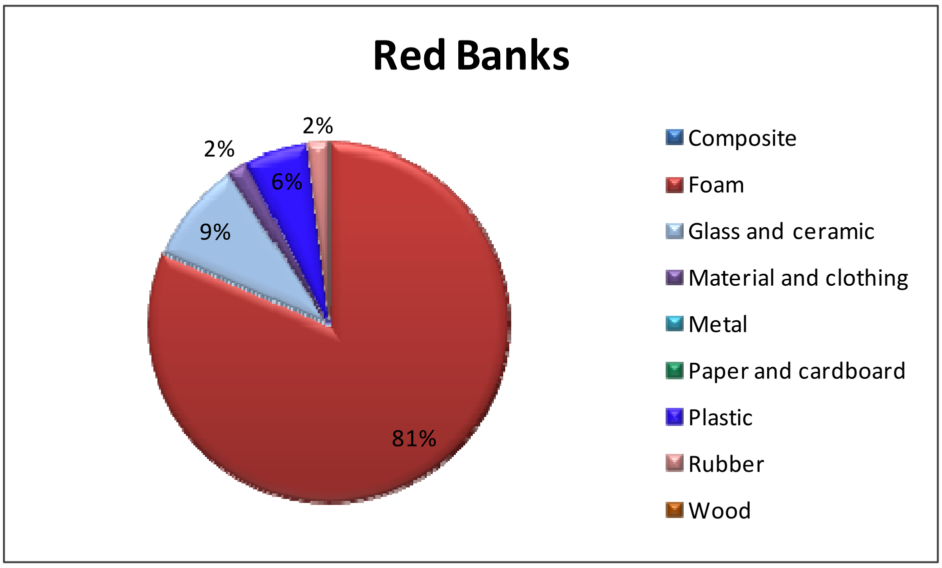


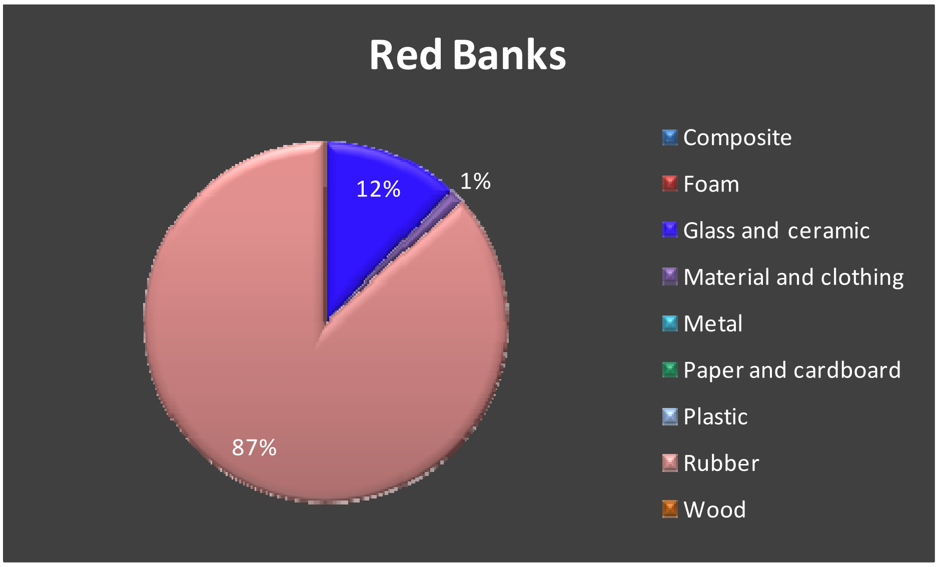
Appendix 5. Summary data of marine debris represented as percent abundance (number items) (upper) and mass (kg) (lower) for major debris categories per site.



