Fisheries New Zealand

Tini a Tangaroa

Plastics and marine debris across the ocean floor in New Zealand waters

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Observation data from seafloor photographic imagery collected by NIWA's Deep Towed Imaging System (DTIS) since 2006 have been re-analysed for occurrences of litter, with emphasis on marine litter. From 169 000 DTIS records around New Zealand, 149 were of marine litter. Each occurrence was located in the original imagery and classified following the United Nation Environment Programme (UNEP) guidelines on remotely observed marine litter. Only a small proportion of the seafloor in the New Zealand Exclusive Economic Zone has been surveyed photographically, leaving large data gaps and uncertainties around litter density in un-surveyed areas. However, highest litter densities in the DTIS data were recorded along the northern shelf of Northland, Bay of Plenty, East Cape, Chatham Rise, and off the coast of Dunedin, with litter densities of more than 0.4 pieces of litter per km of video transect (~133–430 pieces per km^2). Litter densities in these regions were at the lower end of the reported spectrum from other studies outside New Zealand (e.g., Mediterranean and North Sea). Results show most litter was detected within 25 km of the coast, but litter was also recorded on remote seamounts more than 1500 km away from the coast. Most (83%) of the litter can be directly linked to fishing and boating activities, according to the UNEP codes, with pieces of rope being the most common recorded item (77%). Fishing nets accounted for 1% of all samples. To improve understanding of seafloor litter distributions, it is recommended that recording protocols for seabed photographic surveys be updated to incorporate the UNEP categories for marine litter.

1. INTRODUCTION

Anthropogenic litter poses a growing environmental risk, not only on land but also to the marine environment. Plastic items tend to dominate in litter due to their wide-spread use and slow rate of decomposition. In 2018, global plastic production reached 359 million tons (Plastics-Europe 2019) and is expected to grow further (IEA 2018). Between 4.8 and 12.7 million tons of this plastic enter the marine environment on an annual basis (Jambeck et al. 2015), with lost fishing gear (< 10% of total litter flow, Macfadyen et al. (2009)) and shipping (~1400 containers per year, WSC 2021). Only a small portion of plastic floats on the ocean surface and accumulates as garbage patches in the subtropical gyres. Fragmentation occurs due to UV-radiation and/or wave actions, and biofouling causes plastic to sink to the seafloor. As plastic particles become smaller, the potential for ingestion by marine creatures increases. Current studies suggest that around 99% of the plastic which enters the ocean 'disappears' with ingestion and sedimentation as two possible export pathways, neither of which can currently be quantified (van Sebille et al. 2015).

In addition to land-based plastic input to the marine environment, recreational boating and commercial shipping provide further pathways for plastics and litter to enter the ocean. Since 2006, the dumping of litter from vessels has been banned by international law, but items still go overboard intentionally or unintentionally. Items which go overboard do not necessarily sink to the seafloor immediately; wind and ocean currents can carry them a long way before they break up and sink. Abandoned, caught on the seafloor, or misplaced fishing gear is another source of plastic to the ocean introduced by recreational and commercial fishing. Landfills near rivers and the ocean pose an elevated risk of pollution, especially if they are not sufficiently protected from erosion due to landfill operations, river floods, earthquakes, and sea-level rise; these can lead to major releases of litter (e.g., plastics) into the marine environment which are difficult and costly to clean up (https://www.doc.govt.nz/news/media-releases/2019/operation-tidy-fox-ending-sunday-with-a-record-number-of-volunteers/).

Plastic litter poses a risk to living organisms, through the potential for entanglement and ingestion and starvation (de Stephanis et al. 2013). Additives and pesticides can leach from plastic when ingested and enter the food web (Carbery et al. 2018). Plastic has been found in the stomach contents of various marine organisms. Research is progressing to understand if and how plastic particles can penetrate cellular membranes and accumulate in organs and tissue (Vethaak & Leslie 2016). Therefore, marine seafood represents a potential direct pathway of plastic towards humans with associated health risks (Wang et al. 2019).

International efforts to develop a better understanding of marine plastic pollution, improve management strategies, and reduce the amount of litter entering the environment are growing. Programmes such as TOPIOS (https://topios.org/) aim to develop methods to track plastic particles in the marine environment. As part of the United Nation Environmental Programme, guidelines and protocols have been developed to record and monitor plastic in the environment (UNEP/IOC 2009). Unified monitoring standards allow for a better comparison among nations, but most existing datasets have not been produced according to such unified standards. Practicalities and differences in monitoring protocols have led to differences in data recording and incomparability of litter records among nations in the past (Ioakeimidis et al. 2017).

Litter monitoring at beaches is mostly conducted through citizen science programmes; in New Zealand this takes place under the umbrella of Litter Intelligence (https://litterintelligence.org/) and is coordinated through Sustainable Coastlines (https://sustainablecoastlines.org/). More detailed analyses of litter on beaches have been conducted by dedicated Ph.D. projects (e.g., van Gool et al. 2021) and by the Marine Farming Association (https://www.marinefarming.co.nz/). River monitoring projects to quantify the litter flow into the marine environment are also underway in New Zealand (Valois et al. 2019).

Snorkel or scuba diving surveys and image recording surveys have been used to monitor litter in coastal regions in the past (Backhurst & Cole 2000). Offshore trawl surveys are most commonly used to record litter in the open ocean globally (e.g., Maes et al. 2018), but improved camera systems and remotely operated underwater vehicles provide methods to examine litter distribution in the deep ocean with far less environmental impact. However, only a very small percentage of seafloor has been captured by those systems in New Zealand and globally.

1.1 Objectives

As part of this project, a metadatabase has been developed to describe all potential sources of plastics and marine debris in New Zealand waters (Objective 1). Based on this collection, an individual assessment and evaluation for each dataset has been performed to test the feasibility of translating litter data to UNEP litter categories (Objective 2). From this derived dataset, UNEP litter densities have been computed and summary statistics compiled (Objective 3). Based on the outcome of Objective 2, NIWA's Deep Towed Imaging System (DTIS) image data have been re-analysed and litter items classified according to the UNEP monitoring and recording guidelines. Sorting the recorded litter into the categories specified by UNEP helps to identify litter sources and to improve current litter management strategies for reducing pollution. Results of this assessment are compared with other international estimates of plastic pollution as part of Objective 3. Because the majority of litter items identified were fishing or boating related, commercial fishing records have been analysed to test for relationships between fishing and litter densities.

2. METHODS

2.1 Data

Very few datasets have been compiled specifically for monitoring marine litter in New Zealand, but in recent decades several NIWA marine environmental research programmes have incorporated methods with the potential to collect marine litter data, both on the seafloor and floating in the waters above. Eight datasets generated in these research programmes were assessed for their potential to yield useful quantitative data about the spatial occurrence of different kinds of marine litter within the New Zealand Exclusive Economic Zone (EEZ) (Table 1).

The datasets were mostly unsuitable for the current project because (1) lack of resolution of the litter categories, (2) the time that would be required to re-analyse samples to generate data on litter, or (3) incompleteness of data compilation (Table 1). The only dataset that provided detailed quantitative data without undue analysis effort was the body of seabed observation records from NIWA's Deep Towed Imaging System (DTIS; Hill 2009, Bowden & Jones 2016).

DTIS is a battery-powered towed camera frame that records continuous high definition digital video with high resolution digital still images captured simultaneously at 15 second intervals. Seabed transects are routinely of one-hour duration, covering approximately 0.5–0.8 km with an image frame width of approximately 2.5 m. The seabed track of DTIS is recorded by means of an ultra-short-baseline acoustic system (Simrad HiPAP), which gives an accuracy of 2 to 10 m depending on depth. Observations of seabed substrata, benthic fauna, and anthropogenic items are recorded from the video feed routinely in real time at sea, using Ocean Floor Observation Protocol software (OFOP, https://www.emma-technologies.com/products/software/ofop/) and most transects have been subsequently analysed in full detail ashore, again using OFOP. Anthropogenic objects of the size of drink bottles, plastic bags, and items (> 10 cm) are reliably recorded. The OFOP log files record occurrences of individual organisms and items, with each observation referenced by timestamp with a temporal resolution of one second, thus enabling direct reference to the original imagery for confirmation or audit of assigned identities.

Table 1: Datasets considered for this project, which have recorded marine litter or potentially contain unrecorded litter. 'Used' indicates datasets used in current study.

