Australia's National
Science Agency

Global Plastic Leakage Baseline Data Summary Report, Taiwan

Report for fieldwork conducted November 2017

CSIRO Marine Debris Team* in collaboration with the Society of Wilderness+.

February 2021

Citation

CSIRO Marine Debris Team (2021). Global plastics leakage baseline data summary report, Taiwan. CSIRO, Australia. EP197477.

* CSIRO Marine Debris Team contributors included (in alphabetical order) Britta Denise Hardesty, Leigh Keen, TJ Lawson, Vanessa Mann, Tim Reid, Qamar Schuyler, and Chris Wilcox.

[+] Society of Wilderness contributors led by Jason Hu.

Copyright

Important disclaimer

Foreword

Plastic volume in the ocean is increasing rapidly, affecting wildlife, economies and potentially human health. Recent model projections suggest that somewhere between four and twelve million tons of plastic flow into the world's oceans each year, with much of this waste coming from urban centres (Jambeck et al. 2015). However, to date there has been very little data collected to empirically document the existence and extent of these plumes and to validate the model estimates.

Through this collaborative field-based project, CSIRO is developing the first global, empirical baseline estimate of mismanaged waste entering the coastal and marine environments near major urban centres in countries around the world. The project aims to identify links between land-based waste management and pollution entering the marine environment. The data collected is helping to clarify the magnitude of this pollution to the public, to industry and to policy makers. Learnings from the project can serve as a basis for decision making, and to support social pressure for investment in infrastructure and regulation for improved waste management. We hope the results can also be applied to engage with industry, the retail sector, government and consumers alike regarding best-practices. We also aim to improve waste management and increase the value of plastic to reduce poverty and create alternative livelihoods that are socially, culturally, economically, and environmentally appropriate and sustainable.

We are carrying out this research in countries all over the world, and thus far have surveyed major metropolitan centres in numerous countries in the Asia Pacific region, as well as South America and Africa. In Taiwan, CSIRO and the Society of Wilderness have joined together to help achieve this goal, with the support of numerous volunteers.

Contents

Figures

Acknowledgments

This work has been supported by the Society of Wilderness and CSIRO Oceans and Atmosphere, with funding support from Oak Family Foundation, Schmidt Marine Technologies and the PM Angell Family Foundation. We thank the numerous participants for their efforts in the training and field work, including Jason Hu, Achi, He-Yu Yang, Hou Zhao-Yu, Li Yue-E, Chiu Jing-Chun, Liu Shu-Chin, Ariel Wu, Yeungs, LeeLa, I-Wen Hsu, Ya-Hsuan Yang, Ru-Shi Lai, and Sharky . We also thank the citizens, government employees and interested members of the public who are committed to reducing litter, marine debris, and illegal dumping in the environment.

1 Introduction

Increasingly considered a tragedy of the commons of the 21st century (Vince and Hardesty 2016), plastic pollution is a wicked problem (Landon-Lane 2018; McIntyre 2020). Trash knows no geopolitical borders, moving with people, rivers, through the landscape and ultimately, if not managed properly, it can be lost into the global ocean. We know that mismanaged waste results in negative social, economic and ecological outcomes. There is substantial value in collecting data to help improve our understanding of the sources and drivers of why, when, where, and how waste is lost to the environment. Furthermore, knowing how waste moves through the environment, the impact our waste has on people, communities, wildlife and economies, and how we can implement policies to result in better outcomes can arm us with the knowledge to make better decisions. Collected properly and consistently, data affords us a metric, a tangible means of measuring change through time and space. This is fundamentally important to understand how effective new actions, activities and legislative measures are in terms of reducing waste entering the environment.

In late 2016, CSIRO was successful in securing funds to embark on a world first project which aims to quantify how much waste is leaking to the environment, where it is entering the environment, and to identify interventions that may be successful in stemming the flow of plastic pollution from land to the sea. The primary objective of the project is to use field sampling and mathematical modelling to document the distribution of plastic in the ocean, on the coast and in the nearshore environment generated by major urban centres and surrounding areas that have been identified as having significant waste mis-management losses into the coastal/marine environment. We initially targeted 6-8 major metropolitan areas in different countries around the world, with a focus in South East Asia. We are focusing on this part of the world because it has been identified as a region of high waste losses to the environment (Jambeck et al. 2015). Furthermore, recent work has suggested that many of the world's major polluting rivers are located in Asia (Lebreton et al. 2017). Rivers are increasingly recognized as critical conduits to plastic waste entering the oceans (Wagner et al. 2019), further highlighting the need for research such as this where empirical data is used to ground-truth predictions and inform model-based estimates of waste in the environment.

Understanding the transport of plastics from land into coastal and marine systems is critical for modelling the distribution and trends of plastic in the ocean, estimating its impact on regional economies near sources, and clarifying the magnitude of this pollution to the public, to industry, and to policy-makers. With a robust, comparable baseline of information, we not only are poised to evaluate policy effectiveness and change through on-ground activities at local, national and international scales, but we are starting to see these changes happen.

A further objective of the global plastics leakage project is to increase the capacity and skillset for on-ground partners in multiple countries, helping to build the breadth and depth of skills to monitor coastal and ocean health beyond the life of this project. The more people are armed with knowledge and skills across jurisdictions, the better equipped individuals, communities and governments will be to make the decisions needed to ensure the best outcomes possible to ensure growth, health, wealth and well-being and ensure sustainability and a reduction in waste leaking to the environment.

We hope that the results from this work will serve as an international baseline against which progress can be gauged through time and space. Ideally, governments from all levels, from local or municipal to state and national will be able to use the information from this work to inform or underpin policies and decisions that will ultimately lead to a reduction in waste entering the environment. We also hope that the results can provide opportunities to engage with industry regarding best-practices and product identification for major brands which are frequently lost into the environment.

1.1 A Partnership in Action

In November 2017, CSIRO marine debris team and the Society of Wilderness Taiwan staff, worked together with volunteers to quantify the amount of debris coming from land in the metropolitan and surrounding regional areas of Kaohsiung, Taiwan, and arriving at the coast. The Kaohsiung region was selected in collaboration with our partners because it represented an urban region of significance within the country, and it was identified as an area that could be sampled within a reasonable time frame (~ 2 weeks) with a team of volunteers. Furthermore, the region or watershed also has a river system which could transport debris to the sea, and hence was deemed appropriate in the context of the overall global project. Our ultimate goal was to develop a baseline measurement of debris along an approximately 100 km stretch of coastline and the surrounding riverine and inland areas of Kaohsiung, Taiwan. To this aim, we conducted field surveys that included coastal, inland, river-side, and trawl debris surveys following a statistically robust and user-friendly sampling methodology. With a few days of training, the crew was ready to tackle the challenge of sampling.