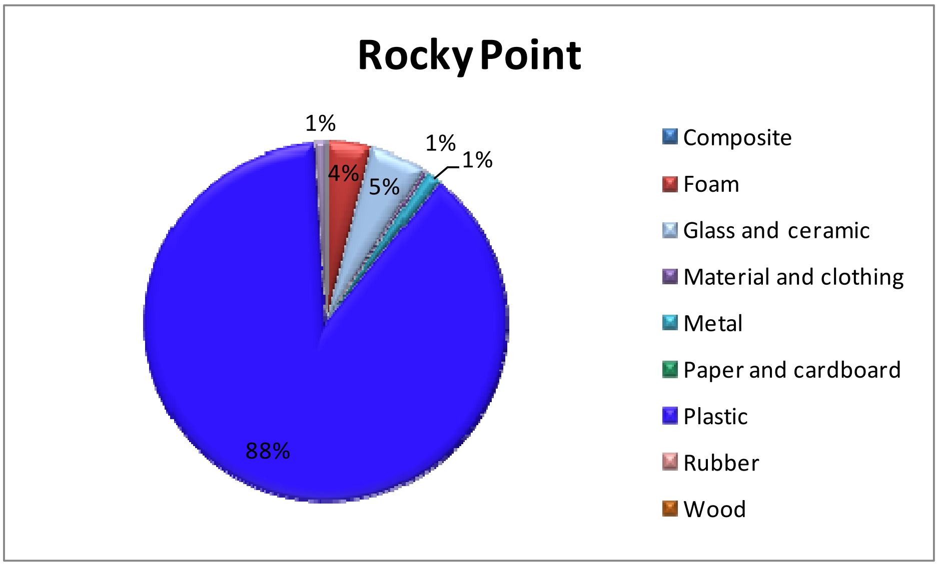


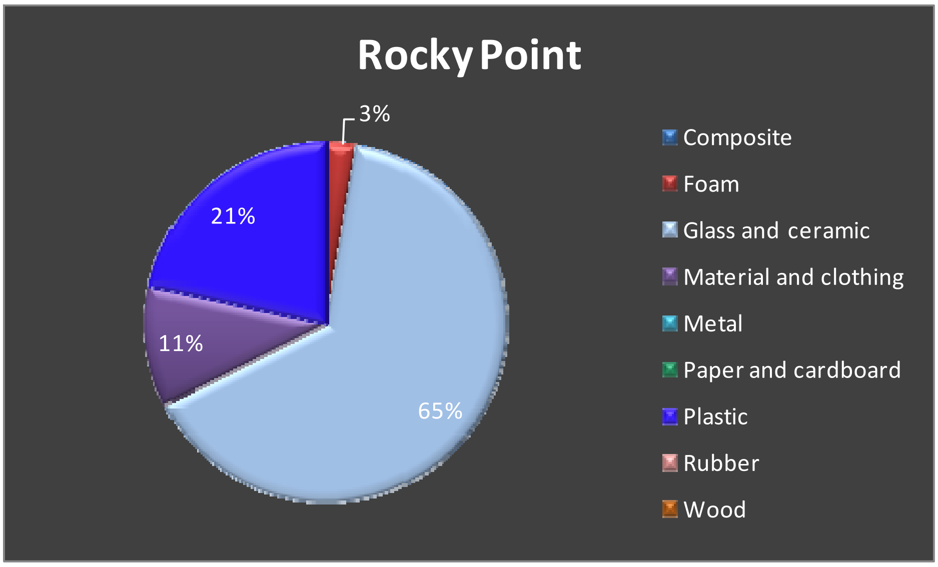
Appendix 5. Summary data of marine debris represented as percent abundance (number items) (upper) and mass (kg) (lower) for major debris categories per site.



