The Guidelines for Harmonizing Marine Litter Monitoring Methods Using Remote Sensing Technologies

Ministry of the Environment, JAPAN

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The Guidelines for Harmonizing Marine Litter Monitoring Methods Using Remote Sensing Technologies

Member of International Expert Meeting on Marine Litter Monitoring Methods by Using the Remote Sensing Technologies:

ISOBE Atsuhiko[1], ALIANI Stefano[2], ANDRIOLO Umberto[3,4], DIERSSEN Heidi[5], GAMA MONTEIRO João[6,7], GONÇALVES Gil[3,4], HIDAKA Mitsuko[8,9], KAKO Shin'ichiro[8], KATAOKA Tomoya[10], MARTINEZ-VICENTE Victor[11], MATSUOKA Daisuke[8,9], MISHRA Pravakar[12], STREETT Davida[13], TAKAHASHI Yukihiro[14], TOPOUZELIS Konstantinos[15], VAN EMMERIK Tim H.M[16]

[1]Kyushu University, Japan
[2]National Research Council of Italy, Italy
[3]University of Coimbra, Portugal
[4]Institute for Systems Engineering and Computers at Coimbra, University of Coimbra, Portugal
[5]University of Connecticut, USA
[6]University of Madeira, Portugal
[7]Marine and Environmental Research Centre, Portugal
[8]Kagoshima University, Japan
[9]Japan Agency for Marine-Earth Science and Technology, Japan
[10]Ehime University, Japan
[11]Plymouth Marine Laboratory, United Kingdom
[12]National Centre for Coastal Research, India
[13]National Oceanic and Atmospheric Administration, USA
[14]Hokkaido University, Japan
[15]University of the Aegean, Greece
[16]Wageningen University, Netherlands

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For copies of this document, please contact:

Office of Policies against Marine Plastics Pollution, Marine Environment Division,
Environmental Management Bureau, Ministry of the Environment, JAPAN
Kasumigaseki 1-2-2, Chiyoda-ku, Tokyo 100-8975, Japan

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Experts and companies with experience in UAV litter surveys that cooperated in the inquiry survey conducted in the preparation of Annex Section I. Plan, preparation, and implementation of monitoring surveys for each remote sensing technology 1.1. Beach litter monitoring survey using UAV

ALIANI Stefano[1], ALMEIDA Sílvia[2], ANDRIOLO Umberto[3,4], CHIRAYATH Ved[5], GAMA MONTEIRO João[2,6], GONÇALVES Gil [3,4], KAKO Shinichiro[7], KOZUKA Akira[8], MATA Aser[9], MERLINO Silvia[1], MISHRA Pravakar[10], PATERNI Marco[1], TOPOUZELIS Konstantinos[11], VAN EMMERIK Tim[12], WAKAIZUMI Takuma[13], ÁLVAREZ Soledad[2],

[1]National Research Council of Italy, Italy
[2]Marine and Environmental Research Centre, Portugal
[3]University of Coimbra, Portugal
[4]Institute for Systems Engineering and Computers at Coimbra, University of Coimbra, Portugal
[5]University of Miami, USA
[6]University of Madeira, Portugal
[7]Kagoshima University, Japan
[8]Northwest Pacific Region Environmental Cooperation Center, Japan
[9]Plymouth marine Laboratory, United Kingdom
[10]National Centre for Coastal Research, India
[11]University of the Aegean, Greece
[12]Wageningen University, Netherlands
[13]Asia air survey co., LTD, Japan

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Chapter I Introduction

1.1 Background

There is a growing international interest in addressing marine litter, including plastics, and discussions are underway at the Intergovernmental Negotiating Committee (INC) on the creation of an international legally binding instrument to end plastic pollution. Under these circumstances, the need for monitoring is emphasized as a means of establishing scientific knowledge to serve as a basis for planning and assessing countermeasures, and the establishment of research/monitoring methods that enable continuous and efficient monitoring over wide areas is essential. Therefore, in order to further improve the comprehensiveness and efficiency of marine litter monitoring, we have developed new international guidelines for marine litter monitoring and image analysis methods using remote sensing technology. Such technology has been increasingly studied in recent years, and relevant knowledge and experience are being accumulated (see Table 1).

Table 1. Number of major studies on marine litter monitoring using remote sensing technology.

Fields	Data acquisition methods (Remote sensing)							Image analysis methods			
	Platform							Manual (Visual)	Automatic		
	Stationary camera	UAV[*1]	Balloon	Aircraft	Satellite	Vessel	Others		Object detection by bounding box	Semantic segmentation	Others
	Sensor										
	RGB	RGB	RGB	multispectral/hyperspectral, LIDAR	Multispectral/hyperspectral	RGB, LIDAR					
Beach (Dune)[*2]	2	13 (6)	2	1				5 (2)	5 (1)	5 (3)	9 (2)
Sea surface			1	1				1			1
Sea water column											
Sea floor[*3]											
Estuary											
Riverbank/lake beach	1	1						1	1		1
River surface	1	4					1	3			4
River water column							2				2
River floor[*3]											
Land											

Notes:

The numbers above are the number of papers listed as references in Kako et al. (2024) . The numbers in this table are subject to change after the review paper is published.

*1 UAV: Uncrewed Aerial Vehicle

*2 In the guidelines, the term “beach” not only refers to the area of the shoreline covered with sand or pebbles, but also includes dunes and vegetation such as mangroves. The numbers in parentheses are the number of literatures that cover dunes in the measurement area.

*3 At the current technical level, feasibility of measuring litter on the “sea floor” and “river floor” using remote sensing technologies is limited.

1.2 Structure of the guidelines

These guidelines consist of 3 parts: the main body, the Annex and the Appendix. The main body provides a general overview of the measurement methods of marine litter using multiple remote sensing technologies. The detailed methodology for each remote sensing technology in the Annex, and the Appendix presents the results of a demonstration test conducted to ensure the practicality of the methodology in the Annex.