Dataset	Contact person	Used	Caveats
Camera surveys Marlborough Sounds	Tara Anderson (NIWA)	NO	This dataset contains underwater still images and footage from Marlborough Sounds. Plastic has been identified and a report for the Marlborough District Council has been compiled (Anderson 2020). The data and report are preliminary and could not be used in this project.
NIWA scampi surveys	Bruce Hartill (NIWA)	NO	Although images potentially contain litter items, they have not been recorded specifically and would require re-analysis of images (1998–2019, 1277 survey stations, around 45 000 images). Survey regions are focused in the Bay of Plenty, on the Chatham Rise, and around the Auckland Islands
NIWA Trawl surveys	Jade Maggs (NIWA)	NO	Although litter was recorded if present in the trawls, no samples or images were taken, preventing re-analysis for type and amount.
NIWA DTIS database	David Bowden (NIWA)	YES	Anthropogenic litter recorded in observation log files since 2006 in such a way that UNEP categories for individual objects can be applied. More information on the method is given above this table.
Plastic recordings from Continuous Plankton Recorder (CPR)	Matt Pinkerton (NIWA)	NO	In a pilot study, a few CPR silks were analysed for plastics and recorded plastics even in remote regions (Grover-Johnson 2018). The recorded plastics are still free floating in the upper water column. Only particles smaller than 1cm^2 were recorded, due to the instrument design.
Plastic data from rivers and streams	Amanda Valois (NIWA)	NO	At present only data from streams in Wellington are being monitored. Litter particles are being removed and do not enter the harbour/environment.
Plastic data from sea birds	David Thomson (NIWA)	NO	Sparse plastic data from sea birds (nests and stomach content) exist in New Zealand. Uncertainty exists around where and when plastic has been picked up by the birds.
Sediment cores (Multi-core)	Scott Nodder (NIWA)	NO	A large number of sediment cores have been preserved and could be analysed for small (micro) plastic particles, given sufficient time and resources.

DTIS has been used for seabed surveys since 2006, with at least one survey in each year since that time. Most DTIS data are from within the New Zealand EEZ (Figure 1), but some include observations from surveys in the Ross Sea, the Louisville seamount chain, and areas of Challenger Plateau outside the EEZ. The DTIS log database currently contains around 169 000 records (observations) from 26 voyages of RV *Tangaroa* and RV *Kaharoa* (see Appendix 3). Although these surveys are widespread across the EEZ, their total swept area represents only a very small proportion of sea floor in the EEZ and the data are spatially biased towards areas of interest for commercial fisheries management (Chatham Rise and seamounts), areas that have been the focus of Ocean Survey 20/20 initiatives (Northland shelf–Bay of Islands and Challenger Plateau), areas of special conservation status (Kermadec Ridge), and areas of interest for gas and petroleum exploration (Aotea Basin). The highest density of transects is on Chatham Rise, which has been the target of three broad-scale surveys of seafloor biodiversity, several surveys of seamounts, and one survey of seabed geological resources.

Observations of anthropogenic items are recorded routinely during analyses of DTIS video transects but are categorised using only two generic labels: "Rubbish" and "Fishing gear". In this process items larger than 10 cm are reliably detected. The rubbish label describes any anthropogenic litter except for items which relate or are likely to relate directly to fishing activity. The fishing gear category aligns with the UNEP category for Fishing and Boating (Appendix 1), which includes buoys (category RL04), fishing nets (category RL05), fishing related items (category RL06), monofilament (category RL07), and rope (category RL08). For clarity, and to align with the UNEP terminology, the term 'litter' is used to describe all forms of anthropogenic waste (including rubbish and fishing gear) in this report. For the current analysis, all still images and video footage labelled with these tags were located and reviewed to identify the type of litter and assign each record to the appropriate UNEP category for remote observations of marine litter (benthic and floating) (UNEP/IOC 2009, see Appendix 1). The UNEP categorisation describes specific litter items and provides categories in which to classify the material they are made from (e.g., plastic, glass). Although the UNEP categories for marine litter are well defined, classifying marine litter from images and footage is not always straightforward. The implications of this ambiguity to the present work are discussed in section 5 of this report. The current DTIS data and UNEP categories do not take the size of the recorded items into account, which would be necessary to fully quantify the amount of marine litter.

2.2 Analyses

Due to the sparseness of the DTIS records over the EEZ, samples were binned into regular 1° x 1° grid boxes to allow for a quantitative analysis of litter densities. Here, the number of litter items has been divided by the total DTIS transect length in each 1° x 1° grid box. In the remainder of the report three types of litter are discussed, based on the UNEP categories: (1) plastic litter, which only excludes glass bottles (RL02) and drink cans (RL10); (2) fishing and boating related litter, which includes buoys (category RL04), fishing nets (category RL05), fishing related items (category RL06), monofilament (category RL07), and rope (category RL08); and (3) bottles and drink cans (RL02 and RL06). At present there is no distinction between recreational and commercial fishing gear. This selection was guided by the project objectives and focused on the more abundant items detected in the dataset. The transect length was defined as the distance between the start and end positions of each DTIS deployment. To compare the results with other international studies, which usually provide items per survey area, a 3-m video transect width was used to translate items per transect length to items per survey area. Due to the heterogeneity of the litter items, ranking statistics as well as linear analysis have been performed.

The distance from the coast of DTIS transect and associated litter items was computed to test if disproportionately more litter was recorded closer to the coast. Relationships between the distribution of commercial fishing data, provided by Fisheries New Zealand for 1989 to 2019, and the distribution of marine litter determined from the DTIS data were analysed. The fishing data recorded the time and location for individual commercial fishing activities, such as bottom trawling.

3. RESULTS

3.1 Data coverage and marine litter distribution

From 169 000 seafloor observations in the DTIS database, OFOP classified 196 as "Rubbish" or "Fishing gear". Of these, 47 were found to be erroneous and did not show any marine litter, leaving 149 records (< 0.1% of all DTIS records) for potential assignment to UNEP categories. From those 149 records, 138 were categorised as plastic, 123 were linked to fishing and boating, and 11 were bottles or drink cans.

The largest abundance of litter items was recorded along the northern part of the shelf off Northland and around East Cape (Figure 1a). Despite a relatively high DTIS coverage over the Chatham Rise, relatively few litter items were recorded in this area.

In addition, a relatively large number of DTIS transects and litter records were from along the northern shelf of Northland (Figure 1b). Many of these litter items were identified as bottles and drink cans, which are not directly associated with fishing activities. Despite the concentration of DTIS transects within the Bay of Islands, no litter items were recorded.

Fewer DTIS transects exist around East Cape (Figure 1c) than along the northern shelf of Northland, with relatively lower proportions of bottles and drink cans and higher proportions of fishing and boating related litter.