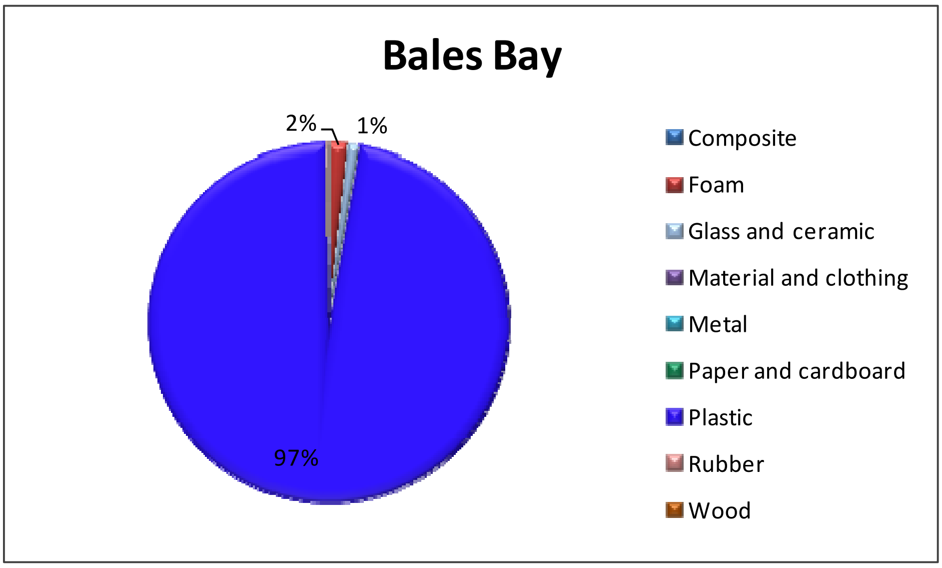


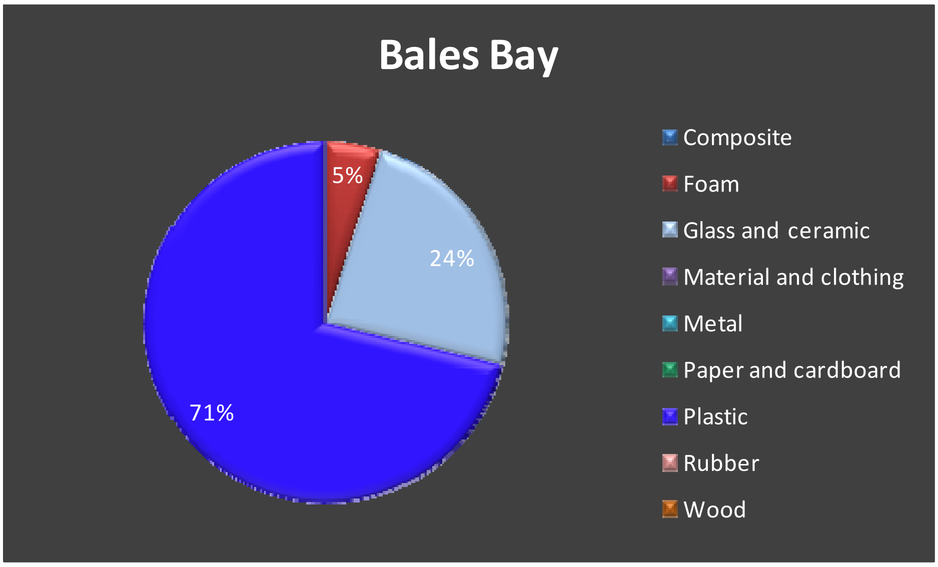
Appendix 5. Summary data of marine debris represented as percent abundance (number items) (upper) and mass (kg) (lower) for major debris categories per site.