1.3 Definitions and terminology

The terms used in the guidelines are defined as follows.

(i) Remote sensing

Remote sensing technologies are used to gather and process information about an object without direct physical contact (ASPRES 2024).
The guidelines cover remote sensing methods using the following platforms. It should be noted that the methods to be covered may change in the future.

- Stationary camera (a camera installed in the environment, e.g., installed on a shoreline with scaffolding, fixed on a bridge, to acquire time-series image data at the same location.)
- Uncrewed Aerial Vehicle (UAV)
- Aircraft
- Satellite
- Vessel

For reference, Table 2-1~Table 2-5 show v of each platform.

(ii) Image processing and analysis

The data obtained by remote sensing is processed to certain images, and then the type or amount of litter can be automatically detected by image analysis methods. Relevant terms in the guidelines are defined as follows:

- **Image processing**
  Means processing captured images taken by remote sensing methods into forms that allow litter detection. It includes color correction, noise reduction, orthorectification, and composite processing with other images (such as orthomosaiccking).

- **Orthoimage**
  Mean aerial images taken by remote sensing methods, which have been corrected for the shooting position, lens distortion, and shooting direction to align the image with ground coordinates. Unlike uncorrected aerial images, orthorectified images can accurately represent the true distance to the Earth's surface.

- **Orthomosaic**
  Mean created images by mosaicking multiple overlapping orthoimages and ensuring that the brightness and color values are consistent across the entire area.

- **Image analysis**
  Means extracting litter information from processed images, such as identifying the types, quantities, or numbers of litter items.
  In recent times, machine learning and deep learning-based image processing techniques for plastic litter quantification have emerged. These methodologies utilize large datasets to develop models capable of detecting complex features—such as colors and shapes—in images, allowing for more flexible litter detection (Kako et al. 2024). Such image analysis methods include "object detection by bounding box" and "semantic segmentation", both of which are briefly described in Figure 1. The term "image analysis" also includes manual litter detection from images.

(iii) Survey and monitoring

In the guidelines, "survey" is defined as the measurement conducted to provide a snapshot of environmental conditions at the time. On the other hand, "monitoring" is defined as the repeated measurement of a characteristic of the environment, or of a process, to detect a trend in space or time (GESAMP 2019).

(iv) Litter

The monitoring targets addressed in the guidelines are litter in the environment (including marine litter).

- **Litter in the environment**

  Includes mismanaged waste (e.g., waste open-burned and dumped in uncontrolled dumpsites), macro plastic litter that will fragment into microplastics in the environment, and leakage and accumulation of other objects that can adversely affect humans and the living and non-living environment.

- **Marine litter**

  Litter in the environment that is persistent, manufactured, or processed solid material that is directly or indirectly discarded, disposed, or abandoned into the open ocean, coastal, or inland aquatic environment (UNEP 1995).

Table 2-1. A monitoring example: stationary camera

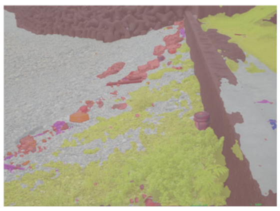
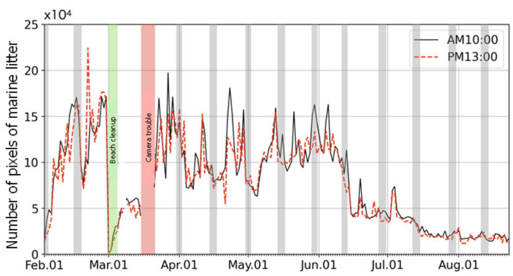
Case	Kagoshima University "Research Chair of Plastic Litter Monitoring System from the City, Sea, and Space" Website. https://www.oce.kagoshima-u.ac.jp/~kako/mpl/analysis/test/ (accessed 2024-6-30)
Survey objectives and overview	The temporal images of beach litter were taken by stationary cameras. The images were processed by the image processing method of “semantic segmentation”. Since time series litter information is obtained, it can be used to understand changes in litter over time and determine the timing of cleanup activities.
Place and Time (duration, frequency)	The beaches in Japan 26th January (2022) ~ Pictures were taken every hour between 6 a.m. and 7 p.m. daily
Area coverage	Approximate 100 m^2
Camera	HykeCame LT4G (RBG camera)
GSD (Ground sample distance)	> 1 mm
Litter information	Number of pieces, covered area, type of litter
Images	(a)  (b)  (a) An image taken by a stationary camera (b) its semantic segmentation  Time series litter data  Stationary camera

Table 2-2. A survey example: UAV

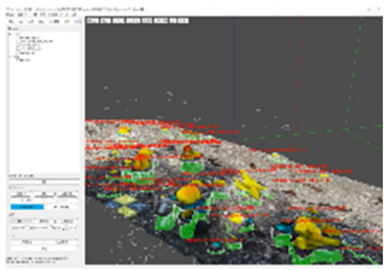
Case	Demonstration test for beach litter survey using UAVs conducted by Dr. Kako lab, JANUS Co. Ltd., Futaba Inc (The details are described in the Appendix 1).
Survey objectives and overview	To ensure the practicality of the guidelines, a demonstration test was conducted (details are described in the Appendix 1). Photographs of beach litter including driftwood were taken by UAV. The imagery data was processed for merging those images. Beach litter was detected automatically using AI developed by Dr. Kako, after which the number of pieces, area coverage, and beach litter volume were estimated.
Place and Time (duration, frequency)	The beaches in Japan A: Gravel beaches in Iyo city, Ehime: 8 a.m. (low tide), 24th July 2023 B: Uwajima city, Ehime: 9 a.m. (low tide), 27th July 2023
Area coverage	Photographing area: A: 5,180 m^2 B: 706 m^2 Survey area: A: 50 x 17.1 m B: 20 x 4.3 m (longshore x cross-shore)
Camera	DJI Zenmuse P1 (RBG camera)
GSD	5 mm/pix
Litter information	Number of pieces, covered area, volume
Images	 UAV  UAV takeoff  UAV imagery  Result of beach litter detection  Volume estimation image