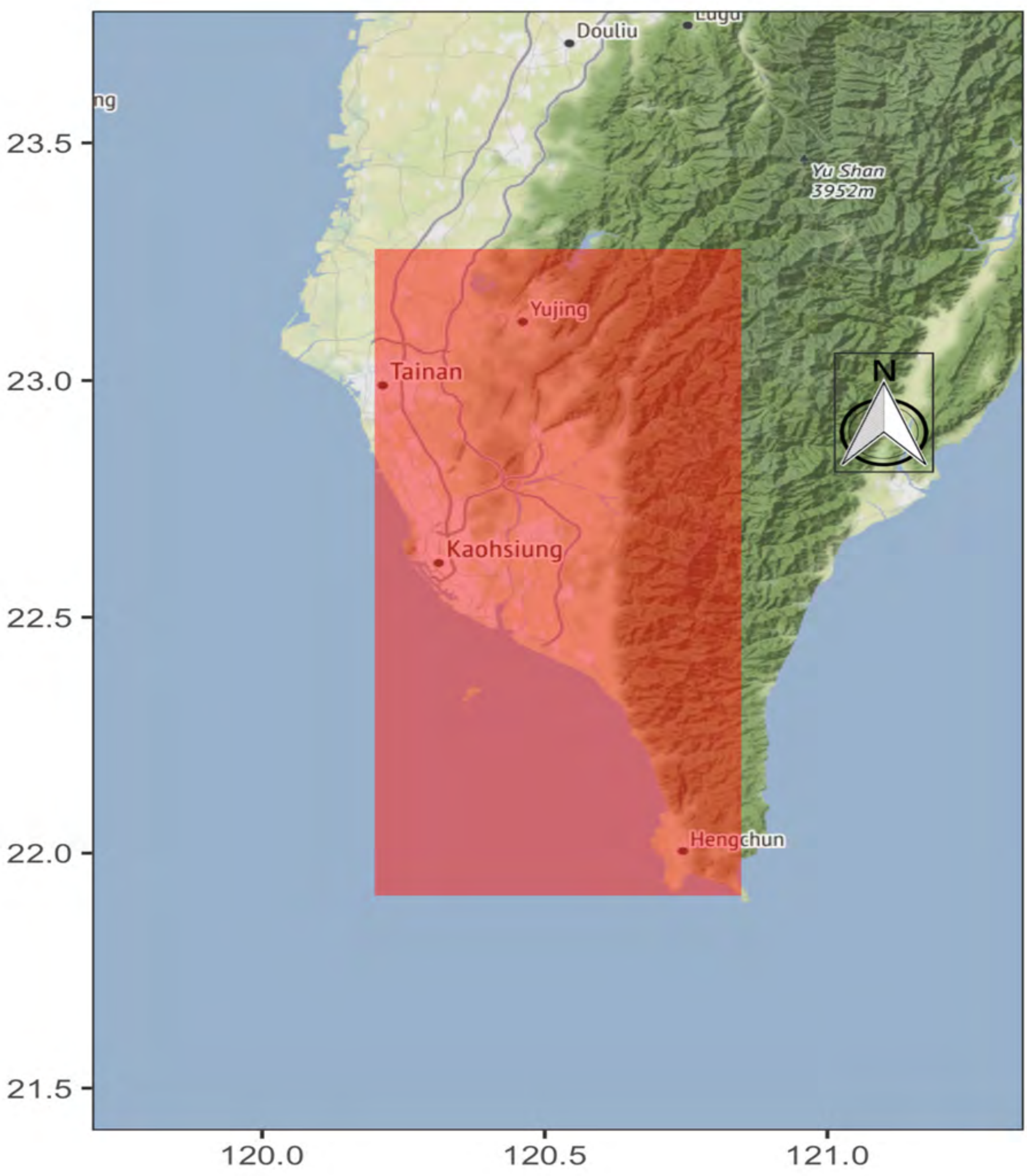

Figure 1. Location of study area.

1.2 Site Selection and Study Area

Our target area included the metropolitan and regional areas surrounding Kaohsiung. We selected a region roughly 120 km long from approximately 20 km north of Kaohsiung, to the bottom tip of the island of Taiwan at Cape Eluanbi. The inland and river sites extended approximately 85 km north-east of Kaohsiung through the district of Liugui.

Survey locations were provided by CSIRO to partners in Taiwan, so they could be assessed for suitability and any alterations needed could be made prior to arrival to conduct fieldwork. Sites were selected based on a suite of criteria and were intended to sample across the range of a variety of covariates, including population density, land use type, road and transportation networks. We aimed to strike a balance between sites that were representative across the watershed region we were surveying and ensuring travel times between sites were not so long as to make field work impractical. While all the sites were selected in advance, occasionally chosen site locations could not be accessed in the field. This could be due to a range of reasons, including that the points fell on private land or were unsafe to access. In these instances, surveyors chose the nearest location that was accessible to and in a similar environment as the originally designated site.

During the first four days, participants and trainers worked together to ensure all participants received consistent, intensive training on how to collect, record, report, and make decisions regarding debris items, site selection characteristics, and other key factors required for consistency in data collection for four different survey methods (coastal, inland, river, and trawl). Following the training period, we divided into a number of teams to carry out fieldwork safely and securely across the chosen study region. The group successfully completed surveys at a total of 95 sites (Figure 2).

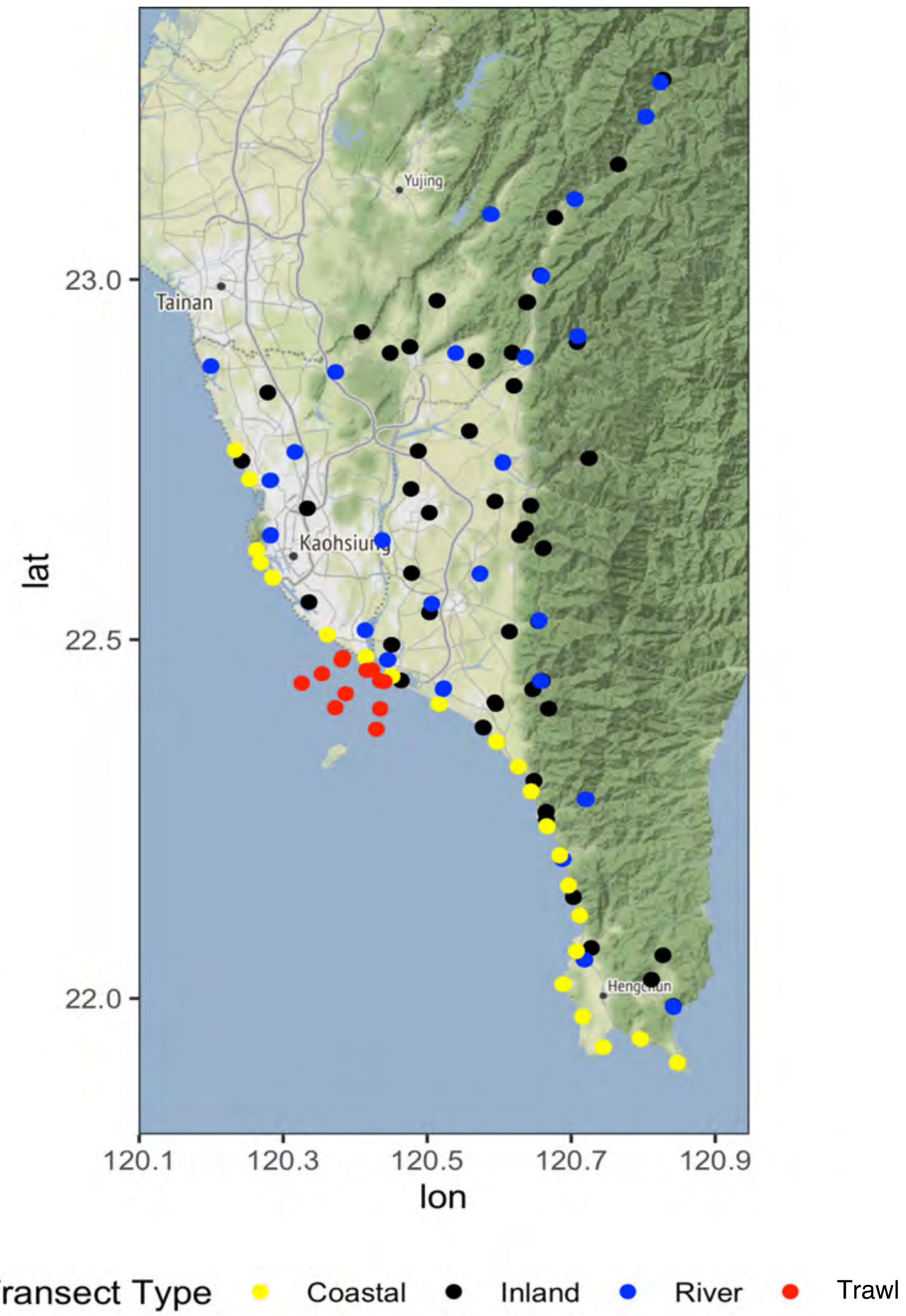

Figure 2. Location of completed surveys along the selected region of coastal Taiwan. The yellow points are coastal sites, the black points are inland sites, the blue points are river sites, and the red points are where trawls sampling took place.

1.2.1 Coastal sites

Coastal sites are defined as those sites that occur directly up to the ocean's edge. They could encompass any of a number of substrates and were not limited to sandy beaches. Coastal sites were selected between Liugui to the north and Cape Eluanbi in the south, at approximately 5 km intervals along the coastline. We selected this interval because this provided us with an adequate or appropriate number of sites to be representative of the coastline as a whole and was enough samples to provide the statistical robustness required for analysis purposes.

1.2.2 Inland sites

To select inland survey sites, we placed a 5 km grid over the study region and selected the centre of each 5 km x 5 km cell. We then used globally available Geographic Information System (GIS) spatial layers to quantify several factors that have been shown in our previous work to be associated with the amount of debris or litter observed (covariates). Covariates included the local population density, land use type, distance to the nearest road, distance to the coast, distance to the nearest river and distance to the nearest railway station. We also used two different proxies for socio-economic status, night lights within 1 km radius of the site, and a measurement of the total monetary value of the built environment (both rural and urban), calculated by the United Nations as part of a global exposure dataset aimed at disaster risk management (UNDDR, 2015).

We carried out a stratified random sampling design to select sites that covered, as much as possible, the full spectrum of these important covariates.

1.2.3 River sites

We are also interested to understand the 'urban plume' of floating plastic around major urban centres. To measure the amount of floating or positively buoyant debris in the nearshore environment, we conducted surface trawl sampling at nine stations along three line transects emanating from the mouth of the Gaoping River, to the south of Kaohsiung city and three stations along one line across the mouth of the river. We conducted three tows (each was ~ 10-15 minutes long) at each station and recorded all the anthropogenic debris collected in the net.