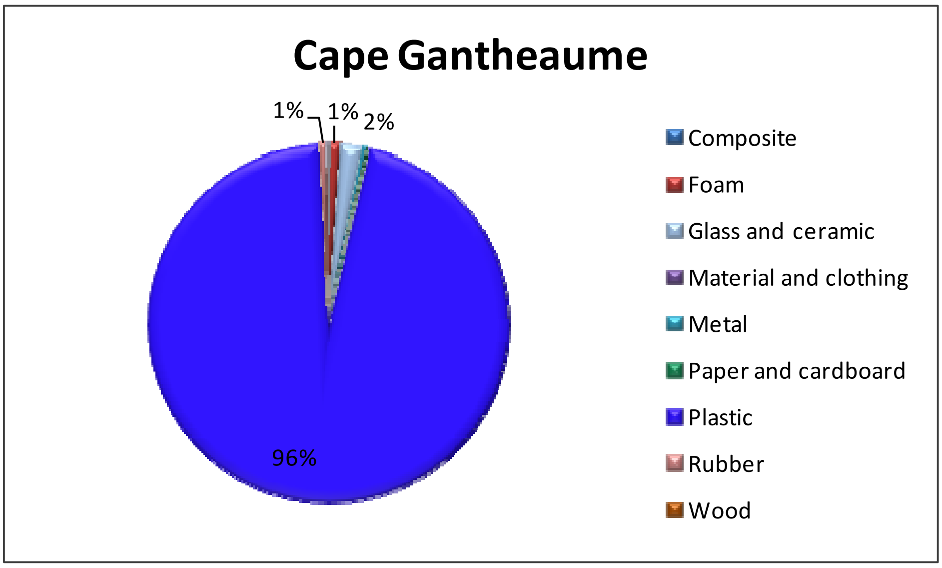


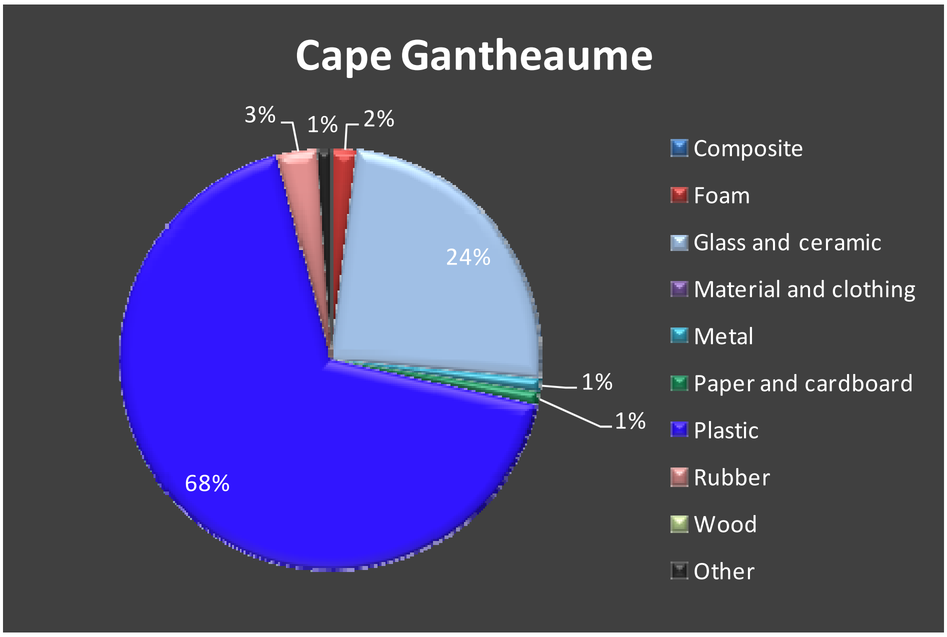
Appendix 5. Summary data of marine debris represented as percent abundance (number items) (upper) and mass (kg) (lower) for major debris categories per site.