Table 2-3. A survey example: aircraft

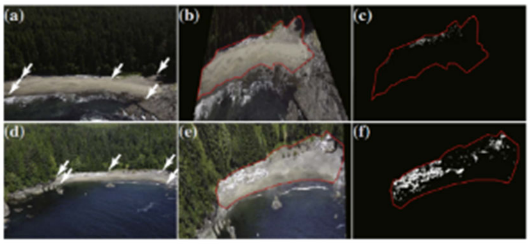
Case	Kataoka et al. (2018)
Survey objectives and overview	The photographs taken from an aircraft at oblique angles were processed for georeferencing. Thereafter, pixels of marine litter were extracted based on their color differences from the background beaches. The litter abundance can be evaluated by the ratio of an area covered by marine litter to that of the beach (coverage). The estimated coverage is useful information to determine priority sites for mitigating adverse impacts across broad areas.
Place and Time (duration, frequency)	The beaches in Canada – The west coast of Vancouver Island: October 7 and December 3, 2014 – The central coast of British Columbia and Haida Gwaii: January 30 and March 2, 2015
Area coverage	Over 1,500 km of British Columbia's coastline
Camera	Nikon D750 (RGB camera)
GSD	0.1 x 0.1 m
Litter information	Covered area
Images	 Aerial imagery Acknowledgement: Lightspeed Digital for Government of Japan/North Pacific Marine Science Organization (PICES 2015)  Image processing to (a, b, and c) Cheewat Beach, and (d, e, and f) Clo-ose Beach. (a) and (d): Original aerial photographs taken by the aerial photography. The white arrows denote the five reference points required for the projective transformation. (b) and (e): The projective transformation method was applied to the images (a) and (d). (c) and (f): The pixels of marine debris shown by the white pixels were extracted by the image processing described in the text. The red outlines in the images (b), (c), (e) and (f) denote the beach areas defined to compute the percent cover. (Kataoka et al. 2018 Fig. 2.)

Table 2-4. A survey example: satellite

Case	Themistocleous et al. (2020)
Survey objectives and overview	This is a pilot study to determine if plastic targets on the sea surface can be detected using remote sensing technologies with Sentinel-2 data. A target made up of plastic water bottles with a surface measuring 3 m x 10 m was created, which was subsequently placed on the sea surface (Themistocleous et al. 2020 Figure 3). Spectral signatures of the water and the plastic litter were obtained by Sentinel-2. By using the specific wavelength identified from the spectral signatures, the "Plastic Index" (equation) was established to identify plastic effectively.
Place and Time (duration, frequency)	The sea surface in Cyprus 15th December (2018)
Area coverage	-
Camera	SVC HR-1024 spectroradiometer (multispectral camera)
GSD	While spatial resolution of Sentinel-2 is 10 x 10 m^2, the study shows a smaller target (3 x 10 m) was able to be identified by setting the Plastic Index.
Litter information	Type of litter (plastic)
Images	 Figure 3. Divers moving target 200 meters from shoreline. Kyriacos Themistocleous. A 3 x 10 m plastic litter target (Themistocleous et al. 2020 Figure 3)  Figure 11. Plastic Index (PI) was used to identify the target, which is circled in yellow. The identified image using Sentinel-2 data Plastic Index (PI) was used to identify the target, which is circled in yellow. (Themistocleous et al. 2020 Figure 11)

Table 2-5. A survey example: vessel

Case	Papachristopoulou et al. (2020)
Survey objectives and overview	Images were obtained through a vessel-based photography survey for a total of 62 beaches, merged into seamless panoramas (photomosaics), and manually processed to quantify beach litter abundance. At four of the beaches selected detailed *in situ* litter sampling surveys were carried out to calibrate and validate the proposed vessel-based method.
Place and Time (duration, frequency)	The beaches in Greece 20 working hours (The total period of this study including *in situ* sampling was August (2017) ~ August (2018))
Area coverage	Coastline extension approx. 8.5 nautical miles (approx. 15.7 km)
Camera	Nikon D80 (RGB camera)
GSD	-
Litter information	Type, Number of items
Images	 Fig. 2. Example of photomosaic digitizing process in QGIS environment. Black points represent the BL items registered in the A-B area. White squares indicate zoomed example areas, while 1–9 numbers show samples of different identified item categories. 1: Plastic water bottle, 2: Plastic cap/lid drink, 3: Plastic cup, 4: Rope, 5: Cigarette filter, 6: Straw, 7: Float for fishing net, 8: Plastic cup and 9: Cup lid. Example of photomosaic digitizing process (Papachristopoulou et al. 2020 Fig. 2.)

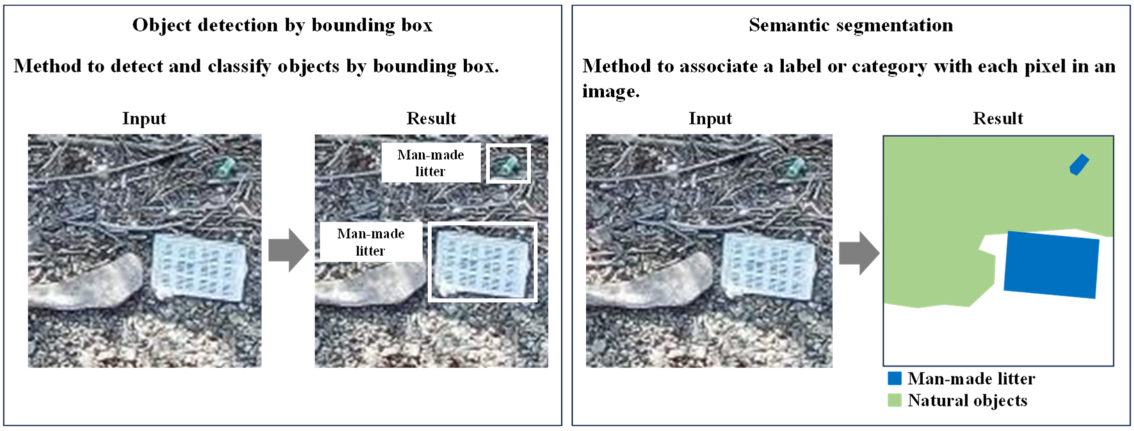


Figure 1. Description of image analysis methods.