2 Methods

The initial few days the team was together were spent explaining the goals of the project and training participants in the survey methods. All participants learned to search for and identify debris based on known categories, to record data (**Error! Reference source not found.**), and to lay out transects for river, inland and coastal surveys. Furthermore, participants were provided an electronic copy of CSIRO's survey methods handbook for reference, and a hard copy of the handbook was available for each vehicle transporting participants.

Debris was measured at each land-based site type (river, coastal and inland) using a consistent survey method. Once a site was chosen, a Site Information Sheet was completed before any surveys took place. This information sheet collected information about the site's aspect, accessibility, apparent cleanliness, number of people present, etc as well as weather conditions, time of day, and details of the survey recorder.

At each site, a minimum of three and a maximum of six transects were carried out. For river and coastal surveys, transect lengths varied depending on site characteristics such as the width of the beach (distance from the waterline to the backshore vegetation) and riverbank height. There is no fixed length for these two survey types, the length of the transect is dependent upon the local environment, and each transect is 2 m wide. For inland surveys, survey length is fixed. Each inland transect was either 12.5 m long x 2 m wide, or 25 m x 1 m wide.

Transects were laid out with a metre tape. For coastal and river transects, the transect always began at the water's edge and ran perpendicular until reaching two meters into the backshore vegetation. For inland transects, the starting point was that which was closest to the GPS location identifying the site. The transect was also divided into ten equal distance intervals that encompassed the full length of the transect. For example, an 18 m long transect would have ten 1.8 m intervals or segments. Typically, two people walked the transect (each surveying a 1 m wide swath) while a third person recorded the debris category for every item found, and whether it was a whole item or a fragment. This information allows us to understand whether the items are likely to have been recently littered or are slightly older and more degraded. Observers were each provided with a string that was one meter wide to ensure only items within the survey width were recorded. This prevents errors that can occur if observers include items that may fall just outside the one meter wide transect zone.

Each item observed was recorded in a debris category (See Appendix). The size class was also recorded for the first item found in each distance interval (and if no item occurs in that distance interval a 0 or dash (-) was recorded). The purpose of recording this size information is to gain an indication of the sizes of items across the each transect. We are striking the balance between time required and important information to collect. We acknowledge it would be too time consuming and labour intensive to record the size of every single item (since we can sometimes report hundreds or even thousands of items on an individual transect, this could be prohibitive).

Trawl surveys were conducted along three line transects emanating from the mouth of the Gaoping River. Three tows were conducted at each station, using a neuston net with mesh size of

330 µm and a mouth opening size of 0.6 m x 0.3 m. Each tow lasted approximately 10-15 minutes. The vessel moved at slow speed (no more than 2-3 knots) to ensure the trawl net does not skip or jump. Sea state and wind conditions must be mild for proper sampling. After returning to the lab, a visual search was conducted to count and categorise all plastics found in the sample net. For each sample, an observer removed all organic material and then searched for 15-20 minutes to locate any non-organic material. This process was repeated 3 times (with at least 2 different observers) to ensure observer fatigue does not reduce detection of small sized plastic items. The minimum size of plastic able to be caught by the net was 330 µm, and the maximum size was anything that could fit within the sixty centimetre mouth of the net.

For an in-depth description of the methodology used for each of the survey types please refer to the CSIRO handbook (Schuyler et al. 2018).

2.1 Analysis

To design effective interventions and prevent mismanaged waste from entering the sea, it is important to understand what is driving the distribution of debris. Based on previous work, we investigated several different factors that could influence debris distribution. At each survey site, we collected information on the local conditions, including the number of visible humans, the slope of the land, the height of the vegetation, the percent of the transect that was bare ground, and the substrate colour (see Schuyler et al. 2018 for example data sheets).

We also integrated information from globally available GIS layers, including the local population density, land use type, distance to the nearest road, distance to the coast, distance to the nearest river and distance to the nearest railway station. We also used proxies for socio-economic status, including night lights within 1 km radius of the site. Additionally, we included a measurement of the total monetary value of the built environment (both rural and urban), calculated by the United Nations as part of a global exposure dataset aimed at disaster risk management (UNDDR, 2015). We put these covariates into a statistical model, designed to determine which factors are most strongly correlated with debris amounts in the survey sites. We used the R program mgcv and MuMin packages (Wood, 2011; R Core Team, 2018; Bartoń, 2018) to find the model with the lowest AIC value, which explains the most amount of the variability in the data. More than one model was within two AIC points of the best model, which means they are essentially equivalent models. In order to incorporate information from all relevant models, we used model averaging to get the best-fit model.

For coastal analyses, we used an offset of lineal metres for the model, to reflect that the measure of interest was the amount of debris along the lineal coast, while for inland analyses, we used the offset of the area of each transect. We examined residuals of the models to look for indications of non-linear patterns in explanatory variables. We ran comparative models using some variables as categorical, or continuous smoothed variables to identify better fit.

To be able to directly compare the covariates and determine which best predicts the observed debris amounts, we calculated the effect size. Terms with a positive effect size have a positive correlation with the amount of debris, while terms with a negative effect size are negatively correlated with the amount of debris. In other words, the higher the value of the covariate, the lower the amount of debris. The higher the absolute value of the effect size, whether positive or negative, the more that particular covariate explains the variability in the debris found (see Figure 9 and Figure 12).

3 Results and Discussion

A total of 25,157 debris items were detected and recorded across the 95 sites surveyed.

The ten most abundant fragment debris items included unknown glass, polystyrene, unknown hard plastic fragments and brick/cement (Figure 3). Unknown/other glass comprised 31.1% of all fragment items found, followed by polystyrene at 17.3%.

The ten most abundant whole debris items found in all the surveys included items such as cigarette butts, brick/cement, and single use-items such as bottle caps, straws, food wrappers and plastic thin film bags (Figure 4). Cigarette/butt accounted for 15.3% of all whole items found, followed by brick/cement at 8.9%.

In terms of debris density, coastal surveys had the highest debris density with 5.28 items found per m^2 (Figure 5). Overall, coastal debris density the highest among the land-based surveys, at six times that observed at river sites, and four times that observed at inland sites.

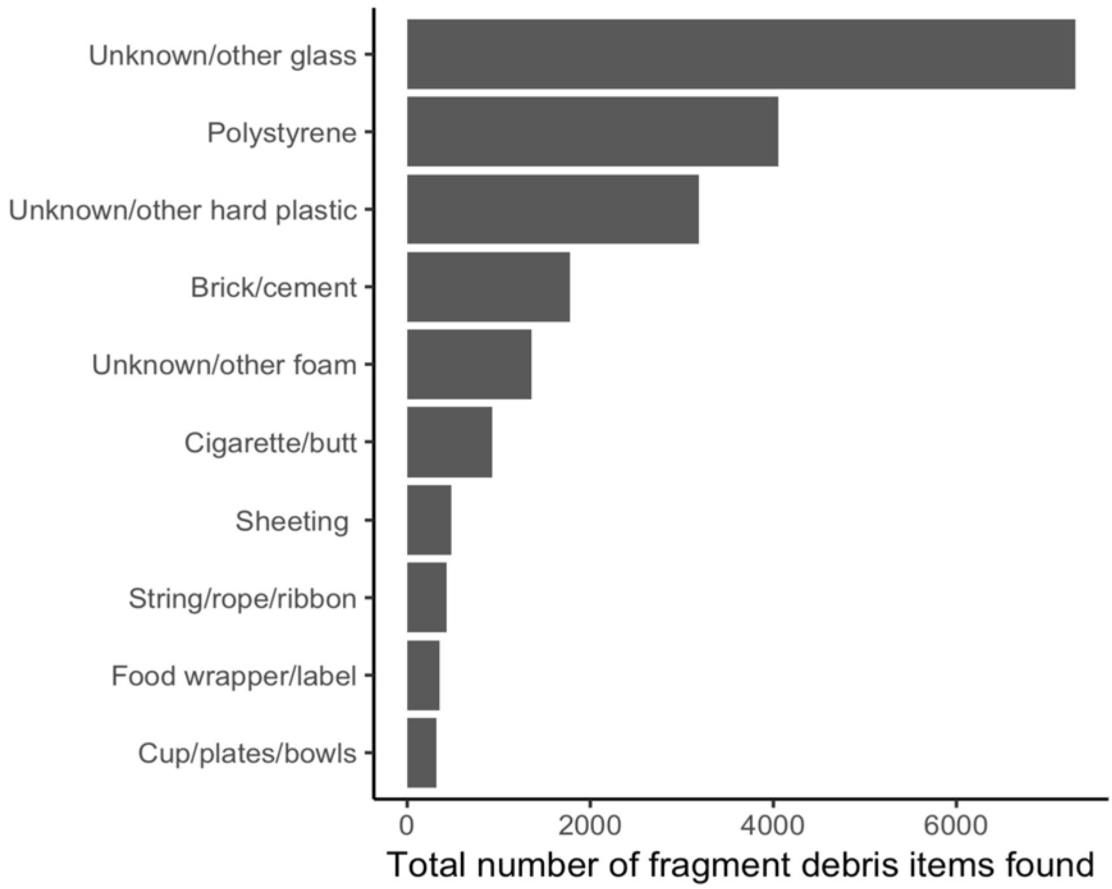

Figure 3. The ten most abundant debris items (fragments) found across the coastal, inland, and river surveys combined.