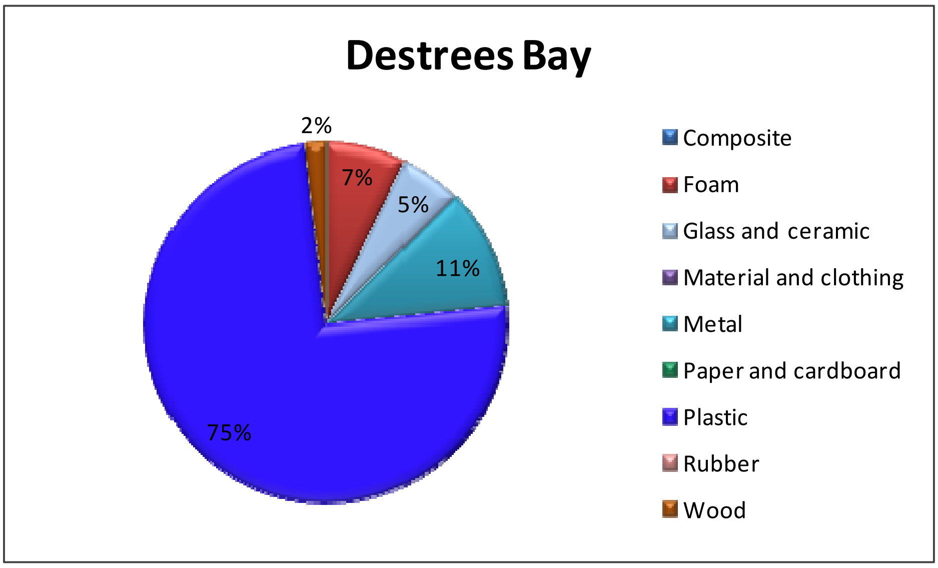


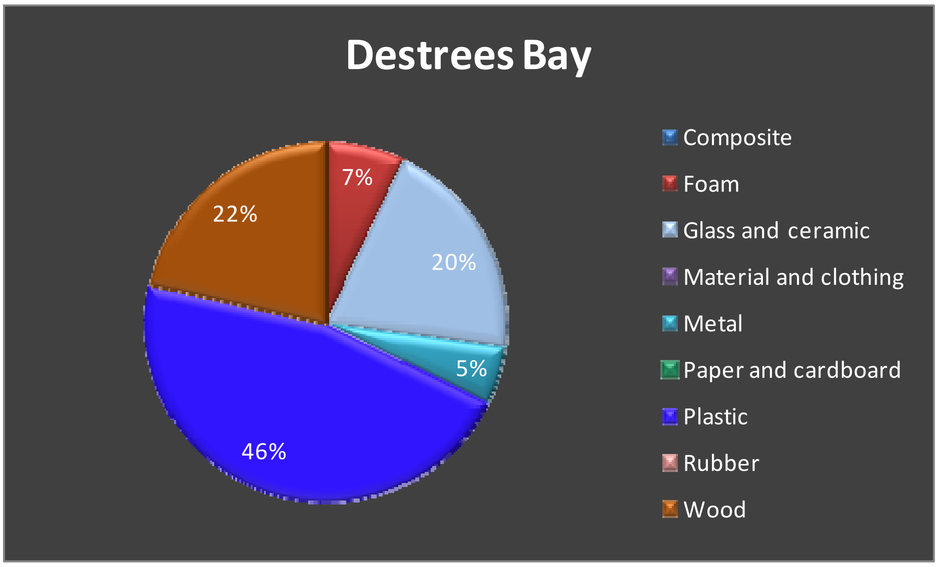
Appendix 5. Summary data of marine debris represented as percent abundance (number items) (upper) and mass (kg) (lower) for major debris categories per site.