1.4 Purpose of the guidelines

To develop and guide the comprehensive use of harmonized monitoring methods using remote sensing technologies that provide continuous and efficient monitoring over wide areas, and to contribute to understanding of the current status of marine litter internationally.

1.5 Scope of the guidelines

1.5.1 Monitoring fields, data acquisition methods, and image analysis methods

The scope of the guidelines is as follows (Figure 2, Table 3). It will be scaled up and updated based on the best available science. The guidelines are mainly aimed at utilization by academic and research institutions, private industries and NGOs, government agencies (policy makers), and citizen scientists.
Regarding marine area classification, the guidelines mainly cover coastal areas in order to avoid duplication with existing efforts on marine litter monitoring of other organizations such as The International Ocean Colour Coordinating Group (IOCCG).

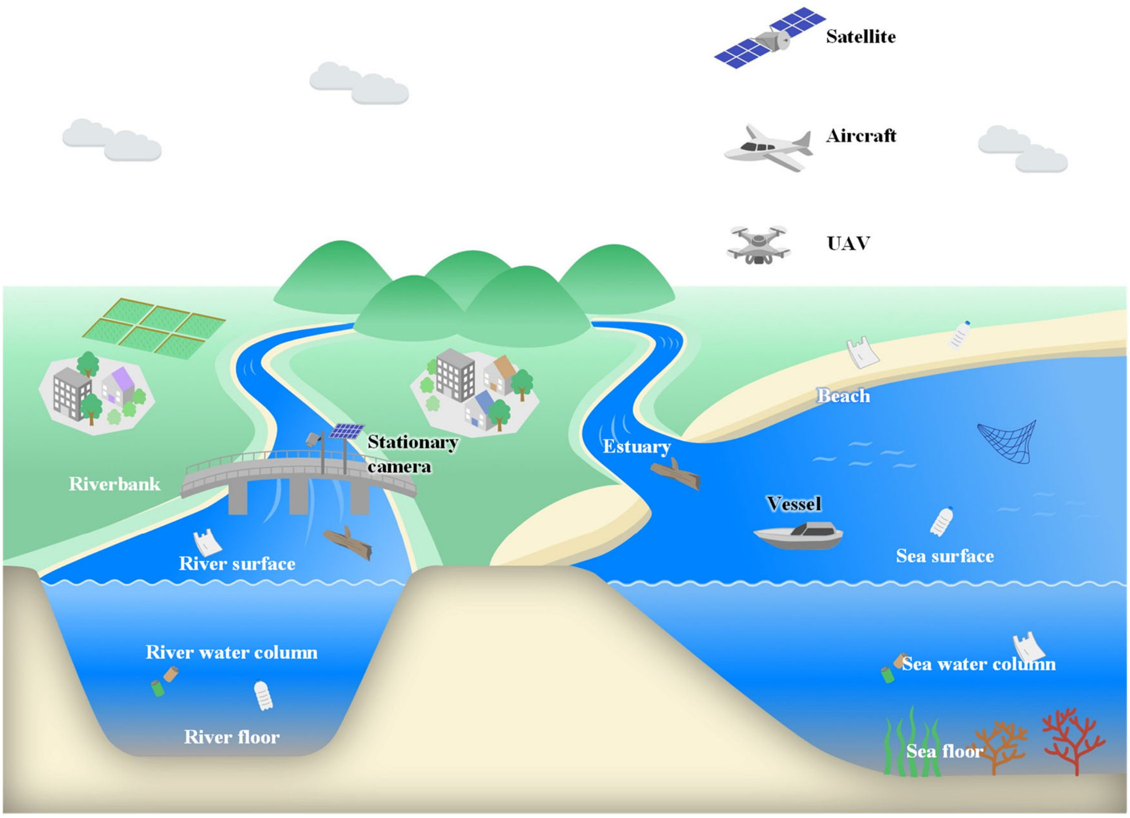


Figure 2. Diagram of the monitoring fields and the data acquisition methods.

Table 3. The scope of monitoring fields, data acquisition methods, and image analysis methods in the guidelines.

Fields	Data acquisition methods						Image analysis methods			
	Remote sensing						Manual (Visual)	Automatic		
	Platform							Object detection by bounding box	Semantic segmentation	Others
	Stationary camera	UAV	Aircraft	Satellite	Vessel	Others				
	Sensor									
	RGB	RGB	Multispectral/ hyperspectral, RGB, LIDAR	Multispectral/ hyperspectral	RGB, LIDAR					
Beach (Dune)										
Sea surface										
Sea water column										
Sea floor										
Estuary										
Riverbank/lake beach										
River surface										
River water column										
River floor										
Land										

Added in the guidelines Version 1.0
To be discussed
Being discussed by other initiatives (e.g., IOCCG Task Force on Remote Sensing of Marine Litter)

1.5.2 Targeted audiences

The following tables (Table 4-1 and Table 4-2) summarize the organizations that are mainly expected to refer to the description of each technology in the guidelines at this time. These tables are created based on the actual surveys and research on marine litter monitoring using remote sensing methods that have been conducted by organizations.

Table 4-1. Targeted audiences of the guidelines.

Organizations	Remote sensing					Image analysis methods	
	Stationary camera	UAV	Aircraft	Satellite	Vessel	Manual*1	Automatic*2
Academic and research institutions	■	■	■	■	■	■	■
Private industries and NGOs	■	■	■	■		■	■
Government agencies	■	■	■	□		□	□
Citizen scientists		□		□		□	□

■ Organizations that are mainly expected to refer to the information on the guidelines

□ Organizations that are expected to refer to the information on the guidelines to a limited extent

Notes:

Depending on the skills, resources, and the purposes of use, a wider range of users may utilize each technology.