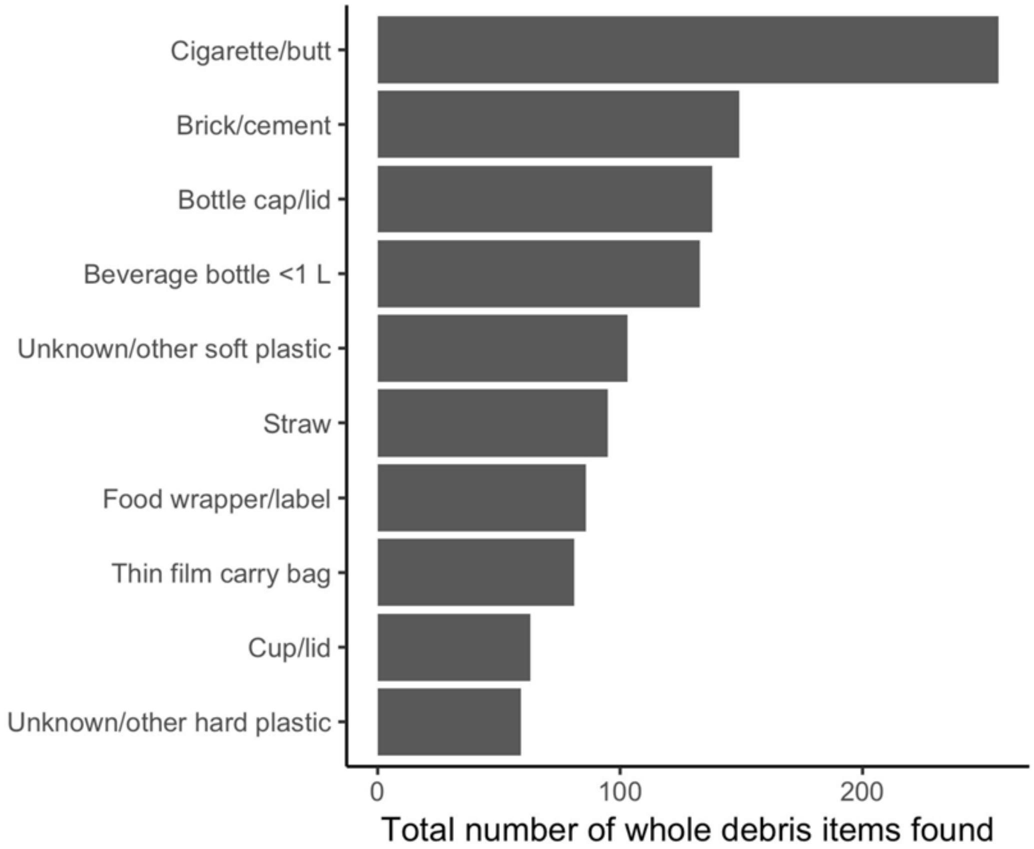

Figure 4. The ten most abundant debris items (whole) found across the coastal, inland, and river surveys combined.

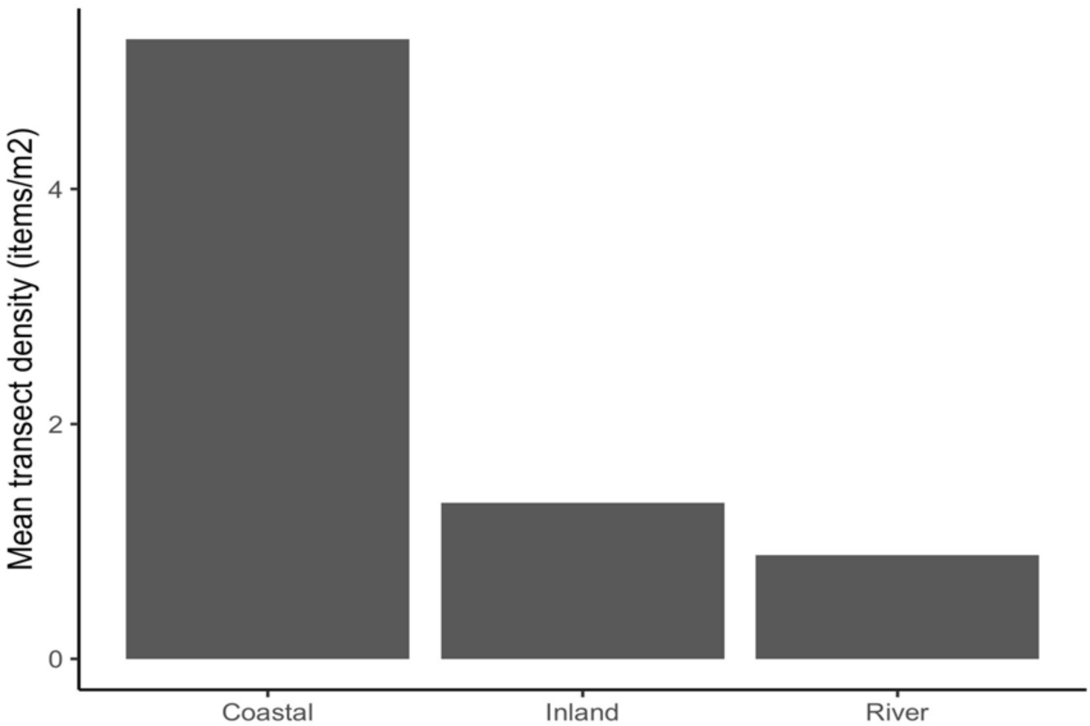

Figure 5. The mean transect density of debris found in the coastal, inland river surveys.

3.1 Coastal Surveys

3.1.1 Results

A total of 66 transects were completed in 22 coastal sites (see Figure 6 and Figure 7 for photos of the team conducting coastal surveys on two different types of transect sites). Overall, 17,863 items were recorded within coastal surveys. On average, across all transects, 135.3 items of debris per lineal metre of coastline were recorded.

Unknown/other glass was the most common *fragment type* found with 7,136 pieces or 41.47% of the total fragment items recorded. Polystyrene was the second most recorded item with 3,891 items recorded and unknown/other hard plastic was the third most common, with 2,511 pieces recorded. Polystyrene in the marine environment is often associated with fishing and aquaculture activities.

Beverage bottle <1 L was the most common *whole* item found with 96 pieces or 14.63% of the total whole items recorded. Bottle cap/lid was the second most recorded item with 92 items recorded and unknown/other soft plastic were the third most common, with 76 pieces recorded. Bottles and lids are typically single use items, used once and then discarded.

A size class was estimated for 440 debris items. Size class 3 was the most common found (size class 3 objects are greater than 2 cm x 2 cm but less than 4 cm x 4 cm). For further information refer to the size class chart in the Marine Debris Survey Handbook. Of all items recorded, 31% were 16cm^2 or smaller.

Figure 6. Team members conducting a coastal debris survey at one of the more challenging sites.

Figure 7. A coastal debris survey at Jia-he Beach.

There was substantial variation in the number of debris items observed across the coastal surveys (in the unit of log number of items per lineal metre) (Figure 8

Figure 10). The highest number of items found on a coastal survey was at site TWC13 at Tai-gu Beach located at 22.116 °N, 120.711 °E, about 5 km north-west of Checheng Township. Of the

7,267 items recorded at this site, 7,018 of them were classified as G4_F: unknown/other glass fragments.

In Taiwan, after running the GAM modelling, four coastal models were functionally equivalent, based on AIC values. These models were averaged to get the best final model. In the best final model, five terms were statistically significant. While the remaining terms were not statistically significant (at $p = 0.05$ level), they did explain some of the variability in the model, and thus were left in the model. The terms with the highest effect size were the direction the shore was facing, and the direction of the wind in relation to the shore, with item density higher on beaches where the wind was blowing at an angle away from the beach but lower when the wind was blowing along the shore or onto the shore, or along the shore but an angle toward it (Figure 9). Densities were high on beaches facing south-east, with increased values of tot_cr (total value of rural infrastructure), and with less distance from rivers.

Overall, if the area surveyed is generally representative of the density of debris across the entire 1566.3 km of Taiwan's coastline (as reported from Wikipedia, accessed 21 October 2020), this would equate to an estimated total debris load of over 211 million items along the entire Taiwan coastline. We acknowledge that this is a rough estimate, given the variability in annual weather patterns, coastal topography, population density, and other factors, but it provides a baseline to understand the relative magnitude of the problem.