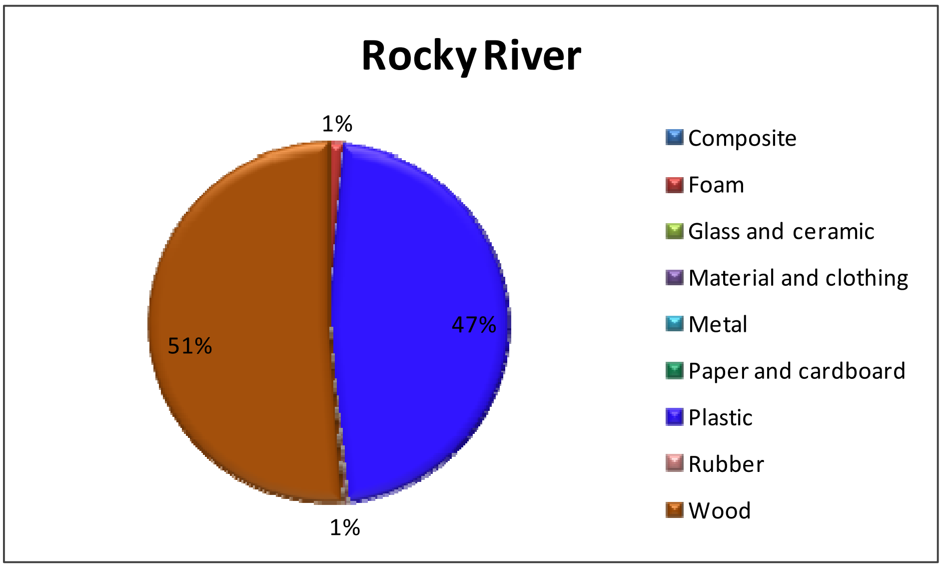


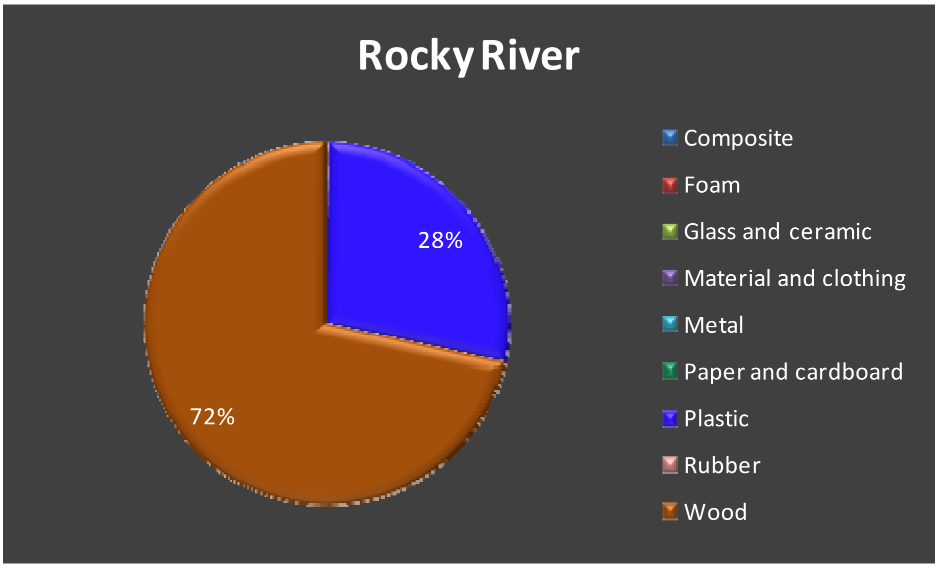
Appendix 5. Summary data of marine debris represented as percent abundance (number items) (upper) and mass (kg) (lower) for major debris categories per site.



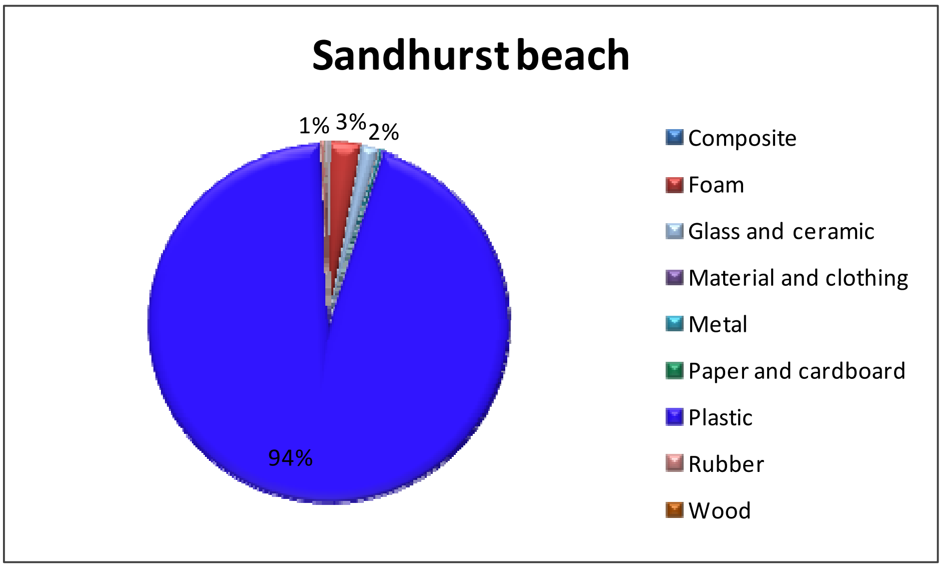


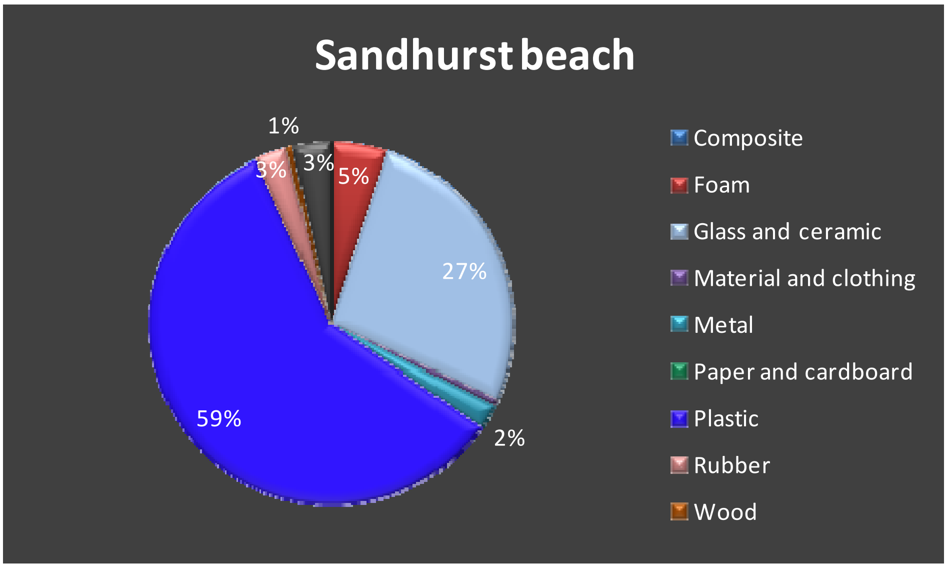
Appendix 5. Summary data of marine debris represented as percent abundance (number items) (upper) and mass (kg) (lower) for major debris categories per site.