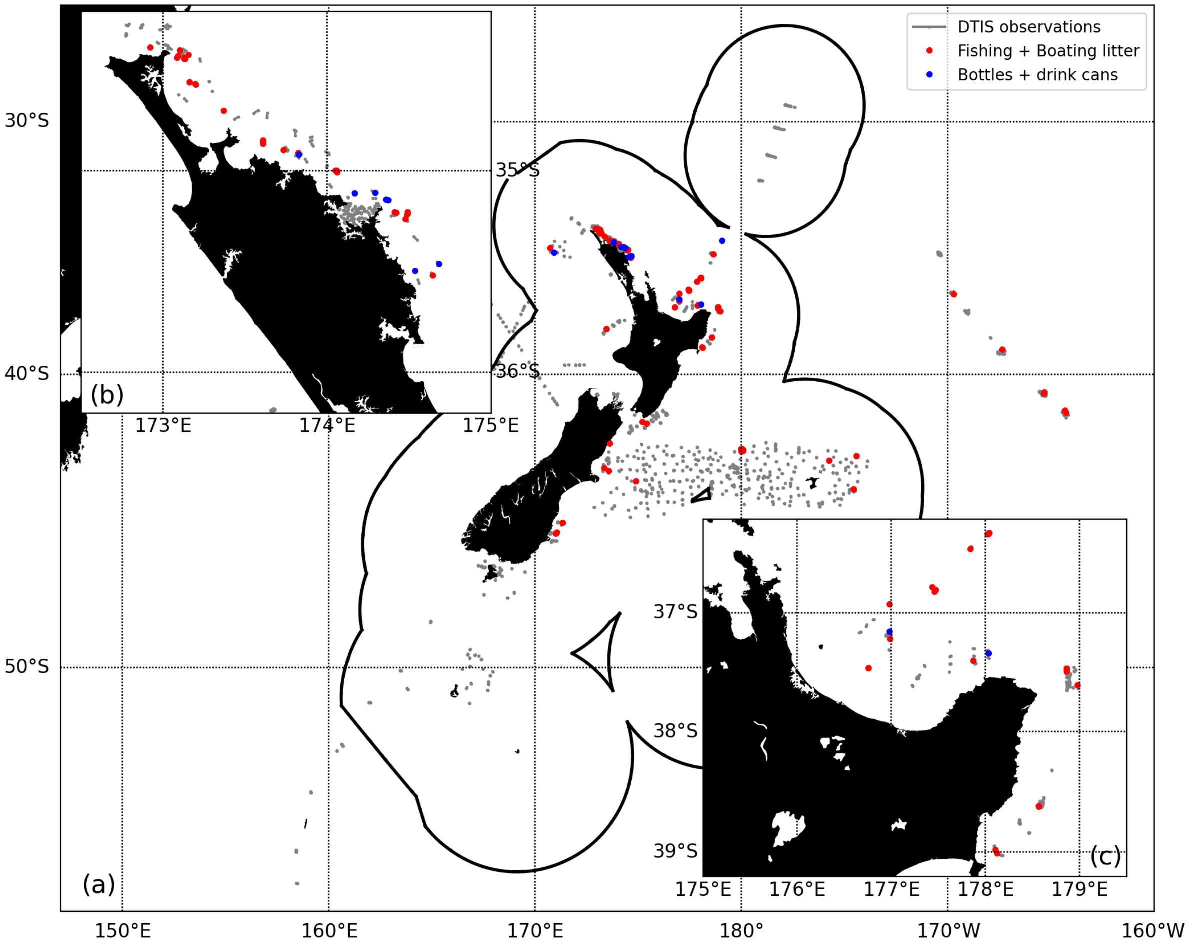

Figure 1: DTIS transect locations (grey lines), fishing and boating related litter (red dots), and bottles and drink cans (blue dots) from the DTIS database. (a) The New Zealand Region; (b) Close-up of Northland; (c) Close-up of East Cape and Bay of Plenty.

The number of DTIS transects per 1° x 1° grid box varies substantially around New Zealand. Most boxes do not contain more than 20 DTIS transects (Figure 2a). Only a few regions on the central Chatham Rise have been visited more than 100 times. The northern shelf of Northland contains between 40 and 80 transects per 1° x 1° box.

The number of plastic items, based on UNEP categories (i.e., excluding metal cans and glass bottles), recorded per 1° x 1° grid box (unadjusted for sampling density) is very heterogeneous (Figure 2b). The highest number of items are found along the northern shelf of Northland where observations of plastic items exceeded 25 per 1° x 1° box. Other regions containing high numbers of plastic items (> 5 per 1° x 1° box) were around the East Cape, on the central Chatham Rise, and off the coast of Dunedin. All these elevated numbers were directly connected to fishing and boating activities (Figure 2c), and bottles and drink cans were found only north of the North Island. Note, these item counts do not take into account how many DTIS observations exist and consequently regions with relatively high DTIS transects generally show more litter records.

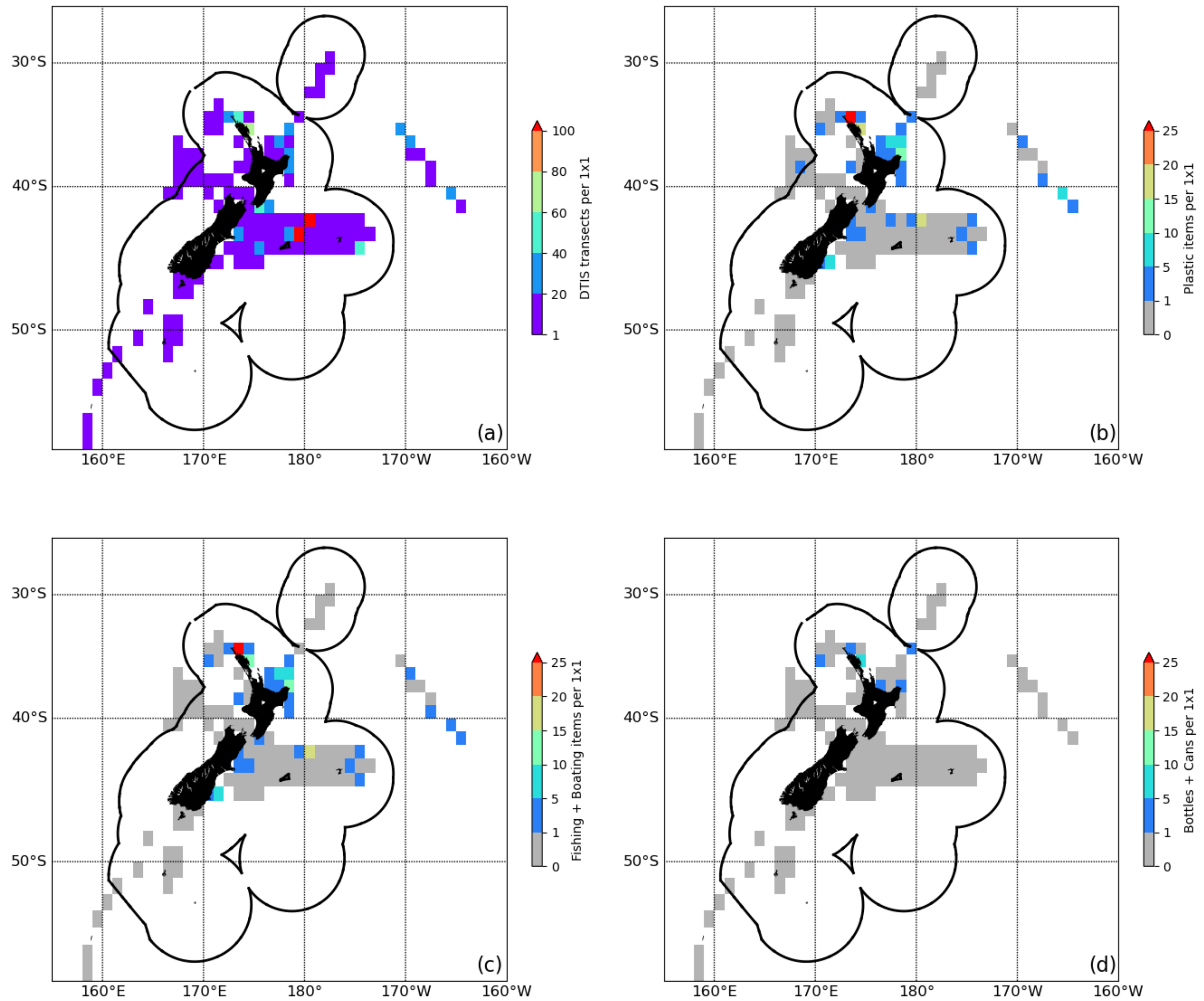

Figure 2: (a) DTIS transects per 1° x 1° box. (b) Plastic items within the DTIS database per 1° x 1° box. (c) Fishing and boating related items within the DTIS database per 1° x 1° box. (d) Bottles and cans within the DTIS database per 1° x 1° box. Boxes with zero items are shown in grey.

The pattern of recorded distance (kilometres) of DTIS transects in each 1° x 1° box (Figure 3a) closely mirrors the number of transects per grid box (Figure 2a). More than 80 km per 1° x 1° box have been captured in some areas of the central Chatham Rise and more than 60 km along the northern shelf of Northland. However, most of the observed regions have had less than 20 km of DTIS transects per 1° x 1° box.

The plastic density, a measure of the number of observed plastic items per distance (kilometres) covered by DTIS in each 1° x 1° grid box from Figure 3a, is shown in Figure 3b. The plastic density was very heterogeneous. The regions north of Northland, in the Bay of Plenty, around Dunedin, and around the East Cape showed the highest plastic density (> 0.4 items per km). Densities over the central Chatham Rise reached up to 0.4 plastic items per km. Most of these plastic items were directly attributed to fishing and boating activities (Figure 3c), whereas bottle and can density was low.