*1 Manual : Extraction and identification of marine litter by visual inspection from images can be implemented by a wide range of users. However, location surveying techniques are required to quantitatively determine the amount of litter per unit area, thus the cooperation of academic institutions or specialized companies is generally considered necessary.

*2 Automatic : If there are user interfaces (UI) and applications that users can operate with simple adjustment of threshold values and images, the method can be used by a wide range of users. However, if UIs or existing applications are not available and specialized skills (e.g., programming or machine learning models) are required, the cooperation of academic institutions or specialized companies are generally considered necessary.

Table 4-2. The reasons why each technology targets the specific organizations mentioned in Table 4-1.

Remote sensing	**Cost** (cost for image analysis not included)	**Expertise**	**Compliance requirements** (difficulty in licensing procedures and precautions in implementation)	**Accessibility** (indicating the number of existing survey cases and the ease of obtaining platforms and services)
Stationary camera	Relatively low if the system is installed and operated.*1	Some skills are required for setup and maintenance during camera installation.	Permits and approvals are required for camera installation in some cases.	Commercially available products can be used.
UAV	Relatively high if the system is installed and operated*2	It is expected to be utilized by a wide range of users, since an autonomous flight can be easily performed by using dedicated applications. However, it is necessary to process positional information correction using surveying technology, if the device is not equipped with RTK (Real-time kinematic)*5.	Permits and approvals are required for flights in some cases.	Commercially available products can be used.
Aircraft	The cost of outsourcing each survey is high.*3	Special skills and licenses are required (generally outsourced).	Permits and approvals are required for flights (generally outsourced).	Although there are few survey cases concerning marine litter, the technology to capture images with a camera fixed to an aircraft is widely used in aerial surveys.
Satellite	There are data sources that can be utilized free of charge or for a fee of several hundreds of dollars for the smallest unit of data (it depends on the measurement range, resolution, etc.).	With regard to understanding the dynamics of litter or estimation of area coverage by litter, people without specialized skills and knowledge can utilize the data. In contrast, regarding the classification of litter, studies are being conducted mainly by academic institutions and specialized companies.	No permits or approvals are required to use data.	Some sources are easily accessible via the Internet.
Vessel	The cost is relatively low when vessels are chartered (it varies depending on the type of vessel).*4	Some skills are required to set up shooting conditions and to take pictures on board while the ship is in motion. (It is considered that in many cases, the operation of vessels is outsourced.)	Licenses and permits may be required depending on the location and size of the vessels. (It is considered that in many cases, the operation of vessels is outsourced.)	Since the number of survey cases is currently very limited and the method is not widely used, it is mainly considered to be utilized by academic institutions. However, it can be effective in environments where it is difficult to conduct aerial photography or human surveys on land (e.g., mangrove forests).

Notes:
The description above is only a guide and might vary by methods, countries, regions, or environment of survey fields.
The operation of the platforms can be outsourced depending on user skills or budgets.

*1 In typical cases in Japan, the introduction cost is about 300,000-400,000 yen ($1,900-$2,500), and the operational cost is about 50,000 yen/year ($300).

*2 In typical cases in Japan, the introduction cost is about 2,000,000-3,000,000 yen ($12,000-19,000), and the operational cost is about 200,000-300,000 yen/year ($1,200-1,900/year).

*3 In typical cases in Japan, the cost of outsourcing per flight is about 2,000,000-3,000,000 yen ($12,000-19,000).

*4 In typical cases in Japan, the cost of chartering a vessel per trip is about 10,000-50,000 yen ($100-300), and the cost of a camera is about 200,000-300,000 yen ($ 1,200-1,900).

*5 RTK is centimeter-level accuracy positioning in real-time based on GPS measurements (or more generally on GNSS (Global Navigation Satellite System) measurements) (Source: IAG (International Association of Geodesy) website).

USD = 161.07 yen (To convert yen to USD, we used the table of exchange rates for yen (TTM) on June 30, 2024. Decimal values resulting from the conversion were rounded off.)

Chapter II Purpose of monitoring and how to select the survey methods

2.1 Purpose and goals of monitoring

The major purposes of monitoring with the harmonized methodology are to utilize the monitoring results in addressing policy-related issues, including policy makings (e.g., understanding of the current status of pollution, estimation and identification of sources and hotspots), regulations (e.g., market restrictions on single-use plastics, extended producer responsibility etc.), public awareness (e.g., environmental education), beach clean-up activities, and verifications of the effectiveness of mitigation measures.

The goals of monitoring of litter in the environment are considered as follows:

- To reveal the abundance of litter
- To reveal the types of litter
- To reveal dynamics (mobilization and deposition) of litter
- To identify litter accumulation sites

2.2 How to select the monitoring methods

Figure 3-1 and 3-2 shows how to select an appropriate platform based on the survey recommendations for each purpose.
Image resolution obtained by surveys and the spatial coverage of a survey area are generally inversely proportional. It is important to select appropriate remote sensing methods depending on survey purposes.
Manual surveys are recommended in detailed litter composition analysis because of the limited ability of remote sensing methods to detect and identify objects. However, the results obtained by remote sensing methods could be used for broader purposes depending on the survey designs or combinations with other survey results.