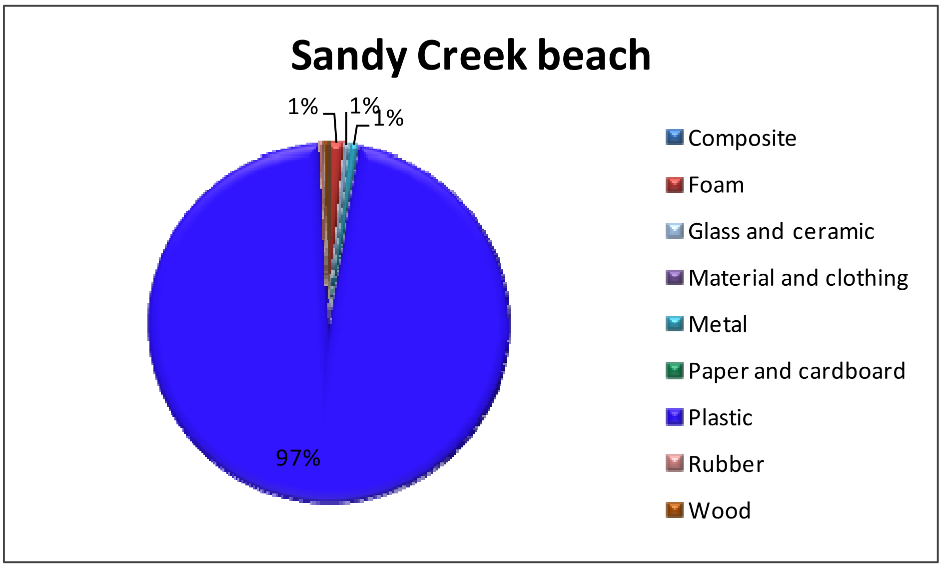


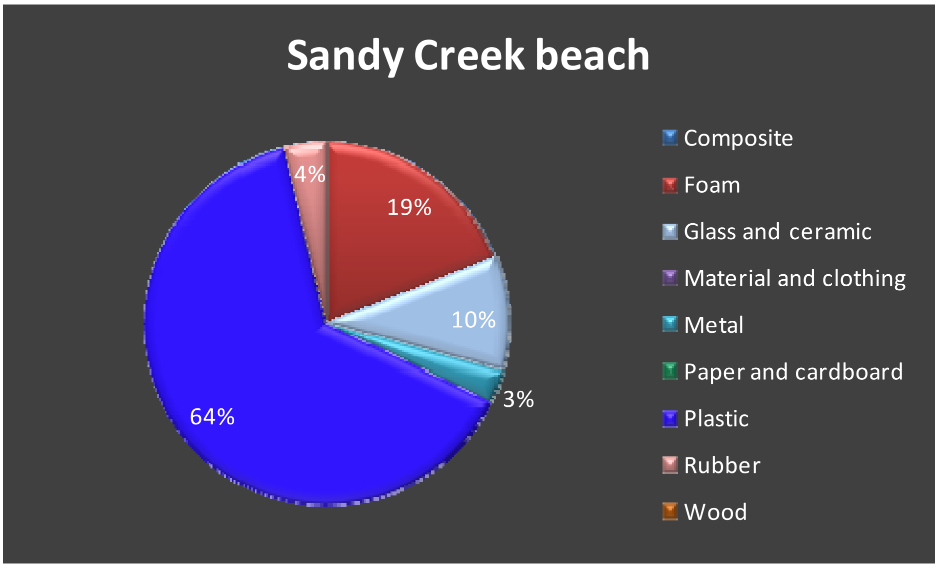
Appendix 5. Summary data of marine debris represented as percent abundance (number items) (upper) and mass (kg) (lower) for major debris categories per site.