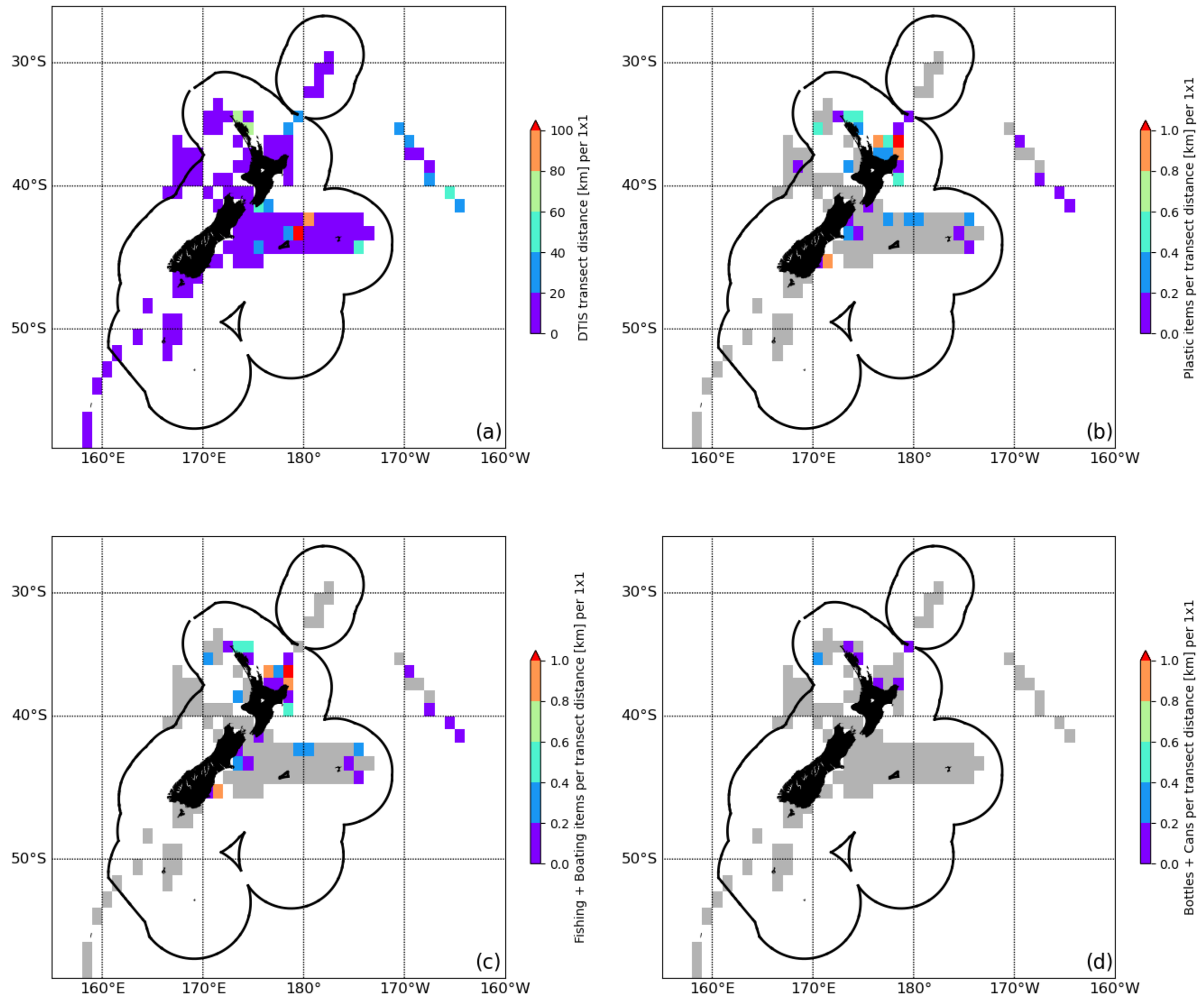

Figure 3: (a) DTIS effort (accumulated transect distance) per 1° x 1° box. (b) Plastic density (plastic items per km of transect) per 1° x 1° box. (c) Fishing and boating related litter density (items per km of transect) per 1° x 1° box. (d) Bottles + cans litter density (items per km of transect) per 1° x 1° box. Boxes with zero items are shown grey in (b), (c), and (d).

The number of 1° x 1° grid boxes for each level of plastic density are shown in Figure 4a, where colours match the keys in Figure 3. The DTIS data in 150 grid boxes did not show any litter (not shown). The number of grid boxes decreases as plastic density increases. The majority of plastic observations (24 grid boxes) show a plastic density less than 0.4 items per km, with only 9 grid boxes showing higher plastic densities. Fishing and boating related litter (Figure 4b) show a very similar distribution with most recorded densities varying between 0 and 0.4 items per km with the occasional higher recorded density. The six 1° x 1° grid boxes containing bottles and cans show less than 0.4 items per km (Figure 4c).

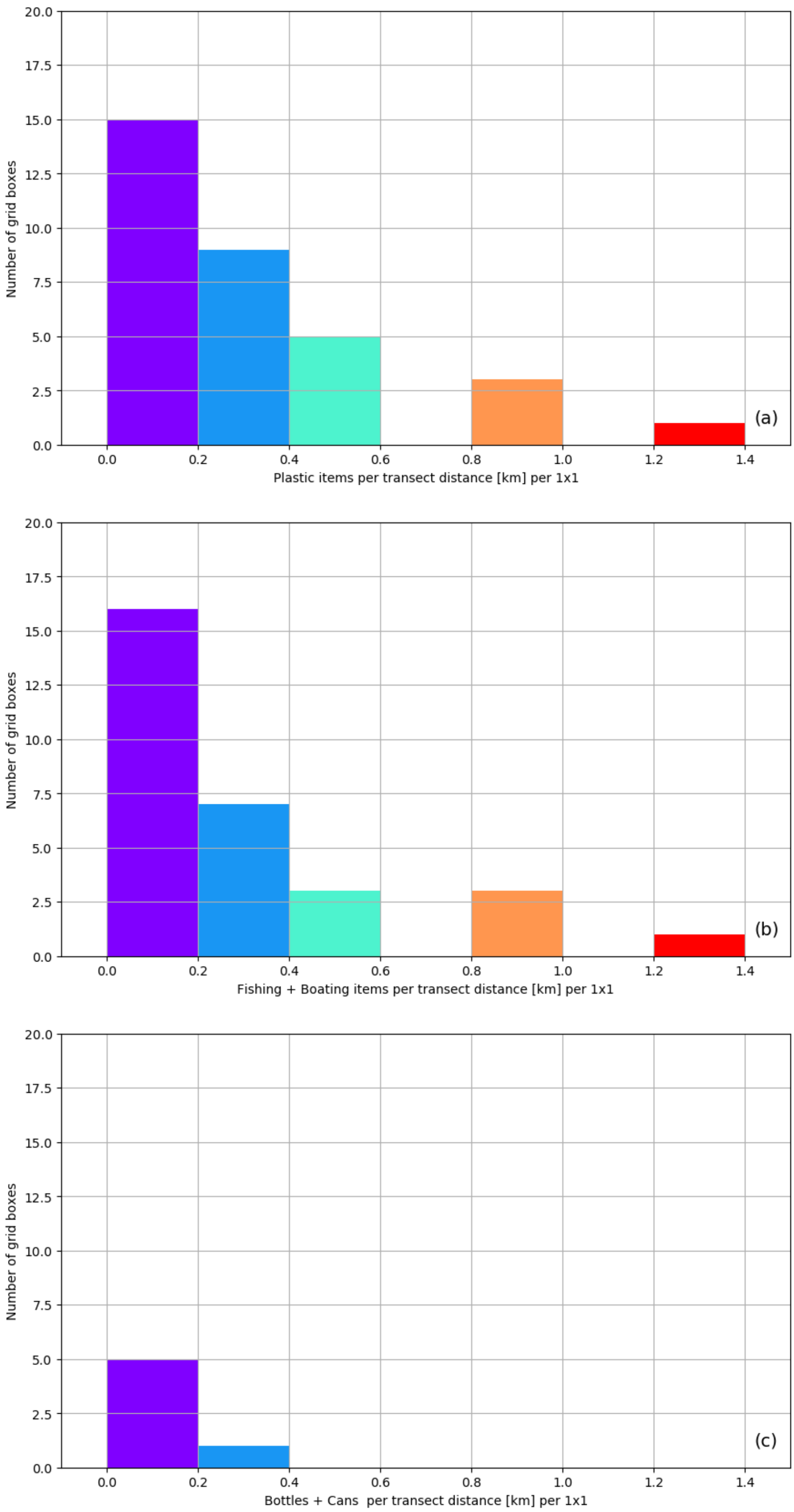

Figure 4: Number of grid boxes per density (items per covered distance [km] per 1° x 1°). (a) plastic items; (b) Fishing and boating related litter; and (c) bottles and cans. The colour coding follows the scheme in Figures 2 and 3. There are 150 grid boxes without any litter records.

The relationship between the number DTIS transects and recorded plastic items is shown in Figure 5a. Even with relatively large numbers of DTIS transects per 1° x 1° grid box (> 40), the number of recorded plastic items can be low, confirming large heterogeneity and no linear relationship. However, there is a tendency for more recorded items with increasing numbers of DTIS transects per 1° x 1° grid box (Figure 5b) shown by the ranked statistic. Here a higher rank is associated with a larger number of transects or larger number of recorded plastic items. When taking the DTIS transect distance into account (Figure 5c), the higher plastic densities occur in areas with lower (< 20 km) and higher (> 40 km) sampling density. Most of the regions with low transect distance but high plastic densities are located close to the coast along the northern shelf of Northland, Bay of Plenty, and the East Cape, where recreational and commercial fishing and boating activity is higher than in other regions around New Zealand. The ranked statistics confirm this behaviour (Figure 5d). Here, boxes with low recorded DTIS distance (lower rank) rank high (large number of plastic items) underpinning the heterogeneity of plastic density between regions with no influence from the DTIS transect distance.