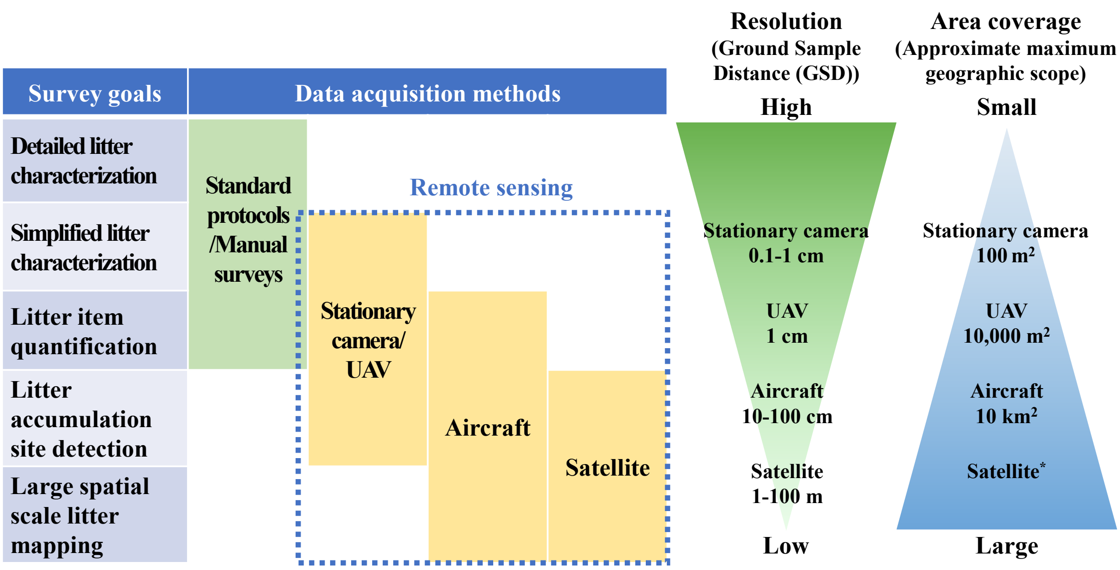
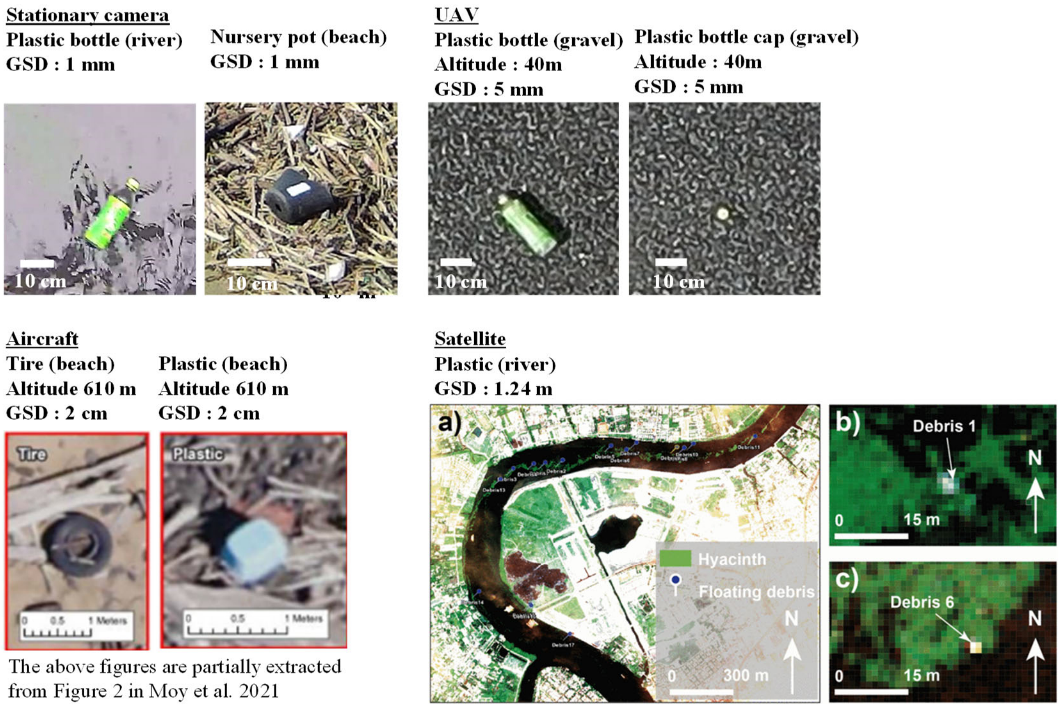


Figure 3-1. Approximate resolution, area coverage and purposes of surveys using each platform.

Notes:
Typical resolutions and area coverages for studies using each platform are shown, in orders of magnitude.
* Satellites are expected to be utilized over a narrow area, such as a specific river or coast, as well as over a larger area, such as an entire global unit.



The above figures are partially extracted from Figure 2 in Moy et al. 2021

Direct detection of floating debris in the Saigon river. a) overview of identified floating debris. b) c) zoomed-in view of two floating debris. The satellite scene is displayed in true color composite. Source: worldview-3 image from 4 March 2020. © 2020 maxar (Schreyers et.al. 2022 Fig .1)

Figure 3-2. Examples of common images produced by each platform.

In addition to the survey purposes in Figure 3-1, stationary cameras and satellites are considered to be suitable for surveying the dynamics (mobilization and deposition) of litter in the environment) because of their high frequency observations.
(For the suitable observation time interval of each platform: see Kako et al. (2024).

Regardless of the resolution, it is possible to determine the litter material composition of plastics (e.g., polyethylene, polypropylene), depending on the range of observation wavelengths of the sensors installed in each platform.

2.3 Overview of monitoring methods to meet policy-related issues.

Table 5. The examples of policy-related issues and output image

What do you want to know? *	Why do you want to know?	Methods to address policy-related issues	How to address policy-related issues
Abundance of marine litter in seas under national jurisdiction	To manage the progress of countermeasures, to understand the impact.	-	-
Type and origin of marine litter	To develop effective and efficient mitigation measures against marine plastic pollution	-	-
The effectiveness of mitigation measures		Stationary camera @river	Identify trends of increase/decrease in river runoff from land areas
Identification of accumulations	To assess the current status of plastic pollution, prioritize countermeasures, and promote efficient measures (including improving the efficiency of clean-up activities)	UAV @beach	Identify the distribution of marine plastics on major shorelines on a prefectural scale and clarify priorities for clean-up activities
		Aircraft @beach	Identify the distribution of marine plastics on all shorelines on a prefectural scale and clarify priorities for clean-up activities
		Stationary camera @beach	Identify detailed litter increase/decrease trends for specific shorelines to improve the efficiency of the limited number of clean-ups

* The left column of the table is based on GESAMP (2019).

