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Web-based Citizen Involvement in Research into Pathways and Hotspots of Marine Litter in the Southern North Sea

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Abstract

This paper demonstrates a way in which citizens can be effectively involved in data collection to generate new knowledge about pathways and hotspots of marine litter abundance in the North Sea region of Germany. This should help to tackle the problem within an interdisciplinary research approach. We use a combination of in-situ experiments involving the release of degradable wooden drifters into the North Sea and a web-based survey provided by the Geospatial Content Management System (GeoCMS) 'HotSpot' to report drifter sightings. The focus lies on the techniques used to provide the web-based report tool as well as on the methods used to ensure data quality and inform participants via web mapping tools. We present an overview of the first results, which are also available in the project's web portal, to increase public awareness of the global litter problem, in particular macroplastics in the oceans and along the North Sea coast.

Keywords:

marine litter, macroplastics, citizen science, web mapping

1 Introduction

Marine litter is commonly observed in all parts of the oceans around the globe and is a ubiquitous major concern, even on the most remote islands (Derraik, 2002; Barnes et al., 2009). The harmful impacts of this plastic pollution on marine animals of all trophic levels and on all marine-associated wildlife, through ingestion and by entanglement, are well known (Derraik 2002, van Franeker et. al. 2011, Rochmann et al. 2013). They are also considered a high risk to human health (Thompson et al. 2009, Rochmann et al. 2013). Additionally, the pollution has the potential to modify habitats by increasing the transport of organic and inorganic contaminants (Barnes & Milner 2005), and the hitchhiking of non-indigenous species to new habitats (Barnes 2002); it also presents a hazard for the economy (Butler et al. 2013).

Given that marine litter is a global issue causing negative impacts, several political programmes (e.g. the UNEP/MAP plan on Marine Litter, or the Marine Strategies Framework Directive MSFD for European Countries) have been set up to find solutions. The aim of

these programmes is to achieve a good environmental status for all major water bodies. As anthropogenic litter has become an indicator of the marine environmental status, the Marine Beach Litter programme for the North-East Atlantic (OSPAR) was developed to standardize data collection. OSPAR surveys have been carried out on different beaches in Europe since 2001 (Schulz & Matthies, 2014; Browne et al., 2015). This long-term data collection should lead to a scientific understanding of the temporal and spatial trends in the composition and distribution of marine litter in Europe, linking those results to the litter's origins (Schulz et al., 2013). Monitoring of marine litter along the German North Sea coastline has been carried out by various NGOs since 1989 for 15 beach sectors. This monitoring has been supplemented since 2002 by four OSPAR beach sites managed by the Lower Saxony Department for Water, Coastal and Nature Conservation (OSPAR, 2010).

However, although the pathways of litter into the marine environment are generally known, there is still a knowledge gap concerning the identification of plastic pieces which could function as indicators for responsible polluters; knowledge of the sources of the litter is important to tackle the marine litter problem (Ryan et al. 2009, Nilsen et al. 2014). Besides the sources and pathways of marine litter entering the marine environment, it is crucial to understand the spatial and temporal patterns of beached anthropogenic litter in order to introduce suitable mitigation and abatement strategies for the future (Browne et al., 2015). To investigate the sources and distribution of macroplastic litter (> 5mm) in the southern North Sea region, we combine interdisciplinary collaborations in our research project, including the public. Because marine litter is a human-made environmental threat, public support is needed to solve the problem (Cigliano et al., 2015).

2 Overall Objectives of the Research Project

With an interdisciplinary consortium of physical oceanographers, physicists, geologists, biologists and environmental scientists, the project aims to investigate the pathways and hotspots of macroplastics along the shorelines of north-west Germany. The sources and those responsible for the plastics pollution and litter need to be identified. Here, we present high-resolution numerical models, coastal observation data for recording hydrodynamic patterns (e.g. waves, currents), as well as the results of the survey conducted by citizen participation. To find sources and clusters of marine litter, we combine modelled data for ocean currents and waves, as well as data about the weather and recordings of wooden drifters done by citizen engagement. Wooden drifters therefore have a branded ID and bear a request to report the drifter's location if found or sighted. The drifters were released at specific locations in the study area. In all, the results should help to collaboratively develop mitigation strategies, involving stakeholders and citizens in examining behavioural patterns with regard to plastics pollution.

As one of the participating working groups, we have three main objectives within the research project:

(1) the development of additional functionalities of the GeoCMS HotSpot (Aden, 2012; Aden & Kirchner, 2016), due to several new requirements regarding the system functionality. The GeoCMS is used for the administration of the survey. Developed for specialized envi-

ronmental monitoring programmes for use by nature conservation organizations, the system now allows anonymous citizen involvement, through specific data control mechanisms.