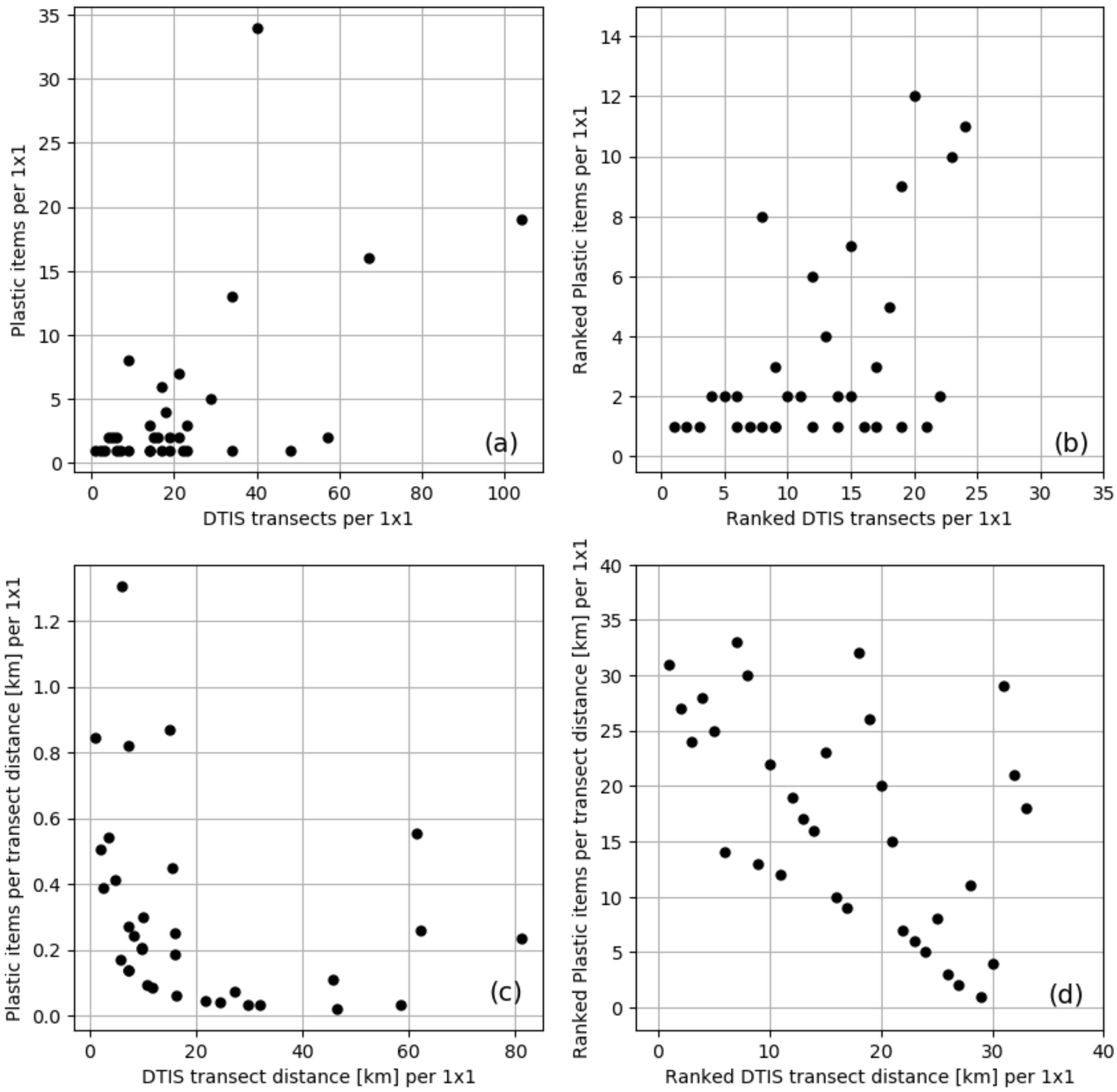

Figure 5: (a) DTIS items versus plastic items per 1° x 1° box. (b) DTIS items versus plastic items per 1° x 1° box ranked (high ranks are associated with higher recorded DTIS transect distance or larger number of plastic items). (c) DTIS covered length [km] versus plastic items per covered length per 1° x 1° box. (d) DTIS covered length [km] versus plastic items per covered length per 1° x 1° box ranked.

3.2 What kind of litter was recorded?

The UNEP categorisation for remote observations (Appendix 1) are listed in Table 2. Results show that 77% of all litter records are classified as ‘Rope’ (RL08), followed by 7% for ‘Bottles’ (RL02), 5% ‘Plastic sheeting’ (RL16), and 4% ‘Fishing related’ (RL06). The remaining items categories are very rare (≤ 2%).

According to the comprehensive UNEP categorisation (Appendix 2, Table 3), 75% were identified as ‘plastic Rope’ (PL19), 7% as ‘Glass bottles’ (GC02), 5% as ‘Plastic sheeting’ (PL16), and 4% as ‘Metal fishing related’ (ME07). The remaining item categories are very rare (≤ 1%).

Table 2: UNEP categorised (remote observations) litter.

UNEP code	Description	Occurrence
RL08	Rope	77%
RL02	Bottles < 2 l	7%
RL16	Plastic sheet	5%
RL06	Fishing related	4%
RL23	Other	2%
N/A	N/A	2%
RL10	Drink Cans	1%
RL06; RL05	Fishing related, Fishing net	1%
RL05	Fishing net	1%

Table 3: UNEP categorised (comprehensive marine) litter.

UNEP code	Description	Occurrence
PL19	Plastic rope	75%
GC02	Glass bottles	7%
PL16	Plastic sheeting	5%
ME07	Metal fishing related	4%
N/A	N/A	2%
PL24	Other	<1%

The distribution of UNEP categorised litter items is shown in Figure 6a. ‘Rope’ (RL08) was identified in all regions where litter was recorded, whereas other litter categories were very heterogeneously distributed. At four locations at the entrance to the Bay of Islands, ‘Bottles’ (RL02) were identified (Figure 6b), but no rope or fishing related items were identified in this region. However, rope was the most abundant litter item along the shelf break of Northland and in the Bay of Plenty (Figure 6c), with occasional records of plastic sheeting (RL16).