Chapter III Monitoring methods

3.1 Technological maturity of current monitoring methods

The purpose of the guidelines is to provide a broad audience and users with information on current state of the art monitoring methods that enable them to obtain high resolution spatio-temporal information and to contribute to further current knowledge and understanding litter pollution in the environment. Therefore, detailed monitoring methods for multiple remote sensing platforms are described in the Annex in a stepwise manner, starting with those that have a high level of technological maturity and practicality.

Following recent research on technological solutions to tackle marine litter related issues a Technological Readiness Level (TRL) * assessment was used as a quantitative approach to establish technological maturity and readiness (Bellou et al. 2021).

There are nine technological readiness levels. TRL 1 is the lowest and TRL 9 is the highest. In the guidelines, the definition of TRLs for remote sensing methods for litter monitoring was set as shown in Figure 4. TRLs of the technologies were assessed based on the existing marine litter surveys and researches referred to in Kako et al. (2024) and other confirmed cases, under the definition in Figure 4 (see Table 6-1).

For image analysis technology, Table 6-2 summarizes the applications (tasks) that are commonly used at this time.

It should be noted that research in this field has been accelerating in recent years, and the maturity of the methods may change in the future.

* TRL is a type of indicator developed by NASA to assess the maturity of technologies and is commonly applied to various technical fields.

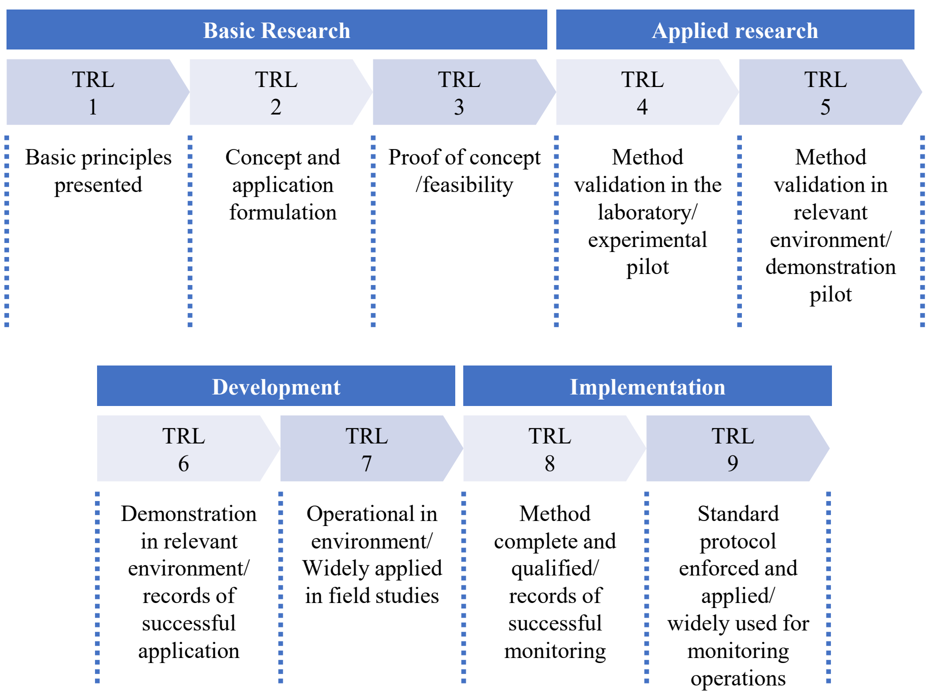


Figure 4. Description of the technological readiness level (TRL) scale on remote sensing technologies used in litter monitoring (Aliani et al. 2023).

Table 6-1. TRL of data acquisition methods.

Tasks	UAV	Stationary camera	Aircraft	Satellite
Beach, Riverbank/Lake beach/Land	8	7	7	TBD (To Be Discussed)
Sea surface/Estuary	6	N/A (Not applicable)	TBD	TBD
River surface	6	7	N/A	TBD

Notes:
TRLs were assessed based on the existing marine litter surveys and research in Kako et al. (2024) and other confirmed cases listed in the references.

Table 6-2. Correspondence table between tasks and image analysis technologies.

	Object detection by bounding box	Semantic segmentation
Evaluation of litter area (Estimation of volume and mass of litter)	N/A (Not applicable)	++*1
Counting the number of litter items	++	N/A
Classification of litter	++	+*2

Notes:
*1 Estimating area (Hidaka et al. 2022) and volume (Kako et al. 2020) requires information on the number of pixels per unit length and surveying techniques. To estimate mass, it is necessary to collect litter and determine its mass per volume on site (Kataoka et al. 2020).
*2 The classification of man-made and natural objects is accomplished, but no further detailed classification has not yet been achieved at this time (Kako et al. 2024).

3.2 Current technical difficulties and future steps

3.2.1 Remote sensing platforms

As described in Figure 3-1, the image resolution obtained by surveys and the spatial coverage of a survey area are generally inversely proportional. Remote sensing technologies can cover larger areas in less time compared to manual surveys. However, remote sensing technologies cannot classify litter in as much detail as manual surveys due to the issue of image resolution. Other typical technical difficulties of remote sensing methods and future applications based on these difficulties are shown in Table 7.

Table 7. Typical technical difficulties and future steps of remote sensing methods (Kako et al. 2024).