(2) to raise awareness about the impact of macroplastics in the oceans by participating at marine events across the coast of Lower Saxony.

(3) a GIS-based heatmap analysis of reported data to obtain an overview of potential locations where specific sorts of litter might also be observed during the period of the study.

Integrative statistical and geo-statistical methods will be used for analysis about pathways and clusters of reported drifters. The results of our part of the study later will be compared with results of numerical models which are carried out by other involved working groups regarding the behaviour of waves and currents and their influence on the drift of litter in the North Sea.

3 Methods for Citizen Involvement

Study Site

The study is focused on the German part of the southern North Sea area; it is conducted at a regional level in the coastal area of Lower Saxony, expanding to the river systems from the Ems to the Elbe, and the open German Bight system, including its waterways, from the English Channel to the northern North Sea. To investigate the macroplastics input from the river systems, data collection is extended to Papenburg, Bremen and Hamburg. According to Vauk & Schrey (1987) and Schulz et al. (2015), submerged and floating items are transported mainly from the Channel along the southern coast of England, eastward to the German Bight, due to the counterclockwise residual tidal currents and westerly winds. Many different economic activities, including shipping, offshore wind farms and fishing, are pursued in the North Sea. The coastal sites and waters of the North Sea are extensively used for tourism, sports and leisure activities. Because of gas and oil production at sea as well as agricultural and industrial businesses close to river catchments, there are further environmental pollution problems (Neumann et al., 2014).

Public Participation

To involve the general public in our research approaches, we used Volunteered Geographic Information (VGI) (Goodchild, 2007) to produce spatial information. VGI is a result of many contributions from people driven by different motivations and objectives. It can be obtained spontaneously or on a regular basis (Elwood et al. 2013). A distinct environmental awareness can be a driver for participation (Kuckartz & Rheingans-Heintze, 2006), as can the techniques and web-based tools available for environmental monitoring and participation (Maué & Ortmann, 2009). Using web-based and mobile techniques ensures the potential for reports from a wide spatial extent (Johnson & Sieber 2013). Reviewing and controlling VGI for quality issues such as the accuracy and correctness of coordinates, textual elements and measurements are required. Often, the data are not comparable with data collected by experts and professionals (Flanagin et al., 2008; Feick & Roche, 2013; Elwood et al., 2013).

To encourage citizen involvement, a collaborative working group produced degradable wooden drifters, which were released into the North Sea at more than 20 locations within the study area (see Figures 1 and 2). The drifters are made of pine wood, measuring approximately 10 cm x 12 cm; half of the drifters are 2 cm thick, and the others are 4 cm thick. As well as a branded massage in English and German informing the finder about whom the drifter belongs to and what to do with it, all drifters have an individual identification number. The ID corresponds to a release site and should be reported. So far, the collaborative working group has released 14,500 drifters, since October 2016.

Figure 1: Wooden drifter with unique ID

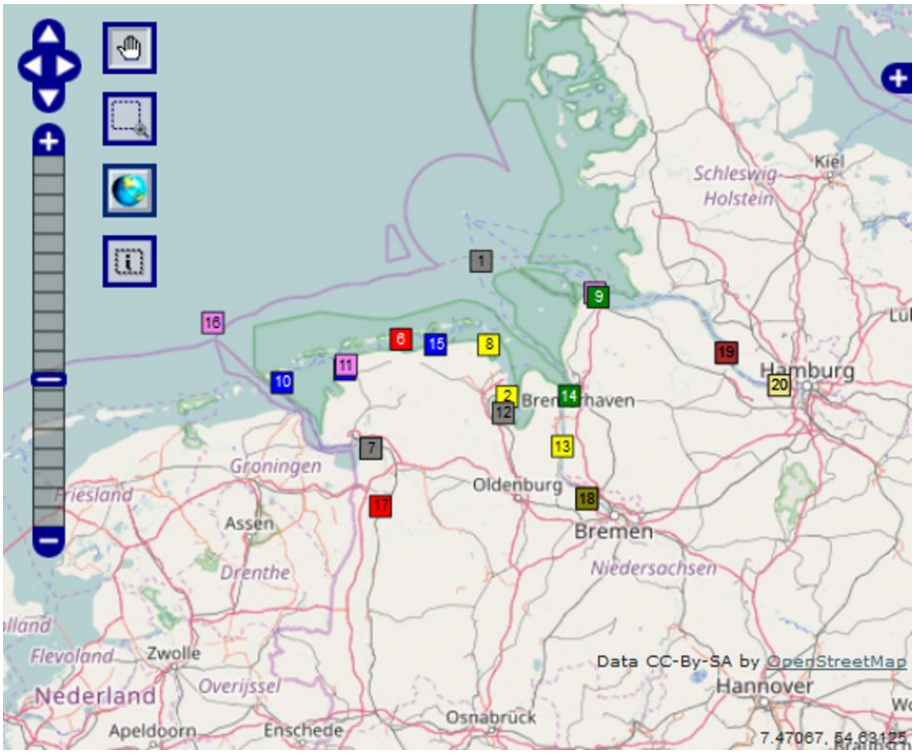


Figure 2: Release locations along the coastline and rivers

Over the next three years, approximately 100,000 drifters will be released. This is the stage of the project where help from the general public will be required, to report locations where drifters have been washed ashore. Our project homepage (http://macroplastics.de) provides more information. Specific modules of the GeoCMS HotSpot that are currently in use are described in the next section of the paper.