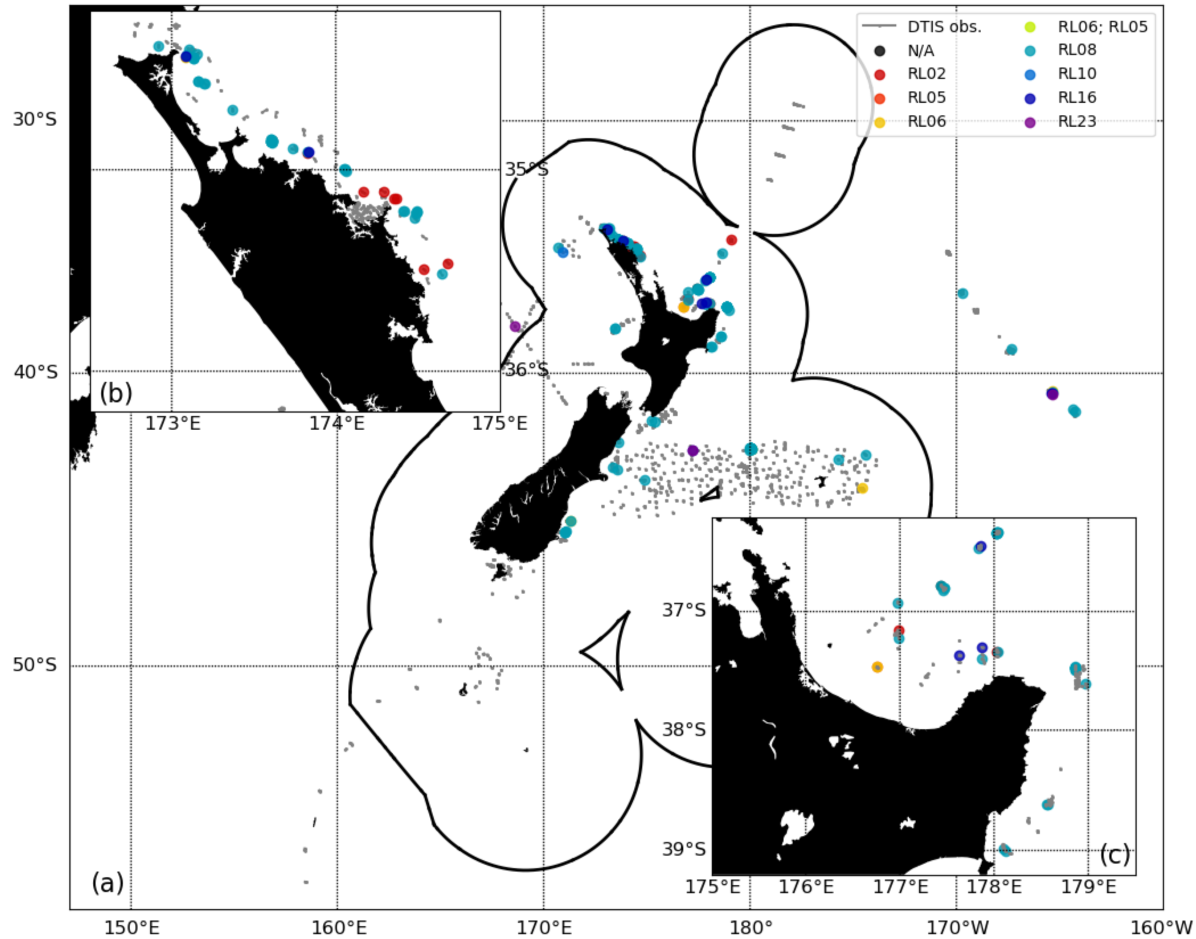

Figure 6: (a) Location of DTIS transects (grey lines/dots) and UNEP categorised items (colour code dots). (b) and (c) Same as (a) but zoomed in for Northland and Bay of Plenty. UNEP codes translate to RL02 (Bottles), RL05 (Fishing net), RL06 (Fishing related), RL08 (Rope), RL10 (Drink cans), RL16 (Plastic sheeting), and RL23 (Other).

3.3 Possible links between marine litter and human activities

The majority of the DTIS transects were conducted within 400 km of the coast (black bars, Figure 7a); around 20% of them between 350 and 400 km and around 27% between 0 and 50 km. Within the 25-km bin, 39% (red bars) of the litter observations were plastic, which is three times larger than the percentage of DTIS transects (13%) in that bin. That shows that the plastic litter was more abundant near the coast and the litter density decreased rapidly with distance from the coast.

More specifically, around 35% of all fishing related litter items (red bars) and nearly 50% of all bottles and drink cans (blue bars) were found within 25 km of the coast (Figure 7b).

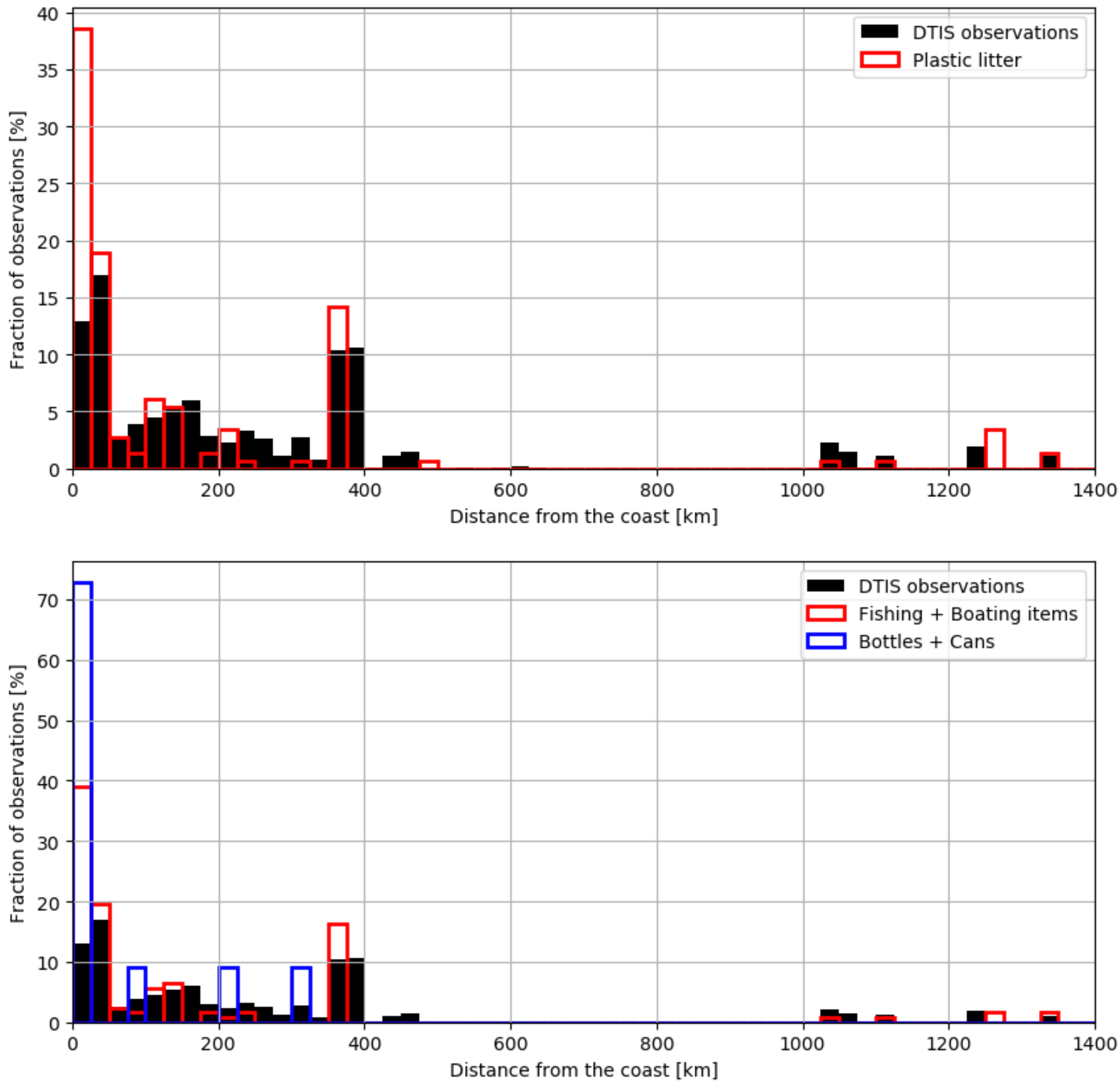

Figure 7: (a) Histogram of number of plastic observations (red lines) and DTIS transects (black bars) with distance from the coast. (b) Same as (a) but differentiation between direct fishing and boating related (red lines) and bottles and cans (blue lines).

Despite the overall low number of litter items, a large portion (83%) was identified as fishing and boating related. Therefore, the fishing and boating related litter observations were analysed in relation to historic commercial fishing data. The fishing event density, in terms of number of fishing events, is concentrated around the coast (Figure 8a). Here, a fishing event is defined as any kind of commercial fishing activity that has been undertaken and a position recorded. In particular, the shelf of Northland, Bay of Plenty, the East Cape, the Banks Peninsula, Greymouth, the Snares Islands, and the coast of Dunedin show intense historical fishing activity (more than 35 000 fishing events per 1° x 1° grid box). The fishing event density over the Chatham Rise has varied between 5000 and 30 000 per grid box. In some of these regions, elevated fishing and boating litter densities have been observed (Figure 8b). However, the current database does not provide evidence that the density of fishing and boating litter is related to the density of fishing effort (Figure 8c, d).