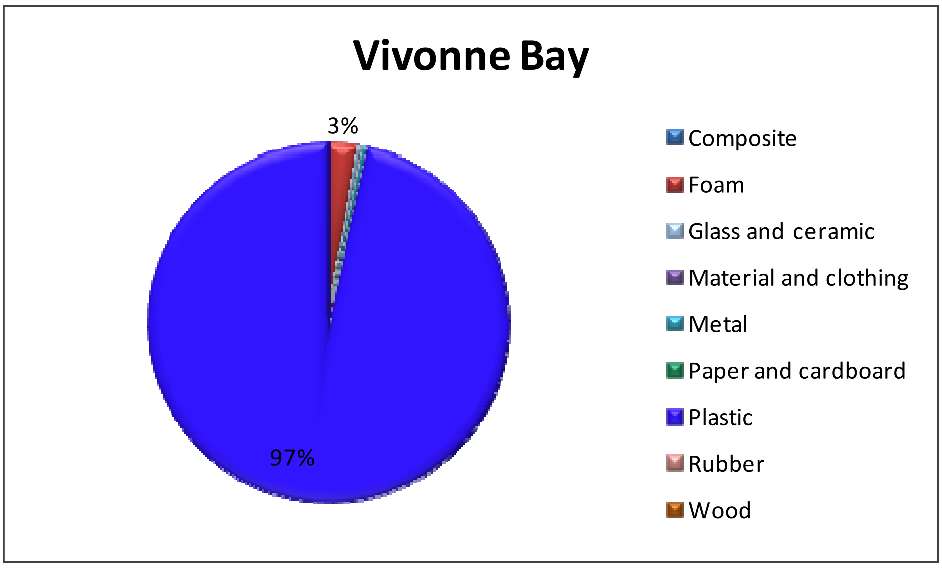


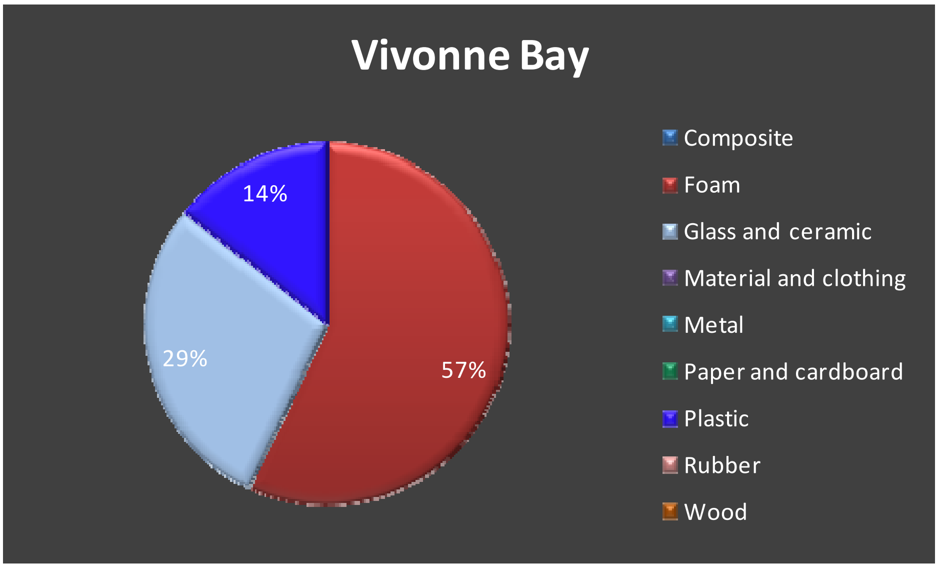
Appendix 5. Summary data of marine debris represented as percent abundance (number items) (upper) and mass (kg) (lower) for major debris categories per site.





Appendix 5. Summary data of marine debris represented as percent abundance (number items) (upper) and mass (kg) (lower) for major debris categories per site.





Appendix 5. Summary data of marine debris represented as percent abundance (number items) (upper) and mass (kg) (lower) for major debris categories per site.