People who have a deeper interest in beach findings can also download the BeachExplorer app. The app is available for different operating systems and allows the identification and reporting of sightings on the beach (http://www.beachexplorer.org). For the lifespan of the research project, the wooden drifter has been included as a possible observation which can be reported via the BeachExplorer web portal. These sightings are added on a regular basis to the main database of the drifter findings.

4 Integration of the GeoCMS HotSpot

The GeoCMS HotSpot is a web-based system which provides tools for the management of spatial data on the web. It was designed as a framework for the administration of web-based surveys, and for the provision of spatial data derived from any environmental monitoring programme in scientific and non-governmental organized projects. The system includes data

control mechanisms for user-generated spatial data and methods for provision of the data (Aden, 2012; Aden & Kirchner, 2016). The main development of the system was to provide a functionality allowing the production of services in line with the standards of the Open Geospatial Consortium (OGC).

In particular, tools for the management of Web Map Services (WMS) and Web Processing Services (WPS) were developed, as were others for ensuring conformity to specific spatial data themes of the European directive 2007/2/EC. Additional PostGIS-based analysis tools as well as the availability of descriptive statistics for reported spatial and measurement data were developed. Another requirement was to ensure simplicity in the use of the tools for people without knowledge of technical environments and programming languages, SQL-based database queries, or the implementation of specific Open Source software as mapservers, spatial database management systems (DBMS), map clients or other software libraries.

The most effective way to implement the required functionalities into a GeoCMS was to design a modularized architecture based on the Open Source software 'CMS made simple' (CMSms). The content management system was originally a software product for the production and provision of web pages and digital media. It is still under further development by a large number of developers who provide specific modules for the administration of forums, or page content such as pictures, among many other things. The basis of the CMS was developed using Hypertext Preprocessor (PHP). Additional languages like JavaScript and Asynchronous JavaScript and XML (Ajax) are used for dynamic functionality and the integration of external software libraries. The development of additional modules and their integration are based on a standardized procedure. The modules can be used independently of each other and can be installed and removed using integrated routines. The advantages of using an existing CMS relate to questions of security and the quality of the source code. A further advantage is the possibility of combining simple web pages and their content (e.g. project description, research topics) with modules for handling spatial data by using interfaces of the software.

The platform for the system is a Linux-based web server, which is located at the computing centre of the Carl von Ossietzky University in Oldenburg. This allows us to complete the system by installing additional software and important libraries as desired, such as GDAL/OGR, proj4, pyWPS, the DBMS PostgreSQL/PostGIS or the UMN MapServer, as well as different map clients (Mapbender, OpenLayers, Leaflet), R for statistics, and GRASS GIS (see Figure 3). Additional modules were developed and added to the base, allowing

- upload and download of spatial data from the underlying DBMS PostgreSQL/PostGIS in common data formats (Shapefile, GML, GPX, GeoTiff), as well as the manipulation of vector-based data (*HotSpot Spatial Data Management*),
- the production of Mapfiles for the provision of WMS via the UMN MapServer (*HotSpot Mapfile Editor*),
- GIS analysis such as intersections, attribute-based data selections, buffering and clipping of vector-based data (*HotSpot GIS Analysis*),
- the calculation and provision of descriptive statistics as bar charts, pie charts and others via the PHP-based software JPGraph (*HotSpot Statistics*),

- the use of specific WPS implemented with python scripts via pyWPS on the server (e.g. ordinary kriging, idw, species distribution modelling, GIS analysis), which make use of R for statistics, and GRASS GIS (*HotSpot WPS Manager*),
- the provision of web maps in web pages, based on spatial data in the form of Geography Markup Language (GML), GeoJson or WMS via OpenLayers (*HotSpot OpenLayers*),
- the production of web-based survey tools which provide forms and maps for reporting drifter or other sightings which can then be included in other web pages or used as an app on any smartphone, tablet or PC (*HotSpot Survey*),
- the integration of citizen science based data about species distributions into the data scheme designed for the relevant spatial data theme of INSPIRE (*HotSpot GoINSPIRED*).