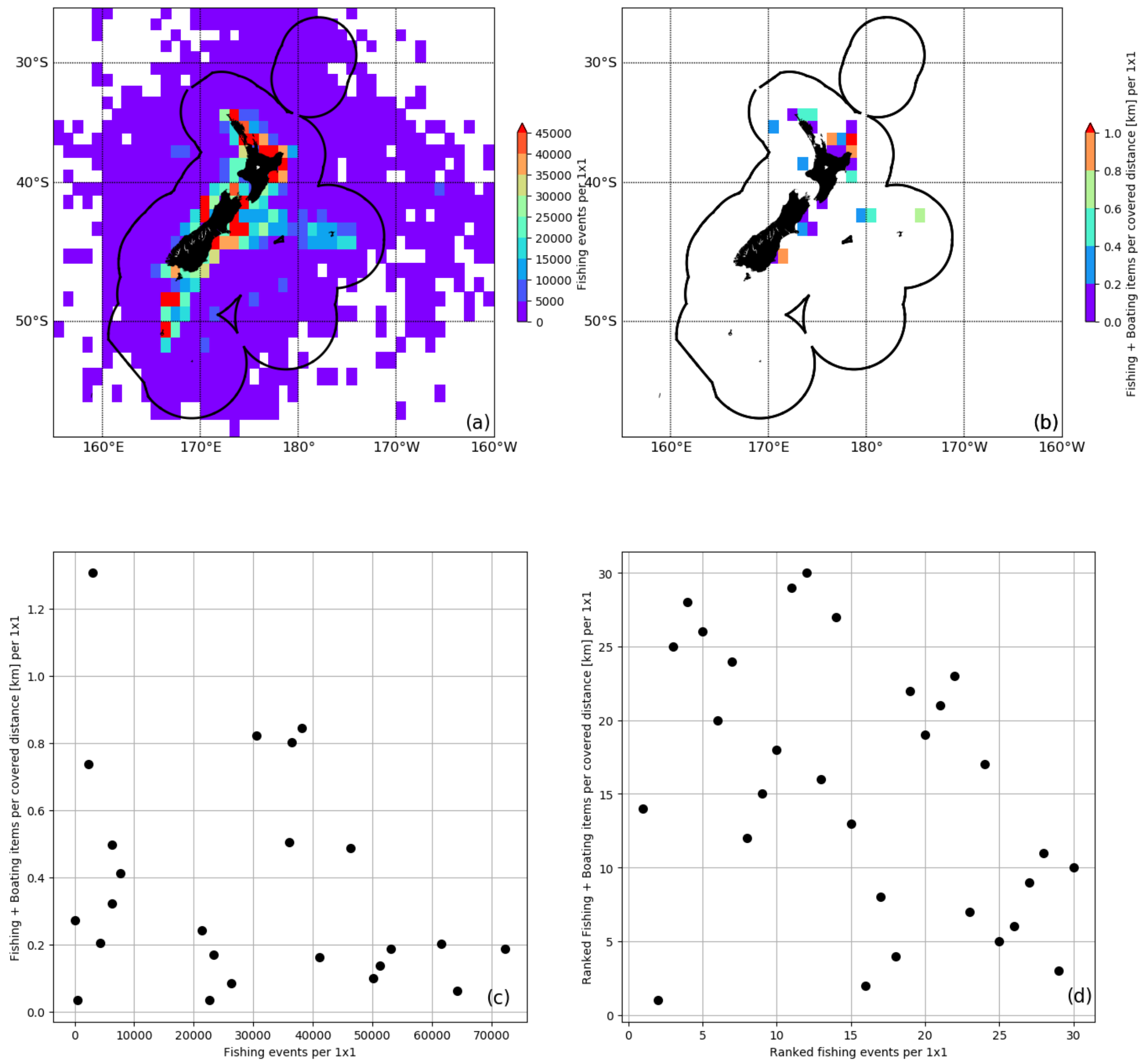

Figure 8: (a) Fishing events per 1° x 1° grid box for the period 1989 to 2019. (b) Fishing and boating litter density (items per km of transect) per 1° x 1° box (zero values not shown). (c) Fishing events versus fishing and boating litter density per 1° x 1° box. (d) Fishing events versus fishing and boating litter density per 1° x 1° box ranked (higher ranks are associated with higher number of fishing events or litter items).

4. DISCUSSION

DTIS observations provide an accurate but limited glimpse of the seafloor within the EEZ. Only a very small fraction of the EEZ seafloor has been captured by this video system and DTIS transects are not evenly distributed over the EEZ. It is also likely that the distribution of DTIS video data is biased with respect to the distribution of marine litter on the seafloor. DTIS surveys are focused on regions with a fishing history and on oceanographic features such as seamounts and shelf regions. These factors may have an influence on how much litter has been recorded and the calculations of litter density made in this report. Despite these potential data limitations, there was no evidence for a relationship between commercial fishing density and fishing and boating litter density, despite 83% of all recorded litter items being attributed to fishing or boating.

Previous studies of trawl and video surveys show a very heterogeneous distribution of marine litter on the seafloor (Bo et al. 2014, Ioakeimidis et al. 2017, Maes et al. 2018, Pham et al. 2013, Tubau et al. 2015). For this reason, the ability to interpret and compare the litter data analysed in this study is limited, especially in light of the above doubts about the representativeness of the relatively few observations available.

However, despite a relatively low number of DTIS transects and recorded DTIS transect lengths, the reported plastic densities were high in a few regions (including Bay of Plenty, Northland, around Dunedin, and East Cape). In these regions, recreational and commercial fishing and boating activities tend to be higher than in other regions and the larger anthropogenic impact in these regions provides a reason for high plastic densities in these areas. Hence, it is likely that reported densities are not affected per se by number of observations.

In addition to these limitations, the number of litter particles recorded and identified in the DTIS data is likely to have been underestimated. This is because only items larger than 10 cm can be reliably identified. Furthermore, biofouling and fragmentation of the plastic items can make it difficult to discriminate litter and plastic from naturally occurring biological and non-biological items. It is likely that the recognition and recording of litter from video data has been mainly limited to large (> 10 cm) and obvious litter objects that either had minimal biofouling or were recently discarded.

As in other international studies, litter densities based on the DTIS analysis showed a large spatial heterogeneity over the New Zealand EEZ, varying between 0 to 1.3 items per km. Litter densities in the Bay of Plenty and offshore Northland, Dunedin, and East Cape are higher than in other regions, with litter densities between 0.4 to 1.3 items per km, which can be translated to 133–433 items per km^2, assuming a video transect width of 3 m. In comparison, litter densities for continental shelf areas in the Mediterranean vary typically between 200 and 5000 items per km^2 (Ioakeimidis et al. 2017), but can reach up to 40 000 items per km^2 around seamounts and over rocky sea floor (see also Appendix 4). The Mediterranean is recognised as a region of high litter densities because it is a semi-enclosed sea surrounded by high-density populations. Litter densities in the eastern Pacific Ocean range between 140 and 632 items per km^2 in nearshore regions and between 2 and 44 items per km^2 in offshore regions. For the western Pacific Ocean, similar litter densities have been reported, except for the marginal seas (e.g., South China Sea), where higher litter densities between 1300 and 3200 items per km^2 have been reported. Less populated and remote Pacific regions such as the Hawaiian Islands report densities between 3 and 62 items per km^2. The densities in the Bay of Plenty, Northland, Dunedin, and East Cape are comparable with values found around the Pacific Ocean in nearshore regions.

Results show that the litter near the coast is more abundant than in offshore regions, with around 50% of all recorded litter items found within 50 km from the coast. This near-coastal region is where recreational boating and fishing is concentrated and the higher densities recorded off the Northland coast are likely to be, in part at least, a consequence of this being the only part of New Zealand's continental shelf that has been the subject of an Ocean Survey 20/20 seabed biodiversity survey (RV

Tangaroa voyage TAN0906). However, it is also notable that marine litter was also observed at remote seamounts, far away from coasts.

Most (83%) of the 149 litter records examined could be positively identified as fishing or boating related items, with the remaining not directly linked to fishing or boating activities. However, that does not exclude the possibility that these items were discarded (intentionally or not) as part of fishing or boating activities (e.g., bottles and drink cans).

Based on the available commercial fishing data, no relationship between the number of fishing events and fishing and boating litter density could be established. However, occasional video footage of trawl nets abandoned on the seafloor show clear evidence that commercial fishing contributes to marine litter. Over the Chatham Rise, where fishing activity is high and relatively good DTIS coverage has been achieved, only a small number of litter items were observed. The seafloor of the Chatham Rise is predominantly soft, providing little potential for trawl nets to come fast and be lost, although legend has it that Graveyard Seamount on the north Chatham Rise was so named because it was a graveyard for lost fishing gear when an orange roughy fishery was developed there in the 1980s (Malcolm Clark, NIWA, pers. comm.). The potential for fishing gear to be lost varies among the different types of fishing techniques and although fish and therefore fishers are in general attracted to oceanographic features such as seamounts, fishers try hard to avoid losing fishing gear due to the substantial financial loss.

5. MANAGEMENT IMPLICATIONS

There is considerable potential to increase the volume and detail of data about the distributions of plastics across the seafloor of New Zealand's EEZ by adjusting the analysis protocols for photographic surveys, including those for scampi, biodiversity, and environmental impact assessment, to include routine identification of litter items following the UNEP guidelines. The present project was only exploratory in scope, analysing available data collected during surveys for which the primary focus was benthic invertebrates, rather than litter. Thus, it is likely that more detail about litter distributions might be gained from dedicated re-analysis of the DTIS imagery in targeted areas, such as the Northland coast and fished seamounts. Comparison of data from such re-analyses against the existing data presented here would be valuable to gauge the utility of current survey methods for detecting plastic debris.