<table>
<tr><th></th><th>Typical technical difficulties</th><th>Future steps</th></tr>
<tr><td>Stationary camera,</td><td>Stationary camera has a limited angle of view and cannot capture an entire beach.</td><td rowspan="2">A combination of stationary cameras and UAVs is suggested, respectively, for a real-time observation to obtain the temporal variation of litter abundance, and for snapshots at specific intervals to record the spatial distributions of the abundance.</td></tr>
<tr><td>UAV</td><td>UAV observations take about half a day from the start of preparation to the completion of UAV observation, even on a beach of the order of 10,000 m^2, and that time is also required for data processing after the images are taken.</td></tr>
<tr><td>Aircraft, Satellite</td><td>Extensive systems using RGB cameras and the others for litter observation have not yet been developed to establish guidelines.</td><td>Since both platforms are very good for bulk observations over wide areas, it may be effective to consider ways of using UAV to carry out more detailed observations and evaluate the accuracy of the locations where litter tends to accumulate using the aircraft and satellite systems.</td></tr>
</table>

3.2.2 Image analysis

Machine learning and deep learning-based image processing model was developed, which utilizes large datasets and can detect complex features—such as colors and shapes—in images, allowing for more flexible litter detection. However, given the high cost associated with creating training data, it is essential to share these datasets regardless of the platform. In addition, manual methods can identify objects of all size ranges, whereas image processing methods struggle to predict relatively small or obstructed objects (Kako et al. 2024).

3.2.3 Overall monitoring using remote sensing technologies

One of the ultimate goals of quantification through monitoring would be to elucidate the flow of litter, such as the extent to which litter from land areas is discharged into the ocean via rivers. To achieve this, it is necessary to standardize the units for quantification, which is currently difficult because data obtained from various platforms differ in GSD and the information obtained (with or without altitude) (Kako et al. 2024).

Different technologies can be utilized for monitoring depending on the expertise or available resources of users (see Table 4-1 and Table 4-2). It is important to understand the characteristics, advantages, and disadvantages of each technology, and to select appropriate methods depending on their survey purposes or situations. It should be noted that the use of each technology and those who can easily access it may change as the technology develops in the future.

3.3 Future revision of the guidelines

The guidelines will be updated periodically in line with the development of remote sensing technologies. As shown in Table 3 and Table 6-1, we plan to add Annex for stationary camera, aircraft, and satellite in the future.

References

American Society for Photogrammetry and Remote Sensing (ASPRS), "What is ASPRS?", https://www.asprs.org/organization/what-is-asprs.html (accessed 2024-6-30)

Aliani S., Lusher A., Galgani F., Herzke, D., Nikiforov, V., Primpke, S., Roscher, L., da Silva, VH., Strand, J., Suaria, G., Vanavermaete, D., Verlé, K., De Witte, B., Van Bavel, B. (2023) Reproducible pipelines and readiness levels in plastic monitoring. *Nat Rev Earth Environ* 4(5), 290-291.

Bellou, N., Gambardella, C., Karantzalos, K. Monteiro, JG., Canning-Clode, J., Kemna, S., Arrieta-Giron, CA., Lemmen, C. (2021). Global assessment of innovative solutions to tackle marine litter. *Nat Sustain* 4, 516-524.

GESAMP. (2019). Guidelines for the Monitoring and Assessment of Plastic Litter in the Ocean. (P.J. Kershaw, A. Turra and F. Galgani, eds). (IMO/FAO/UNESCO IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP/ISA Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). GESAMP Rep. Stud. No. 99.

Hidaka, M., Matsuoka, D., Sugiyama, D., Murakami, K., Kako, S. (2022). Pixel-level image classification for detecting beach litter using a deep learning approach. *Mar. Pollut. Bull.* 175, 113371.

International Association of Geodesy (IAG), Commission 4: Positioning & Applications, Sub-Commission 4.5: Next Generation RTK, Working Group 4.5.1: Network RTK (2003-2007). https://www.wasoft.de/e/iagwg451/intro/introduction.html (accessed 2024-6-30)

Kagoshima University "Research Chair of Plastic Litter Monitoring System from the City, Sea, and Space" Website https://www.oce.kagoshima-u.ac.jp/~kako/mpl/analysis/test/ (accessed 2024-6-30)

Kako, S., Morita, S., Taneda, T. (2020). Estimation of plastic marine debris volumes on beaches using unmanned aerial vehicles and image processing based on deep learning. *Mar. Pollut. Bull.* 155, 111127.

Kako S., Kataoka, T., Matsuoka, D., Takahashi, Y., Hidaka, M., Aliani S., Andriolo, U., Dierssen, H., van Emmerik, T., Gonçalves, G., Martinez-Vicente, V., Mishra, P., Monteiro, JG., Streett, D., Konstantinos, T., Isobe, A. (2024). Advances in plastic litter diagnostics using remote sensing and image processing. (draft as of June 2024)

Kataoka, T., Murray, CC., Isobe, A. (2018). Quantification of marine macro-litter abundance around Vancouver Island, Canada, based on archived aerial photographs processed by projective transformation. *Marine Pollution- Bulletin.* 132, 44-51.

Kataoka, T., Nihei, Y. (2020). Quantification of floating riverine macro-debris transport using an image processing approach. *Sci Rep*. 10, 2198.

Moy, K., Neilson, B., Chung, A., Meadows, A., Castrence, M., Ambagis, S., Davidson, K. (2018). Mapping coastal marine debris using aerial imagery and spatial analysis. *Mar. Pollut. Bull.* 132, 52-59.

Papachristopoulou ,I., Filippides, A., Fakiris, E., Papatheodorou, G. (2020). Vessel-based photographic assessment of beach litter in remote coasts. A wide scale application in Saronikos Gulf, Greece. *Marine Pollution Bulletin.* 150, 110684

Schreyers, L., van Emmerik, T., Biermann, L., van der Ploeg, M. (2022). Direct and Indirect River Plastic Detection from Space. *IGARSS 2022 - 2022 IEEE International Geoscience and Remote Sensing Symposium.*

Themistocleous, K., Papousta, C., Michaelides S, Hadjimistsis D. (2020). Investigating detection of floating plastic litter from space using Sentinel-2 imagery. *Remote Sensing* 12(16) 2648.

UNEP. (1995). Global Programme of Action for the Protection of the Marine Environment from and-based Activities, United Nations Environment Programme, Nairobi.