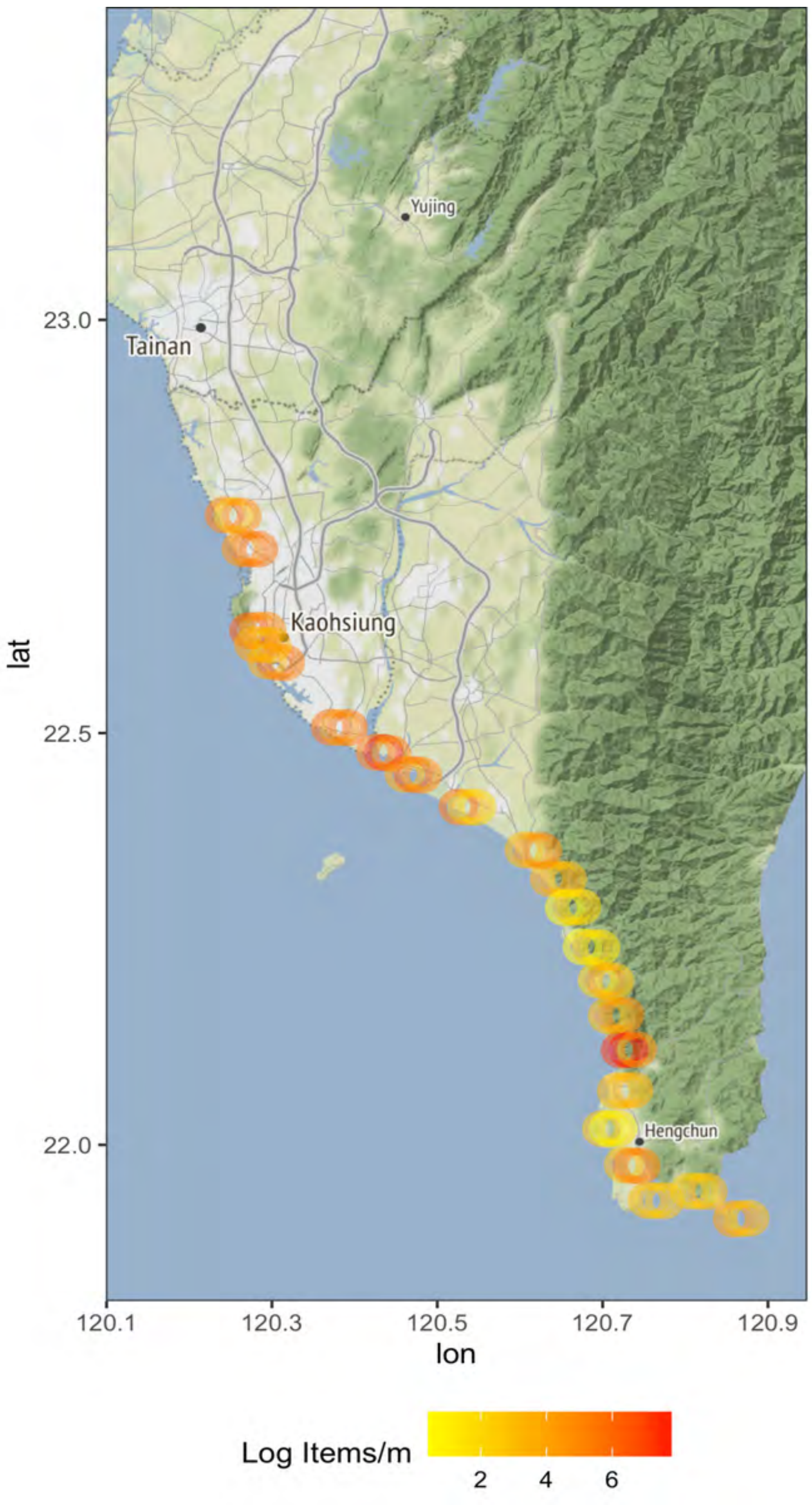

Figure 8. The log number of items per lineal metre for coastal sites in Taiwan.

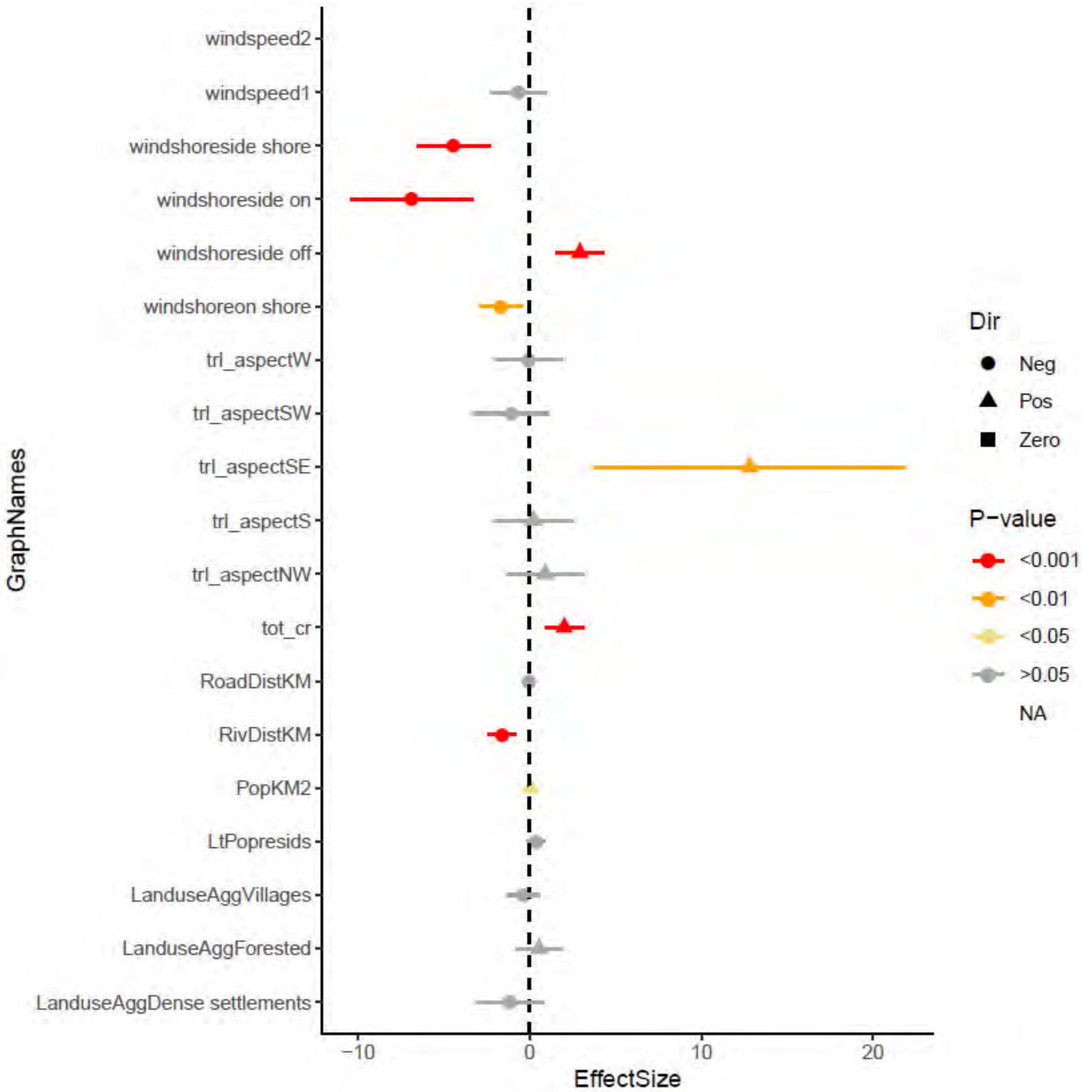

Figure 9. Model average effect size plot for coastal surveys. Colour represents the p-value significance level, and the lines are the standard error for each term. Triangles denote a positive coefficient for a given factor, whereas circles denote a negative coefficient. The effect size is calculated as the median value of the factor times its coefficient. The reference levels were none for wind shore (wind direction relative to the shore), north-east for trl_aspect (direction the shore was facing) and croplands for land use.

3.2 Inland Surveys

The team completed 142 transects over 47 inland sites across a range of site types including vegetated areas and roadways (Figure 10). A total of 4,725 items were recorded; equivalent to an average of 1.3 pieces of debris for every square metre of land surveyed.

Interestingly, cigarette/butt was the most abundant *fragment* type found with 826 pieces or 20.7% of the total fragment items recorded. Brick/cement was the second most recorded item with 560 items recorded and unknown/other hard plastic was the third most common, with 504 pieces recorded.

Cigarette/butt was the most abundant *whole* item found with 187 pieces or 25.44% of the total whole items recorded. Brick/cement were the second most recorded item with 114 items recorded and food wrapper/label was the third most common, with 42 pieces recorded.

