Annex - Planning, preparation, and implementation of monitoring/survey for each remote sensing technology, and analysis and publication of survey data

CONTENTS

Section I. Plan, preparation, and implementation of monitoring/surveys for each remote sensing technology

1.1 Beach litter monitoring survey using UAV

1.1 of this Annex assumes that a variety of groups will conduct monitoring or surveys (hereinafter in this Annex referred to as "surveys") using a UAV for a variety of survey purposes to target litter in the environment, especially litter on the beach (and dunes), based on the common items listed in the main body of the guideline.

In this section, for each item, the methods mentioned in 16 references (Table 1) and in the inquiry to experts and others are organized to provide suggestions that should be recommended for standardization whenever possible.

The results of the demonstration test conducted using a survey methodology based on this Annex are presented in Appendix 1 Result of demonstration test for beach litter survey using UAVs.

Table 1. Major examples of coastal litter research using UAVs

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1.1.1 Survey planning and preparation

(1) Survey purpose

- It is important to clearly identify the survey purpose at the beginning since the survey plan depends on the survey purpose.
- See the main guideline “Chapter II Purpose of monitoring and how to select the survey methods” for examples of survey objectives, methods for selecting survey (/monitoring) methods, and monitoring methods to address various policy issues.

(2) Survey procedures

- A rough flow from the planning of the investigation to the image analysis is shown below. Stages 1 and 2 correspond to Section I of this guideline Annex, and Stages 3 and 4 correspond to Section II.

<u>Stage 1. Survey planning and preparation</u>

- Determination of survey targets
- Selection of survey locations considering flight regulations and legislation
- Determination of survey timing
- Confirmation of legal requirements and implementation of necessary procedures
- Ensuring an adequate number of personnel to be involved in the survey
- Preparation of equipment
- UAV Settings

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<u>Stage 2. Survey implementation</u>

- Determination of the survey area
- Weather check
- Installation of survey equipment (ground control point, RTK equipment)
- Safety management
- Measurement
- Data record

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<u>Stage 3. Image processing and analysis</u>

- Making Digital Surface Models and Orthoimages
- Litter object detection on orthoimage and/or on single image (manual detection and/or automated detection)

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<u>Stage 4. Quantification of beach litter</u>

- Characterization of litter in the environment (counting objects, types, materials, analysis of the size of items)
- Litter maps and spatial distribution (covered area, density, accumulation)

(3) Survey target

(A) Target size

- Determine the target size of litter in consideration of the survey purpose. Examples of target sizes of litter for each survey purpose in past studies are shown in Table 2. Examples of target sizes by survey purpose.
- In several existing guidelines for beach litter surveys, such as EU (European commission 2013), GESAMP (GESAMP 2019), NOAA(Burgess et al. 2021), and Japan (Ministry of the Environment, Government of Japan, 2023), the survey targets are litter of 2.5 cm or larger, which generally corresponds to macro litter. Therefore, it is recommended that litter of 2.5 cm or larger be targeted for comparability with existing surveys.
- It is necessary to note in advance, however, that the lower limit of the survey target size is related to the flight altitude of the UAV and the size of the survey area. In general, imaging at a lower flight altitude will provide higher resolution images, which will allow for the identification of smaller litter. However, the lower the flight altitude, the smaller the area captured per image, and thus the smaller the flight range per set of UAV batteries.

Table 2. Examples of target sizes by survey purpose

Survey purpose	Target size (cm)	Notes
Estimation of the amount of beach litter (number of pieces, volume, density)	2.5-25	The smaller the target size, the more accurate the estimation.
Identification of types of beach litter	2.5-5	The larger the target size, the more difficult it is to determine the target type.
Identification of the spatial distribution of beach litter	2.5-25	The smaller the target size, the more accurate the estimation. However, since litter may appear to be clumped adjacent to each other in areas where litter has accumulated, it may be possible to identify the location of litter even if the lower limit of the target size is large.
Identification of temporal distribution of beach litter	2.5-5	The smaller the target size, the more accurate the estimation.

■ Point

For comparability with existing surveys, it is recommended that the target litter be 2.5 cm or larger.