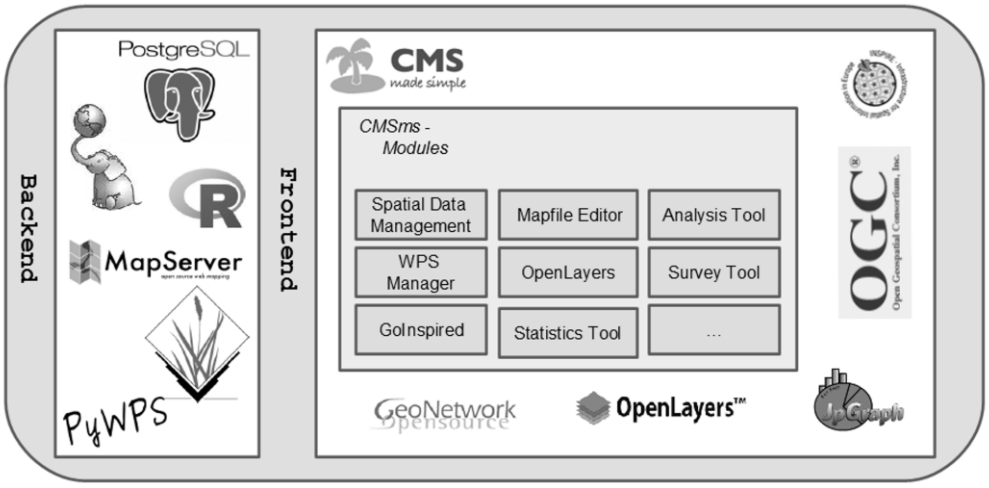


Figure 3: Software and modules of GeoCMS HotSpot

Survey Portal

The web portal provides information on the research background together with a call for participation. A blog presents specific activities of the researchers working on the project, including PhD students, and can be accessed via http://www.macroplastics.de. A manual explains how to report observed drifters. If participants have a deeper interest in the project, they can register their e-mail address to receive monthly information.

The most important web page for reporting is automatically provided by the GeoCMS after preparing a questionnaire using the *HotSpot Survey* module. This is done very simply (see Figure 4).

First, a survey project and questionnaire have to be named and saved. Administrators are then allowed to define attributes or questions and optional information, for example regarding units used for measurements. They have to decide whether an answer should be numeri-

cal (integer, float ID) or text-based, and the maximum number of characters. The type of form field which will be created for the questionnaire has to be selected (e.g. list, radio buttons, checkboxes, text area); the order of the attributes or questions within the questionnaire can still be changed. Code lists or possible answers can be included for each question by inserting them manually or by direct database access. Later, these codes or answers can be selected from a list when the web-based questionnaire is finally provided. The system automatically prepares fields inside the questionnaire for the coordinates to report a sighting and for the date of the sighting. For each report, the timestamp and the user's identification are saved.

A polygon dataset can additionally be selected to verify the reported locations for the observed phenomenon (e.g. the North Sea area).