A size class was estimated for 775 pieces, with size class 3 being the most common found (size class 3 objects are greater than 2 cm x 2 cm but less than 4 cm x 4 cm). For further information refer to the size class chart in the Marine Debris Survey Handbook. Of all items recorded, 35% were 16cm^2 or smaller.

Figure 10. (L) Transect method at a vegetated inland survey site – Shan Chiao Lu. (R) Transect at He Ping Xi Lu - an inland survey site along a roadway.

There was substantial heterogeneity in the number of debris items observed across the inland surveys (in the unit of log number of items per m²) (Figure 11). The highest number of items found in a single site was at site TWI47 Chi-shan-liao, located at 22.511 °N, 120.614 °E, which was in a mango orchard located near Chaozhou township. Of the 426 items recorded at this site, 300 of them were classified as S3_F: sheeting fragments.

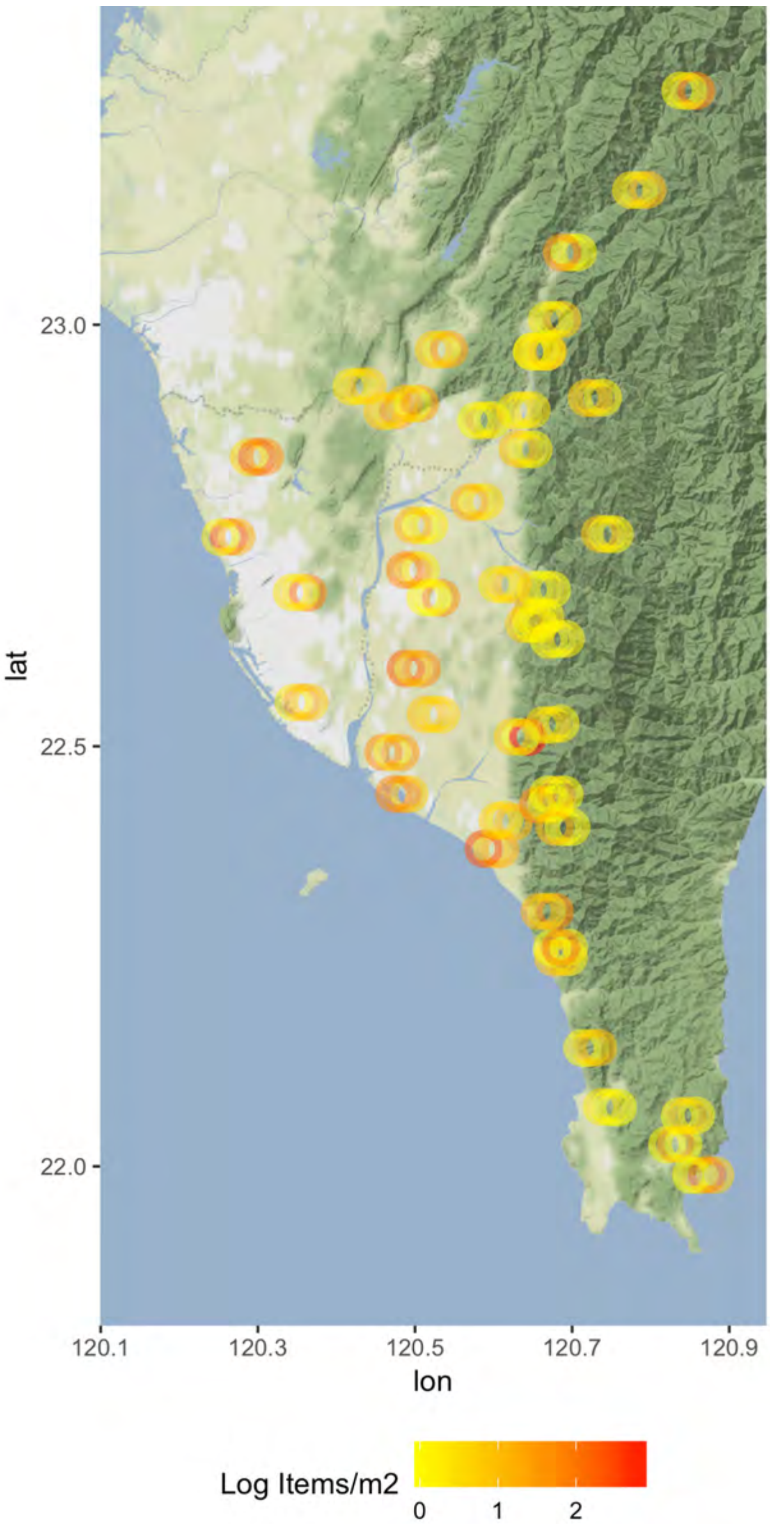

Figure 11. The log number of items per square metre for inland sites in Taiwan.

In Taiwan, after running the GAM modelling, 24 inland models were equally as good as one another. These models were averaged to get the best final model. In the best final model, none of the terms were statistically significant at the P = 0.05 level. While the terms were not statistically significant, they did explain some of the variability in the model, and thus were left in the model. It is likely that the variability between sites is quite high, leading to the lack of statistically significant terms. With additional data collection, model results would undoubtedly improve.

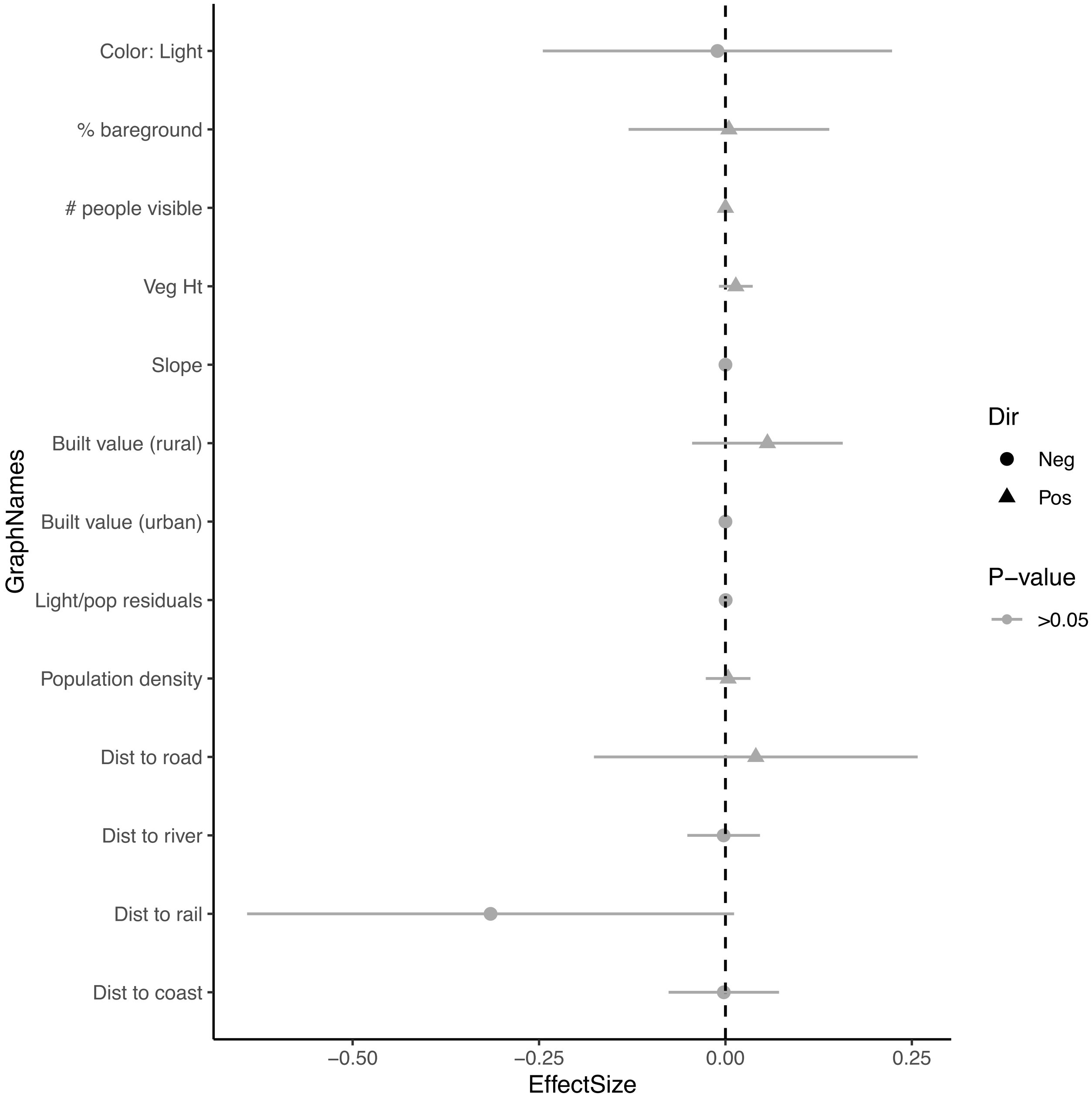

Figure 12. Model average effect size plots for inland sites. Colour represents the p-value significance level, and the lines are the standard error for each term. Triangles denote a positive coefficient for a given factor, whereas circles denote a negative coefficient. The effect size is calculated as the median value of the factor times its coefficient.