(B) Type of litter

- In surveys of beach litter, not only man-made litter but also natural objects may be surveyed.
- For example, in Japan, driftwood affects ship operations and coastal landscapes, and is therefore a target item for litter composition surveys.
- In the demonstration test shown in Appendix 1, driftwood and other natural objects were also

targeted. See Appendix 1 for details.

(C) Classification

- If identification of the type of man-made litter is included in the survey purpose, it is recommended to plan in advance the type of litter that you would like to classify.
- Table 3 shows the basic categories of litter used in this guideline and Annex, and their correspondence to the EU (European commission 2013), OSPAR (OSPAR commission 2010), UNEP (Cheshire et al. 2009), NOAA (Burgess et al. 2021), and Japanese (Ministry of the Environment, Government of Japan, 2023) guidelines for each category.
- The items in Table 3 are classified as litter in the above-mentioned guidelines for beach litter surveys, and since they are frequently found in the world, it is recommended to conduct surveys from the viewpoint of comparison with other surveys. However, some food packaging, lighters, and cigarettes are not items that must be classified because their small size makes them difficult to distinguish at this time. Also, if there are other items that cannot be classified due to image resolution, only classifiable items should be classified.
- In addition to the above, the final litter classification is determined based on the litter considered to be a problem in the survey area and the comparability to other surveys conducted in the same area.

Table 3. Classification item proposal and correspondence with other guidelines

Classification item		Correspondence with other guidelines				
Level1	Level2	EU (item code and name)	OSPAR (item code and name)	UNEP (item code and name)	NOAA (item name)	Japan (item name)
Plastic	Caps/lids	G21-G24 (Plastic caps/lids drinks, Plastic caps/lids chemicals, detergents (non-food) , Plastic caps/lids unidentified, Plastic rings from bottle caps/lids)	15 (Caps/lids)	PL01 (Bottle caps & lids)	Bottle or container caps	Bottle cap, lid
	Beverage bottles	G7-G8 (Drink bottles <=0.5L, Drink bottles >0.5L)	4 (Drinks (bottles, containers and drums))	PL02 (Bottles < 2 L)	Beverage bottles	Plastic bottles for beverage (pet bottle) <1L, Plastic bottles for beverage (pet bottle)≧1L
	Plastic bags	G3 (Shopping Bags incl. pieces)	2 (Bags (e.g. shopping))	PL07 (Plastic bags (opaque & clear))	Bags	Plastic shopping bag
	Floats, buoys	G62, G63 (Floats for fishing nets, Buoys)	37 (Floats/Buoys)	PL14 (Plastic buoys)	Buoys and floats	Buoy (fishing implements) (plastics), Float/buoy made of foamed polystyrene
	Fishing nets, ropes, and twine (including ropes and twine other than fishing tools)	G49, G50, G52-G54, G56 (Rope (diameter more than 1cm), String and cord (diameter less than 1cm) , Nets and pieces of net, Nets and pieces of net < 50 cm, Nets and pieces of net > 50 cm, Tangled nets/cord)	31, 32, 33, 115, 116 (Rope (diameter more than 1 cm), String and cord (diameter less than 1 cm), Tangled nets/cord/rope and string, Nets and pieces of net < 50 cm, Nets and pieces of net > 50 cm)	PL19, PL20 (Rope, Fishing net)	Rope and nets	Rope/string (fishing implements), Fishing nets (fishing implements)
	Food packaging*	G3 (Crisps packets/sweets wrappers)	—	—	Food wrappers	Container and package for food
	Lighters*	G26 (Cigarette lighters)	16 (Cigarette lighters)	PL10 (Cigarette lighters)	Disposable lighters	Lighter
	Cigarettes*	G27 (Cigarette butts and filters)	64 (Cigarette butts)	PL11 (Cigarettes, butts & filters)	Cigarettes	Cigarette butt (filter)
Rubber	—	—	—	—	—	—
Cloth/textile	—	—	—	—	—	—
Paper/cardboard	—	—	—	—	—	—
Processed/worked wood	—	—	—	—	—	—
Metal	—	—	—	—	—	—
Glass/ceramics	—	—	—	—	—	—

*Food packaging, lighters, and cigarettes are not items that must be classified because their small size makes them difficult to distinguish at this time. However, future technological development may make it possible to identify them.