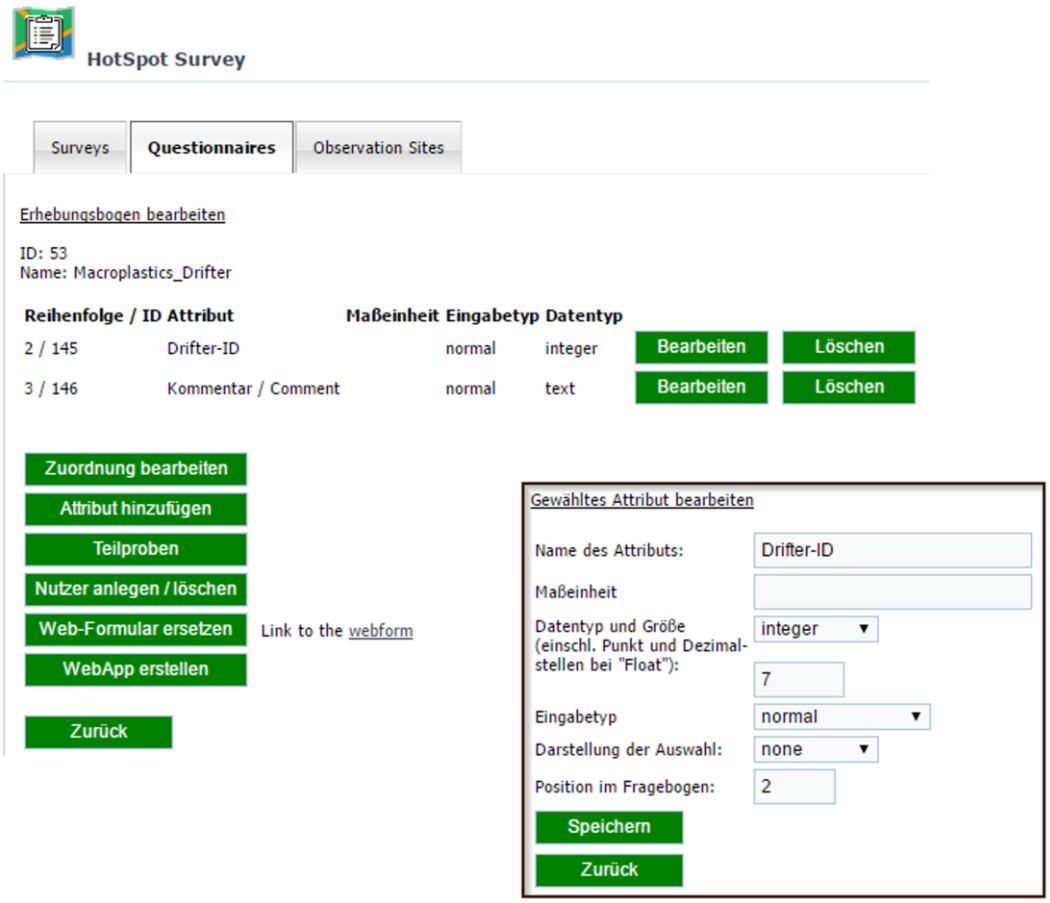


Figure 4: Preparation of a questionnaire with settings for attributes and input methods (black frame)

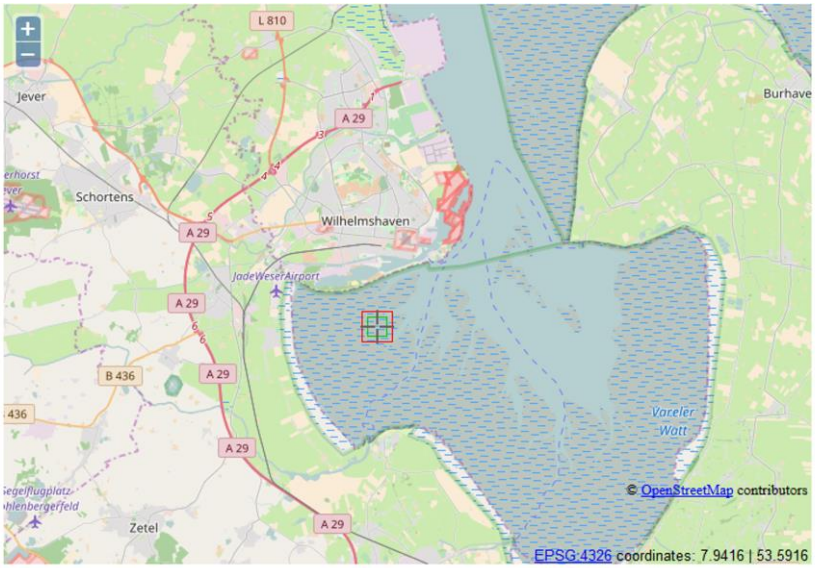
After the tasks for creating a questionnaire have been completed, a new table is created which allows the storage of incoming reports. A hyperlink which leads to the web-based questionnaire is then created and visualized. Additionally, an app can be produced and downloaded via a second hyperlink. The app could be supplemented with additional functionality by using SDKs for native app support.

The hyperlink for the questionnaire can be sent to people interested in data collection for the specific topic. Usernames and passwords have to be created for each of them. This is not the case for the project described in this paper, for which just one anonymous user was created. The respective access information is supplemented to the hyperlink, which leads directly to the questionnaire.

Reporting Drifter Sightings

For the reporting of sightings, the questionnaire provides a form and a map based on OpenLayers and OpenStreetMap, together with tools for zooming and panning. Marking the location of a sighting is done simply, by placing a crosshair symbol on the map (see Figure 5).

The coordinates (long./lat.; WGS84) are visible in the form but can also be inserted manually, while the date of the sighting can be selected via a so-called 'date picker'. The requested attribute (the observed drifter ID) and an optional comment can be keyed into the appropriate fields in the form elements. Logged users with individual usernames and passwords have access to additional tools to edit and download their contributions, and can respond to specific data requests (e.g. time range, species); they are also able to communicate more widely via a social media tool.



Attribut / Attribute	Wert / Value	Maßeinheit / Measuring Unit
Datum / Date:	08-06-2017 09:33 (Observation Date)	
Longitude:	8.113297 (WGS84, e.g. 8.1234)	
Latitude:	53.489134 (WGS84, e.g. 54.1234)	
Drifter-ID:	11486	
Kommentar / Comment:	Found the drifter one day after a storm event together with litter and wood.	
	Speichern / Save	

Figure 5: The web-based questionnaire for the research project

To ensure data quality, a polygon covering the whole North Sea was digitized. Some parts of the Baltic Sea as well as parts of the coastal zone of the riparian states, including an onshore buffer of about 200 to 300 metres are included. This prevents reports of locations where wooden drifters could not be found naturally, given the time it takes for them to float through the North Sea, or that are too far inland.