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APPENDIX 1

List of litter types and codes for remote observations (benthic and floating). Litter categories are adopted from the UNEP/IOC Guidelines on Survey and Monitoring of Marine Litter (UNEP/IOC 2009)

General litter	Litter Code	Class description with examples
Containers	RL01	Bottle caps, lids & pull tabs
	RL02	Bottles < 2 L
	RL03	Bottles, drums & buckets > 2 L
Fishing & Boating	RL04	Buoys
	RL05	Fishing net
	RL06	Fishing related (sinkers, lures, hooks, traps, pots, & baskets/trays)
	RL07	Monofilament
	RL08	Rope
Food & Beverage	RL09	Cups, food trays, fast food wrappers, & cardboard drink containers
	RL10	Drink cans
	RL11	Drink package rings
	RL12	Ice-cream sticks, chip forks, chopsticks, toothpicks, matches, & fireworks
Packaging	RL13	Foam (insulation & packaging)
	RL14	Paper & cardboard
	RL15	Plastic bags (opaque & clear)
	RL16	Plastic sheet or plastic tarpaulin
	RL17	Strapping
Sanitary	RL18	Sanitary (nappies, tampon applicators, cotton buds, condoms, etc)
Smoking	RL19	Cigarette butts
	RL20	Cigarette lighters
Other	RL21	Fluorescent light tubes
	RL22	Light globes
	RL23	Other (specify)
	RL24	Processed timber
	RL25	Rags, clothing, shoes, hats, & towels
	RL26	Tableware
	RL27	Toys
	RL28	Tyres & Inner-tubes
	RL29	Wire, wire mesh, & barbed wire

APPENDIX 2

List of litter types for comprehensive and rapid beach surveys. Litter categories are adopted from the UNEP/IOC Guidelines on Survey and Monitoring of Marine Litter (UNEP/IOC 2009) (continued on next page).

Category number	Material	Litter code	Class description
1	Plastic	PL01	Bottle caps & lids
2	Plastic	PL02	Bottles < 2 L
3	Plastic	PL03	Bottles, drums, jerrycans & buckets > 2 L
4	Plastic	PL04	Knives, forks, spoons, straws, stirrers, (cutlery)
5	Plastic	PL05	Drink package rings, six-pack rings, ring carriers
6	Plastic	PL06	Food containers (fast food, cups, lunch boxes, & similar)
7	Plastic	PL07	Plastic bags (opaque & clear)
8	Plastic	PL08	Toys & party poppers
9	Plastic	PL09	Gloves
10	Plastic	PL10	Cigarette lighters
11	Plastic	PL11	Cigarettes, butts, & filters
12	Plastic	PL12	Syringes
13	Plastic	PL13	Baskets, Crates & trays
14	Plastic	PL14	Plastic buoys
15	Plastic	PL15	Mesh bags (vegetable, oyster nets, & mussel bags)
16	Plastic	PL16	Sheeting (tarpaulin or other woven plastic bags, palette wrap)
17	Plastic	PL17	Fishing gear (lures, traps, & pots)
18	Plastic	PL18	Monofilament line
19	Plastic	PL19	Rope
20	Plastic	PL20	Fishing net
21	Plastic	PL21	Strapping
22	Plastic	PL22	Fibreglass fragments
23	Plastic	PL23	Resin pellets
24	Plastic	PL24	Other (specify)
25	Foamed Plastic	FP01	Foam sponge
26	Foamed Plastic	FP02	Cups & food packs
27	Foamed Plastic	FP03	Foam buoys
28	Foamed Plastic	FP04	Foam (insulation & packaging)
29	Foamed Plastic	FP05	Other (specify)
30	Cloth	CL01	Clothing, shoes, hats, & towels
31	Cloth	CL02	Backpacks & bags
32	Cloth	CL03	Canvas, sailcloth, & sacking (hessian)
33	Cloth	CL04	Rope & string
34	Cloth	CL05	Carpet & furnishing
35	Cloth	CL06	Other cloth (including rags)
36	Glass & ceramic	GC01	Construction material (brick, cement, pipes)
37	Glass & ceramic	GC02	Bottles & jars
38	Glass & ceramic	GC03	Tableware (plates & cups)
39	Glass & ceramic	GC04	Light globes/bulbs
40	Glass & ceramic	GC05	Fluorescent light tubes
41	Glass & ceramic	GC06	Glass buoys
42	Glass & ceramic	GC07	Glass or ceramic fragments
43	Glass & ceramic	GC08	Other (specify)
44	Metal	ME01	Tableware (plates, cups, & cutlery)
45	Metal	ME02	Bottle caps, lids, & pull tabs
46	Metal	ME03	Aluminium drink cans
47	Metal	ME04	Other cans (< 4 L)
48	Metal	ME05	Gas bottles, drums, & buckets (> 4 L)
49	Metal	ME06	Foil wrappers
50	Metal	ME07	Fishing related (sinkers, lures, hooks, traps, & pots)
51	Metal	ME08	Fragments

52	Metal	ME09	Wire, wire mesh, & barbed wire
53	Metal	ME10	Other (specify), including appliances
54	Paper & cardboard	PC01	Paper (including newspapers & magazines)
55	Paper & cardboard	PC02	Cardboard boxes & fragments
56	Paper & cardboard	PC03	Cups, food trays, food wrappers, cigarette packs, drink containers
57	Paper & cardboard	PC04	Tubes for fireworks
58	Paper & cardboard	PC05	Other (specify)
59	Rubber	RB01	Balloons, balls, & toys
60	Rubber	RB02	Footwear (flip-flops)
61	Rubber	RB03	Gloves
62	Rubber	RB04	Tyres
63	Rubber	RB05	Inner-tubes and rubber sheet
64	Rubber	RB06	Rubber bands
65	Rubber	RB07	Condoms
66	Rubber	RB08	Other (specify)
67	Wood	WD01	Corks
68	Wood	WD02	Fishing traps and pots
69	Wood	WD03	Ice-cream sticks, chip forks, chopsticks, & toothpicks
70	Wood	WD04	Processed timber and pallet crates
71	Wood	WD05	Matches & fireworks
72	Wood	WD06	Other (specify)
73	Other	OT01	Paraffin or wax
74	Other	OT02	Sanitary (nappies, cotton buds, tampon applicators, toothbrushes)
75	Other	OT03	Appliances & Electronics
76	Other	OT04	Batteries (torch type)
77	Other	OT05	Other (specify)

APPENDIX 3

DTIS voyages. TAN = RV *Tangaroa*; KAH = RV *Kaharoa*; first two numbers = year (e.g., KAH0907 is 2009).

Identifier
KAH0907
TAN0616
TAN0705
TAN0707
TAN0802
TAN0803
TAN0905
TAN0906
TAN1004
TAN1007
TAN1105
TAN1108
TAN1206
TAN1306
TAN1402
TAN1503
TAN1505
TAN1603
TAN1612
TAN1701
TAN1805
TAN1901
TAN1904
TAN1802
TAN1903

APPENDIX 4

Reported litter densities, see also (Ioakeimidis et al. 2017).

Observing method	Location	Litter density	Reference
Imagery/ROV	Mediterranean, 4 rocky offshore banks, 70–280 m deep	17–70 m rope per $100m^2$; 0.5–8 m^2 per $100m^2$	(Bo et al. 2014)
Imagery/ROV	Coast of California	0–38 items per 100 m^2, 1.7 items per 100 m^2 (average)	(Watters et al. 2010)
Imagery/ROV	North East Atlantic, Condor seamount	Up to 397–1439 items per km^2	(Pham et al. 2013)
Imagery/ROV	North Western Mediterranean, submarine canyons	8090–15 057 items per km^2	(Tubau et al. 2015)
Bottom trawl	North Sea	Up to 1835 items per km^2	(Maes et al. 2018)
Bottom trawl	Alaska, Kodiak Island	4.5–25 items per km^2	(Hess et al. 1999)
Bottom trawl	Portugal Coast	Up to 178 items per km^2	(Neves et al. 2015)
Bottom trawl	US West Coast	30–128 items per km^2	(Keller et al. 2010)
Bottom trawl	Belgian Coast	1250–11 527 items per km^2	(Van Cauwenberghe et al. 2013)
Diving Survey	Hawaiian Islands	3.4–62.2 per km^2	(Donohue et al. 2001)
Bottom trawl	Gulf of Greece	72–437 items per km^2	(Koutsodendris et al. 2008)
Bottom trawl	China Sea	30 –109 kg per km^2	(Lee et al. 2006)
Bottom trawl	Northern Mediterranean	Up to 40 500 items per km^2	(Sanchez et al. 2013)
Bottom trawl	Eastern Mediterranean, Antalya Bay	115–2762 items per km^2	(Guven et al. 2013)