3.3 River Surveys

A total of 78 river transects were conducted at 26 river sites. Some river sites had no infrastructure around them (Figure 13) while other river sites were in built up areas, and one even had special guests (Figure 14). A total of 2,569 items were recorded; an equivalent of 16.6 pieces of debris for every lineal metre of riverbank surveyed (on average).

Brick/cement was the most abundant *fragment* type found with 639 pieces or 27.8% of the total fragment items recorded. String/rope/strap was the second most recorded item with 213 items recorded and unknown/other hard plastic was the third most common, with 173 pieces recorded.

Cigarette/butt was the most abundant *whole* item found with 48 pieces or 17.2% of the total whole items recorded. Thin film carry bag was the second most recorded item with 42 items recorded and food wrapper/label was the third most common, with 32 pieces recorded. These are typically single use consumer items which are often used once and then discarded.

A size class was estimated for 329 pieces with size class 7 being the most common found (size class 7 objects are greater than 22 cm^2). For further information refer to the size class chart in the Marine Debris Survey Handbook. Of all items recorded, 13% were less than 16 cm^2.

Figure 13. An example of a river transect site.

Figure 14. Another interesting river transect site with special guests.

We observed substantial variability in the number of debris items recorded across the river surveys (in the unit of log number of items per lineal metre) (Figure 15). The highest number of items found in a single river site was at site TWR7 Dong-gang River Estuary, located at 22.472 °N, 120.445 °E. The site was at the mouth of the river, and surveyors noted the presence of household dumping. Of the 588 items recorded at this site, 208 of them were classified as C1_F: string/rope/strap fragments.

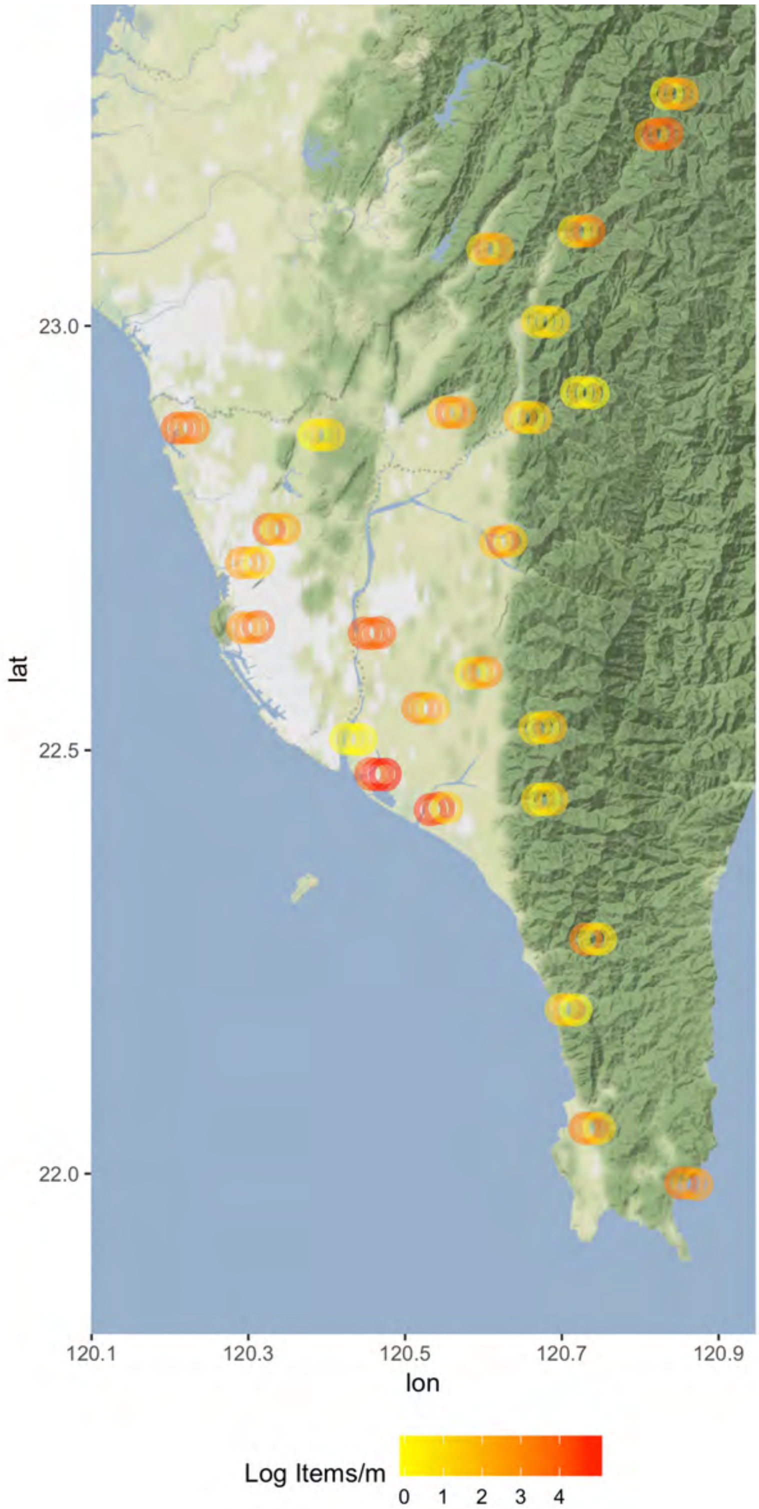

Figure 15. The log number of items per lineal metre for river sites in Taiwan.

3.4 Trawl Surveys

Figure 16. Trawl surveys with the manta net.

A total of 36 tows were conducted at twelve sites, along 4 lines, one across and three emanating from the mouth of the Gaoping River (Figure 17). The mean density of the debris found across all tows was 77,829.5 items per square kilometre and ranged from 3 to 107 items observed on any single tow. Overall, the most common type of debris found was hard plastic, with a total of 490 items, or 51.9% of all items found.

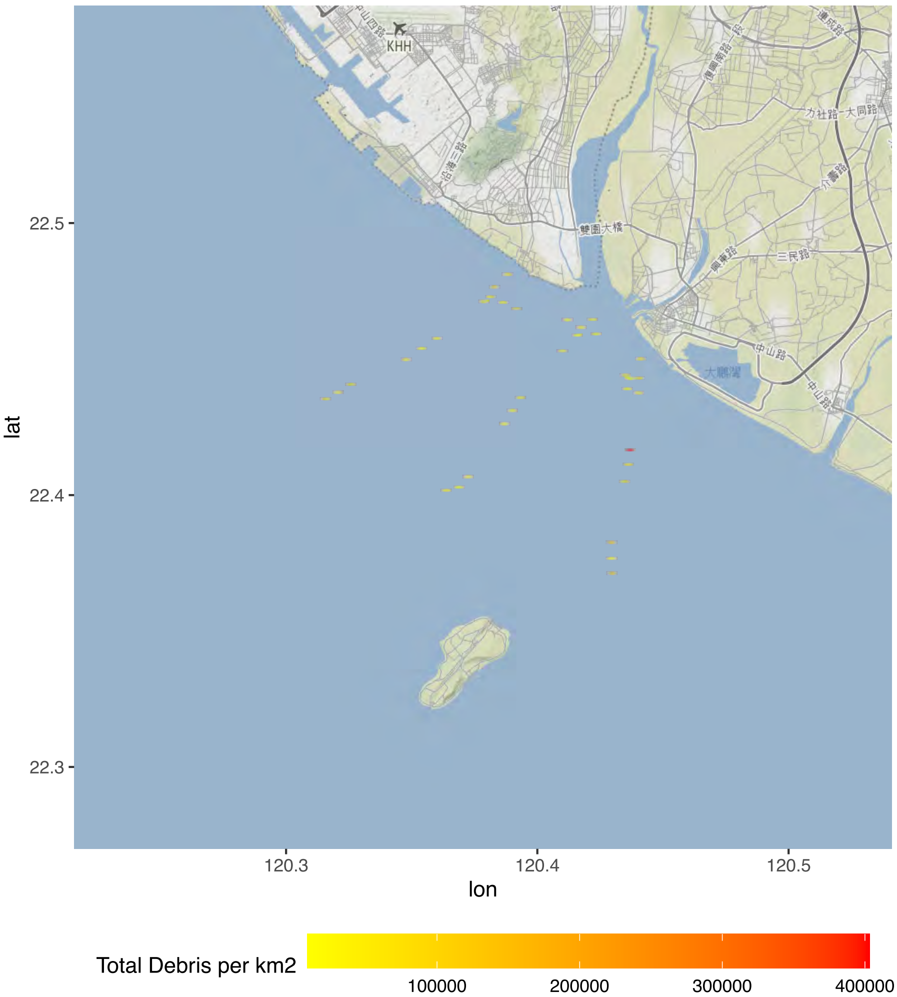

Figure 17. The total number of items per square kilometre for trawl sites in Taiwan.