The second control method is based on the ID. The wooden drifters are numbered consecutively, and so the reported ID can be checked against the IDs of floaters already released or already reported. The ID, coordinates and date recorded in the form fields are verified by cross-checking them with the data types defined while preparing the questionnaire using the *HotSpot Survey* module.

A third control deletes double reports, which might be created if the contribution is saved two or more times in a short space of time. They can be detected by the timestamp value. An additional visual control has to be carried out for reported drifter locations which are far away from those where other drifters of the same specific release have been detected in significant numbers. This check is carried out by a student assistant.

Specific control mechanisms based on additional information like periods of time (e.g. seasonal occurrences of species) or spatial extents (e.g. well-known areas for species occurrences), modelling via WPS (e.g. habitat modelling), and crowd-based evaluations or expert reviews are available in the system but are not useful in this case study. A WPS which allows the modelling of the drifters' pathways would be useful to compare with reported locations of drifters, but it is quite processor-intensive. Designing such a WPS is work-in-progress for one of the working groups collaborating on the project.

5 Drifter Reports and Data Quality

Since the project has been running for just one year now, the first results can be considered very successful in terms of citizens contributing information about drifter sightings, as well as about litter on the shoreline. In all, 6,922 drifter sightings were reported in the period mid-October 2016 to mid-June 2017 (see Figure 6). 137 of the sightings were exported from the BeachExplorer database and integrated into the database of the GeoCMS. After performing quality control and manual controls, we are left with 6,847 mistake-free reports. 5,036 unique IDs were reported, which is more than a third of the drifters released. 1,006 drifters were reported more than once, 660 of them on different days at different locations; many other multiple sightings of the same drifters were reported on the same day, with an offset in time; a lot of drifters were reported repeatedly over a very short period of time, perhaps caused by saving the data more than once.

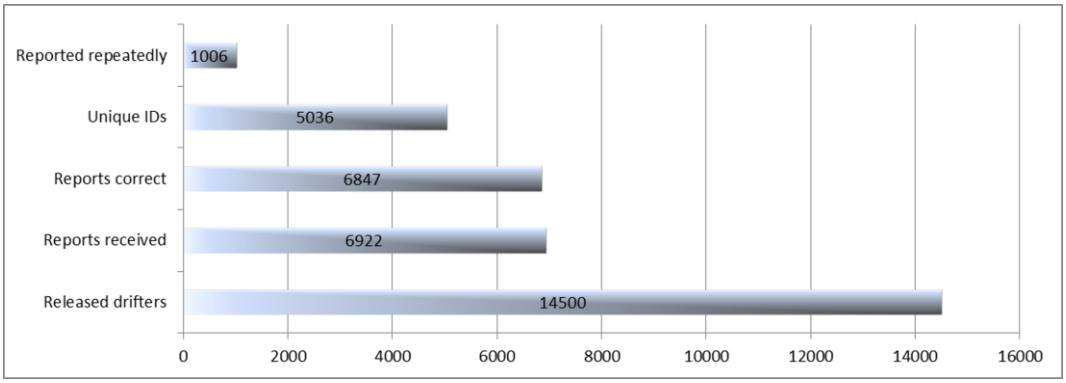


Figure 6: Overview for the number of drifters released, the unique IDs reported, the number of correct reports, and the number of repeatedly reported IDs

Sightings were reported from the West-Frisian region of the Netherlands up to north-west Denmark near Hirtzhals, covering the whole shoreline between these areas as well as the islands. Maps of release positions and corresponding sightings are provided (see Figure 7). The data are visualized using specific colours for the different releases and corresponding sightings. Reported information can be requested via the map. Additional layers were implemented to enable the clustering of sightings (see Figure 8), using the animated cluster strategy of OpenLayers.