(4) Survey location

(A) Survey region

- In selecting the study area, the following points should be confirmed.
  - Environmental conditions for flying UAVs (wind, rain, temperature and humidity, cloud-haze, tide, light conditions).
  - No legal prohibition on flying UAVs (flight permission, flight altitude restrictions, radio regulations, and whether an application is required).
  - Whether the equipment can be brought to the site or procured.
  - Whether there is a suitable environment for obtaining location information.
  - No problems with local residents. (If possible, it would be helpful to get cooperation from local residents.)
- In some cases, UAVs may be transported when the survey is conducted in a distant location, but transporting them by air may not be possible for high-capacity batteries and thus, land transportation is required. However, it takes time to transport them by land, necessitating careful scheduling of transportation planned well in advance.

(B) Survey beach

- If the beach to be surveyed has already been identified for the purpose of the survey, check (iii) to (viii) below to see if the survey can be conducted.
- If the coast to be surveyed is not fixed, the coast to be surveyed will be selected after confirming (i) to (viii) below.
- The method of prior confirmation may include obtaining information from satellite images, interviewing nearby residents, or conducting a preliminary survey.

(i) **Whether the location of the beach litter survey is consistent with the survey purpose**: For example, if litter entering directly from a river is to be determined, the beach litter survey should be conducted near the mouth of the river. On the other hand, when you study the impact of ocean currents, it is desirable to be away from large estuaries.

(ii) **Whether the type of litter is appropriate for the survey purpose**: The type of beach litter that tends to drift and the season when it tends to drift differ depending on the orientation and slope of the beach.

(iii) **Whether the coast is a nature conservation area or not**: If the coast has high nature values and is designated as a conservation area, etc., a separate permit may be required for surveying or care may be required for entry. In addition, beware of UAV flights on beaches with high tourism value, as it is expected that many people will be entering the area.

(iv) **Accessibility**: It is not always necessary for people to enter the beach when only a UAV survey is conducted. However, it is recommended that the beach be visually checked for safety prior to the survey, so it is necessary to access the beach at a location where the beach can be seen.

(v) **Whether the terrain is suitable for surveying**: Beaches with cliffs in the hinterland are not suitable locations because of the possibility of radio waves from GPS and other equipment being blocked and the risk of the aircraft coming into contact with the cliffs. If it is unavoidable to conduct a survey on such beaches, it is recommended to fly at least 10 to 20 meters away from the cliffs for safety reasons. In addition, if there is vegetation protruding from the hinterland directly above the survey area, the coast will not be visible from the UAV image, so it is necessary to shoot from an oblique direction.

(vi) **Beach substrate**: Any beach substrate can be surveyed; however, it may be difficult to distinguish litter of the same size or smaller from gravel on a gravel beach in image analisys. Therefore, it should be avoided depending on the lower size limit of the survey target. In addition, on beaches with many large rocks, it may be difficult to detect litter in the UAV image because it is hidden behind the rocks.

(vii) **<u>The shore where cleaning is done</u>**: It is advisable to confirm in advance the frequency and timing of cleaning, since there may be no litter immediately after the cleaning and the desired results may not be achieved.

(viii) **<u>Whether UAVs are allowed to fly</u>**: UAVs may be prohibited around densely populated areas or near airports. Check the legal regulations of the survey area in advance.

(C) Survey area

- The survey purpose and the following points will be taken into consideration when determining the scope of the survey. Table 4 shows the scope of each survey purpose in past cases.
  - Flight range per set of UAV batteries and number of battery sets available.
  - Data storage capacity.
  - Time and effort for data processing.
  - Comparability with existing surveys.
  - Survey schedule.
  - Combination with other surveys such as collection surveys.
- In some cases, surveys are not necessarily conducted over the entire coast, but only the most frequently used areas, or the survey areas are aligned with those of previous surveys. Whether or not the entire coastal area is to be surveyed depends on the purpose of the survey, and it should be considered with reference to the past cases shown in Table 4.
- Even in the case of manual UAV flight operations, the size of the survey area should be determined in advance in anticipation of comparing the survey results with other survey results, such as litter density.
- The takeoff/landing point should be found in advance, and the time required to fly to and from the survey area should be included to allow sufficient time for a smooth flight. In particular, in remote coastal areas, be aware that there is a risk of crashing at sea. For example, a UAV with a flight time of 30 minutes will not be able to conduct a survey if the distance between the takeoff/landing point and the survey area is more than 15 minutes (Kako et al. 2024).