4 Summary

The surveying of the Kaohsiung region of Taiwan was a massive undertaking that involved 20 people across 14 days. To our knowledge, the data collected provides the first comprehensive baseline look at plastics and other anthropogenic debris on land, along rivers and at the coastal interface for such a large portion of the island country of Taiwan. While we acknowledge these data provide a ‘snapshot’ in time, this information can be used as a baseline against which change and seasonal differences in debris deposition and movement can be compared. Such information provides an important first step that can be used to inform policy and decision making. Furthermore, as new policies or practices are implemented island-wide or in some areas of the country, the data can be used to quantify the changes that may come with such policies, practices or awareness-raising campaigns. We also hope to use these data in conjunction with statistical models to produce figures that highlight the litter plume of this particular urban and nearby area.

Furthermore, the data collected here contributes to a world first, statistically robust, global baseline study of how much waste is lost to the coastal and marine environment. By using the same methodology and building capacity for individuals in multiple countries around the world, we are better able to make large scale predictions about not only local, but also national, regional and global debris losses into the environment. Additionally, we can look at differences we identify in types and amounts of debris across coastal, inland and riverine areas between countries to identify the drivers that may be similar or different amongst surveyed regions.

It appears that the density of debris on the Taiwanese coastline around 10 times higher than the loads estimated along the Australian coastline. Using this dataset and others collected from around the world, ultimately we will be able to estimate the amount of waste, most of which is plastic, from these plumes that is lost to the open ocean or redeposited back to land. We are also able to discern regional differences that may occur. For instance, the most common debris item found in Kenya was hard plastics compared to Seychelles which was glass. With a robust, comparable baseline of information gathered in multiple major metropolitan centres around the world, we will have the data in hand to evaluate policy effectiveness and change through on-ground activities at local, national and international scales.

Understanding the transport of plastics from land into marine systems is critical for modelling the distribution and trends of plastic in the ocean and estimating its impact on regional economies. This project will clarify the magnitude of this pollution and hopefully help identify opportunities for interventions or interdiction to the public, to industry, and to policy-makers.

Appendix A

An example of the debris survey items list showing all debris categories

Site ID Code: **ITEMS LIST** **Page _____ of ______**

Date: ☐ **No debris found** **Transect No. _____ of ____** **Subsampled? Y N**

	ITEMS	ID	Fragment	Whole
Hard Plastic	Pipe/PVC	H1		
	Beverage bottle <1 L	H2		
	Other bottle	H3		
	Bottle cap/lid	H4		
	Food container	H5		
	Utensil/plate/bowl	H6		
	Bucket/Crate	H7		
	Lighter	H8		
	Lollipop stick/earbud	H9		
	Unknown/other hard	H10		
Soft Plastic	Thin film carry bag	S1		
	Food wrapper/label	S2		
	Sheeting	S3		
	Cup/lid	S4		
	Straw	S5		
	Unknown/other soft	S6		
	Other plastic bag	S7		
Plastic Straps	String/rope/ribbon	BP1		
	Packing strap	BP2		
	Cable ties	BP3		
	Unknown/other strap	BP4		
Metal	Pipe	M1		
	Wire	M2		
	Aerosol	M3		
	Beverage can	M4		
	Food can/tin	M5		
	Lid/cap	M6		
	Food wrapper	M7		
	Aluminium foil	M8		
	Bucket/drum	M9		
	Unknown/other hard	M10		
	Unknown/other soft	M11		
Glass	Beverage bottle	G1		
	Jar	G2		
	Light globe/tube	G3		
	Unknown/other glass	G4		
Rubber	Thong/shoe	R1		
	Tyre	R2		
	Balloon	R3		
	Rubber band	R4		
	Unknown/other	R5		
Cloth	String/rope/strap	C1		
	Clothing/towel	C2		
	Wipes/cloths	C3		
	Insulation/stuffing	C4		
	Unknown/other	C5		
Timber	Wood/timber	T1		
	Utensil/food stick	T2		
	Bottle cork	T3		
	Pallet	T4		
	Unknown/other	T5		

	ITEMS Cont.	ID	Fragment	Whole
Foam	Food container	D1		
	Cup/plates/bowls	D2		
	Polystyrene	D4		
	Unknown/other	D5		
Paper	Cigarette/butt	P1		
	Paper/cardboard	P2		
	Magazine/newspaper	P3		
	Bag	P4		
	Box	P5		
	Food container/box	P6		
	Food wrapper/bag	P7		
	Beverage container	P8		
	Cups	P9		
	Plates/bowls	P10		
	Unknown/other	P11		
Fishing	Net	F1		
	Fishing line	F2		
	Fishing Lures	F3		
	Buoys/floats	F4		
	Glow stick	F5		
	Fishhook/sinker	F6		
	Unknown/other	F7		
Miscellaneous	Battery	Z1		
	Brick/cement	Z2		
	Carpet	Z3		
	Ceramic	Z4		
	E Waste	Z5		
	Furniture	Z6		
	Appliances	Z7		
	Large car parts	Z9		
	Large boat parts	Z10		
	Bag/box dom. waste	Z11		
	Nurdles	Z12		
Other		O1		
		O2		
		O3		
		O4		
		O5		
		O6		

Size class (and sub-sampling intervals)

Interval start (m)	Dist on tran	ID (F/W)	Size class
1 0-			
2			
3			
4			
5			
6			
7			
8			
9			
10 - (end)			

References

Bartoń, K. (2018). MuMIn: multi-model inference. R package version 1.40.4.

Hardesty, BD, TJ Lawson, T van der Velde, M Lansdell and C Wilcox. (2016) Estimating quantities and sources of marine debris at a continental scale. Frontiers in Ecology and Evolution, 15, 18-25. https://doi.org/10.1002/fee.1447.

Hardesty, BD, C Wilcox, Q Schuyler, TJ Lawson and K Opie (2017). Developing a baseline estimate of amounts, types, sources and distribution of coastal litter – an analysis of US marine debris data. A final report for Ocean Conservancy and NOAA, 23 October 2017.

Jambeck, JR, R Geyer, C Wilcox, TR Siegler, M Perryman, A Andrady, R Narayan, K Lavender Law (2015). Millions of tons of plastic waste end up in our oceans every year. *Science* 768-771. DOI: 10.1126/science.1260352.

Landon-Lane, M, (2018). Corporate social responsibility in marine plastic debris governance. *Marine pollution bulletin*, *127*, pp.310-319.

Lebreton, LC, J Van Der Zwet, JW Damsteeg, B Slat, A Andrady, and J Reisser (2017). River plastic emissions to the world's oceans. *Nature communications*, 8, 15611.

McIntyre, O (2020). Addressing Marine Plastic Pollution as a 'Wicked' Problem of Transnational Environmental Governance. 25/6 Environmental Liability: Law, Policy and Practice 282-295., Available at SSRN: https://ssrn.com/abstract=3637482.

R Core Team (2013). R: A language and environment for statistical computing.

Schuyler QA, K Willis, TJ Lawson, V Mann, C Wilcox and BD Hardesty (2018). Handbook of Survey Methodology - Plastics Leakage, V1.2. CSIRO Australia. ePublish 182021.

United Nations Office for Disaster Risk Reduction UNDDR (2015). Global Assessment Report on Disaster Risk Reduction 2015. https://www.preventionweb.net/english/hyogo/gar/2015/en/home/.

Vince, J and BD Hardesty (2016). Plastic pollution challenges in the marine and coastal environments: from local to global governance. Restoration Ecology. http://doi/10.1111/rec.12388/.

Wagner, S, P Klöckner, B Stier, M Römer, B Seiwert, T Reemtsma, and C Schmidt (2019). Relationship between discharge and river plastic concentrations in a rural and an urban catchment. *Environmental science & technology,* 53(17), 10082-10091.

Wood, SN (2006). Generalized Additive Models: An Introduction with R. Chapman Hall/CRC: Boca Raton, FL, USA.

As Australia's national science agency and innovation catalyst, CSIRO is solving the greatest challenges through innovative science and technology.

CSIRO. Unlocking a better future for everyone.

Contact us

1300 363 400
+61 3 9545 2176
csiroenquiries@csiro.au
csiro.au

For further information

Oceans & Atmosphere
Britta Denise Hardesty
+61 3 6232 5276
denise.hardesty@csiro.au
https://research.csiro.au/marinedebris/