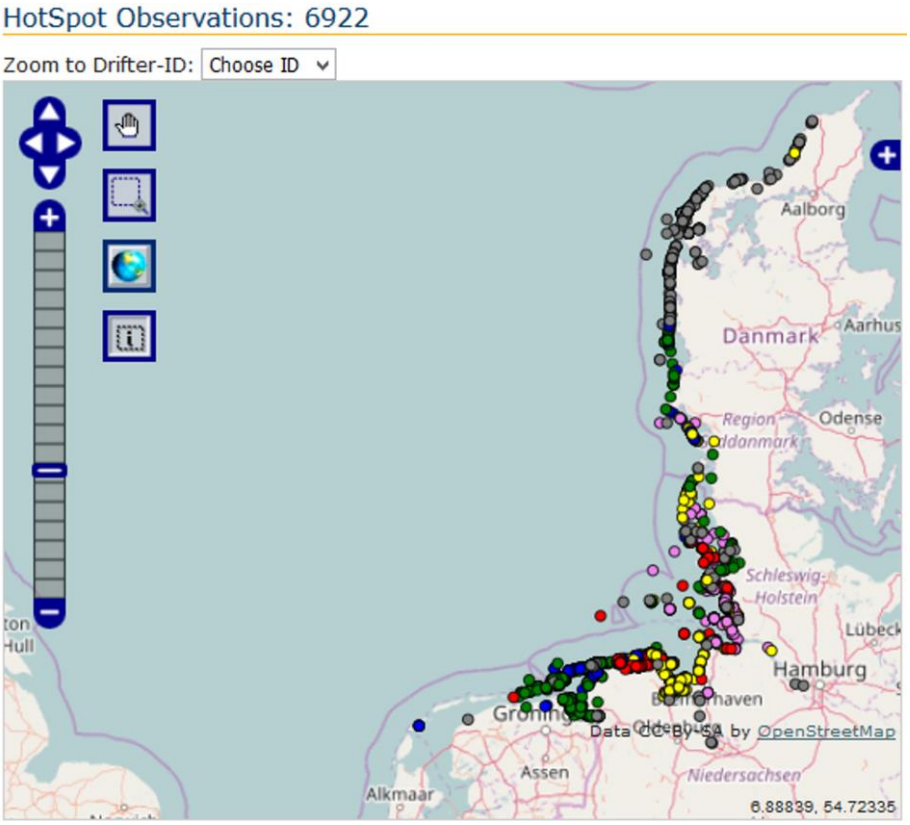


Figure 7: Reported drifters from the first campaign with six release sites

Most of the drifters were observed between the cities of Emden and Leer in the eastern Frisian region and the southern west-coast of Schleswig Holstein.

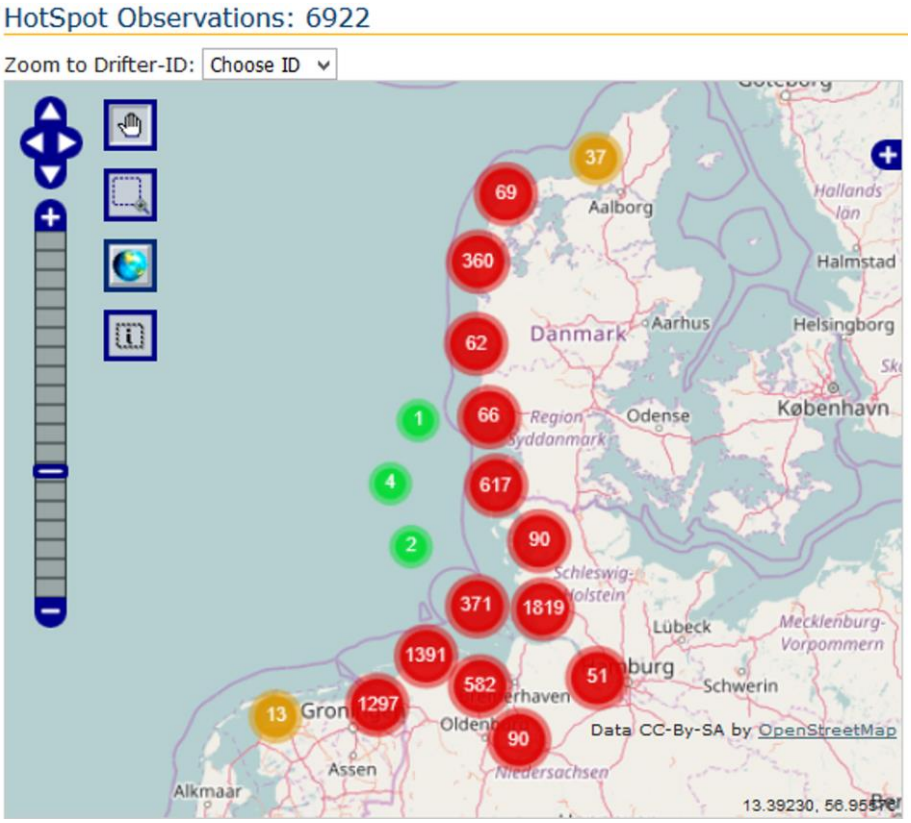


Figure 8: Cluster map visualizing the number of reports based on the zoom factor

A dynamically produced list including information about release sites and dates, the drifter IDs, and the number as well as the percentage of reported IDs per release is provided on the web page (see Figure 9).