Table 4. Examples of survey purpose and survey area

Survey purpose	Survey area			Notes
	Whether the whole beach or not	Length of the survey area horizontal to the shoreline (m)	Length of the survey area vertical to the shoreline (m)	
Estimation of the amount of beach litter (number of pieces, volume, density)	Only part of the beach	100-1000	20-800	When one attempts to determine the amount of beach litter on a certain beach, there are two possible methods: one is to survey the entire beach area, and the other is to survey only those areas of the beach that are representative of the amount of beach litter and estimate the overall amount of beach litter.
	The whole beach	200-5000	20-2500	
Identification of types of beach litter	Only part of the beach	50-500	50-202	If one attempts to understand the types of beach litter on a certain beach, it is sufficient to cover most of the types of beach litter on that beach by surveying only a portion of the beach. Since the length of the survey area required in this case varies from region to region due to the influence of ocean currents and other factors, it is possible to unify the survey area with that of existing beach litter composition surveys used in each region.
Identification of the spatial distribution of beach litter	Only part of the beach	95-1000	20-800	In understanding the spatial distribution of beach litter, it is necessary to survey the entire area of interest.
	The whole beach	60-5000	20-2500	
Identification of temporal distribution of beach litter	Only part of the beach	100-1000	15-120	In understanding the temporal variation of beach litter, it is not necessary to set a wide survey area, but it is possible to select an area that can be surveyed at high frequency.

(5) Survey timing

(A) Survey frequency

- The survey frequency is determined based on the survey purpose. Examples of survey frequencies for each survey purpose from past literature and surveys are shown in Table 5.

Table 5. Survey frequency of existing research cases

Survey purpose	Survey frequency			Notes
	Random (1-3 times a year)	Seasonal (about once every 3-4 months)	High frequency (about once every 1-2 weeks)	
Estimation of the amount of beach litter (number of pieces, volume, density)	■	■	■	It can be conducted at any frequency, but by conducting it on a regular basis, temporal variations can also be observed.
Identification of types of beach litter	■	■		
Identification of the spatial distribution of beach litter	■	■	■	
Identification of temporal distribution of beach litter		■	■	In order to understand the temporal distribution of beach litter, a large amount of data is needed for statistical analysis. Therefore, it is recommended that observations be conducted as frequently as possible.

■Survey frequency that has been surveyed in the past for each objective.

(B) Survey timing

- The survey timing will be determined based on the following considerations.
  - Whether the timing of the survey is appropriate for the purpose
    - ✧ Season: There may be seasonal variations in the amount of beach litter due to the influence of seasonal winds. In such cases, it is necessary to select the season when the amount of drifted litter is highest in order to know, for example, the maximum amount of drifted litter per year. It is advisable to confirm the season with the literature or field survey in advance, since the season with the highest quantity of litter drift differs between beaches depending on the beach orientation and seasonal wind fluctuations.
    - ✧ Waves: The amount and composition of beach litter changes significantly after storm and waves. For example, if you want to know the maximum annual amount of beach litter or the impact of waves, it is recommended to survey after the waves, but if you want to know the steady state of beach litter, it is recommended to avoid surveying immediately after the waves.
    - ✧ Cleaning: When beaches are cleaned, there is less litter immediately after cleaning. If the purpose of the survey is to verify the effectiveness of the cleaning, it is possible to conduct the survey before and after the cleaning, but if the purpose is to know the steady state of beach litter, it is advisable to refrain from conducting the survey immediately after the cleaning. The accumulation and discharge of litter per unit of time could be surveyed in advance to check the period of time until a steady state is reached after cleaning.
  - Whether UAVs can fly.
    - ✧ Absence of other beach users: If there are third parties within the survey area, it is

advisable to refrain from flying the UAV for safety reasons. Therefore, it is necessary to select a time or times when no other beach users are present.

  - ✧ Seasons when surveyable weather conditions are available: Since UAVs cannot fly in rainy weather or strong winds, it is necessary to select seasons when weather conditions are available for UAV flights.