Release	Date	Site	Drifter-ID range	No. of reported IDs	... in percent
1	05.10.2016	Offshore (near Helgoland)	1 - 800	376	47.06 %
2	11.10.2016	Wilhelmshaven	801 - 1600	440	55.07 %
3	13.10.2016	Emssperrwerk, Gandersum	1601 - 2400	487	60.95 %
4	18.10.2016	Norddeich	2401 - 3200	419	52.44 %
5	26.10.2016	Kugelbake, Cuxhaven	3201 - 4000	324	40.55 %
6	27.10.2016	Langeoog	4001 - 4800	293	36.67 %
7	21.02.2017	Emssperrwerk	5201 - 6000	125	15.64 %
8	22.02.2017	Schillig	6001 - 6800	423	52.94 %
9	23.02.2017	Cuxhaven	6801 - 7600	61	7.63 %
10	24.02.2017	Borkum	7601 - 8400	357	44.68 %
11	27.02.2017	Norddeich-Mole	8401 - 9200	480	60.08 %
12	06.03.2017	Dangast	9201 - 10000	221	27.66 %
13	07.03.2017	Brake	10001 - 10800	98	12.27 %
14	09.03.2017	Nordenham	10801 - 11600	141	17.65 %
15	10.03.2017	Neuharlingersiel	11601 - 12400	361	45.18 %
16	13.03.2017	Offshore (near Borkum)	12401 - 13200	375	46.93 %
17	18.03.2017	Papenburg	13201 - 14000	8	1 %
18	21.03.2017	Niederbüren	14001 - 14050	10	20.41 %
18	21.03.2017	Niederbüren	14401 - 14450	5	10.2 %
19	22.03.2017	Stade	14051 - 14100	1	2.04 %
19	22.03.2017	Stade	14451 - 14500	2	4.08 %
20	22.03.3017	Hamburg	14101 - 14150	13	26.53 %
20	22.03.3017	Hamburg	14501 - 14550	14	28.57 %

Figure 9: List of release sites, ID of the releases, and reported IDs per release

The current list shows that for five releases more than 50% of the IDs were reported back. Another five releases have returns for more than 40% of the IDs. Figure 10 shows some statistics for the number of reports per month (using the JS-based library JSXGraph).

Number of reported observations without faults:	6847
Number of unique IDs:	5036
Number of repeatedly reported IDs:	1006
Longest linear distance between release site and observation (WGS84 spheroid-based calculation):	approx. 436.61 km Drifter-ID: 1333 Release: 2

Figure 10: Number of reports per month since October 2016

The high number of reports we received ensures a high quality of information. Only a small proportion of the reports had to be deleted because of mistakes or for other reasons. Four drifters were observed in the Baltic Sea. Two of them were reported near to the west of the city of Rostock, and the others on the shoreline of the isle of Rügen. Because of weather conditions and the known current patterns, as well as the fact that we did not receive any reports from the east coast or islands of Denmark, we assume that these drifters were removed altogether by the people who observed them in the west of Denmark where they were reported first.

Several locations were edited using information included in the comments. Those mistakes were mainly due to the wrong zoom level being used for digitizing the location. After comparing the IDs of drifters which were reported far away from correctly reported drifters belonging to the same release batch, we had to delete 16 reported drifter sightings because of missing information.

6 Discussion and Further Work

The GeoCMS HotSpot enables actors and citizens to record their sightings of wooden drifters. The numbers of sightings reported and comments were very encouraging, showing that the general public is active in tackling the marine litter problem. This also indicates that people are increasingly aware of marine litter pollution.

The dataset extracted from the reports shows that the more people are involved, the better the quality of the data. As already shown by the results of the quality control, public participation can help facilitate scientific research. Research campaigns and results of analysis can help to influence management and policy, improving administration departments, and encouraging entire communities to address environmental issues (Bonney et al., 2014; Danielsen et al., 2014).

One reason for the high quality of reported data and the numbers of citizens motivated to participate is that the tools offered were easy to use. Only four negative comments were received about the difficulties of making a report. Many other comments expressed appreciation, but also highlighted the need for more research and strategies for dealing with litter in the oceans. 164 people registered to receive a regular newsletter for further information on upcoming releases and the methods used for data analysis.

The development of tools and modules for the GeoCMS HotSpot is an ongoing process. Future implementations will include a procedure for photographs. Other functionalities are the implementation of an OGC-based Sensor Observation Service, which will provide real-time data from GPS-based drifters that will be released together with other drifters in the shipping lanes near the German Bight. This will also help to increase the quality of reported sightings.

Although we have received positive feedback from participants, we need to work on a procedure for reports which will allow non-digital natives to make their contributions.

Acknowledgements

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We would like to take this opportunity to thank all the people who participated in the campaign and provided us with valuable data and information on the pollution of the seas and coast.

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