- The survey months of existing research cases and the inquiry results are de-scribed in Figure 1 and Figure 2 shows that surveys were conducted almost evenly in all seasons. The number of surveys conducted in winter is slightly lower than in other seasons, but this may be due to climatic factors such as snow cover and strong winds.

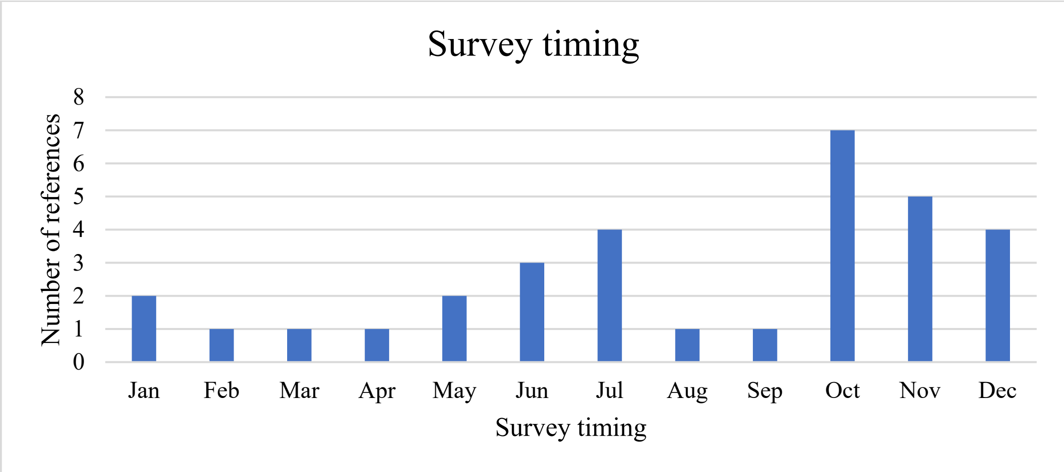

Figure 1. Survey timing of existing research cases

Note: If a single reference covered more than one survey month, the number of references was counted for both months (16 eligible references and 32 total references).

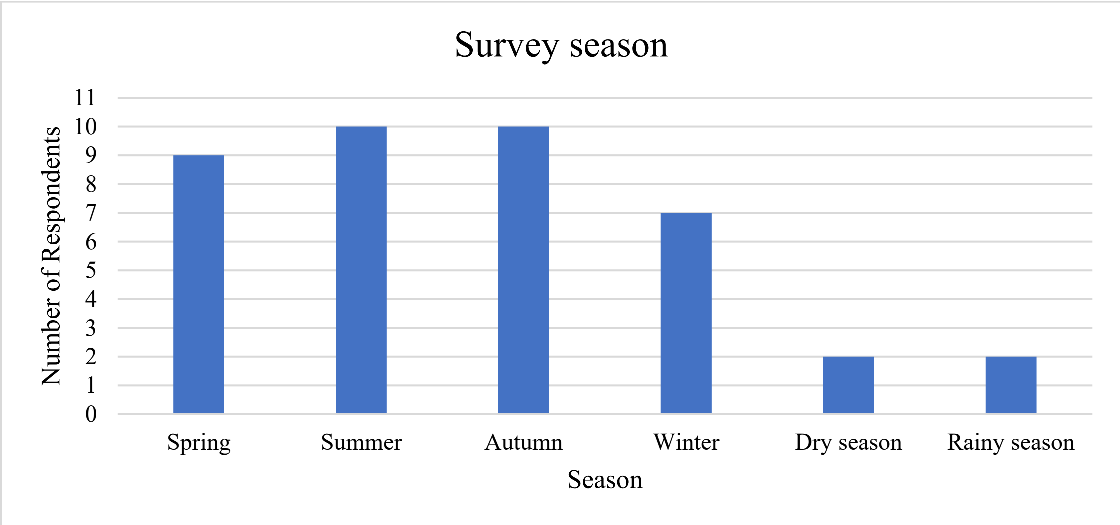

Figure 2. The inquiry results _ Survey season

Note: If a single response included more than one season, it was accounted for in both seasons (16 survey respondents, 40 total responses for this item).

(C) Survey times

- To ensure that litter can be identified from the images taken by the UAV, the photography should be conducted during the daytime when it is bright.
- However, if the beach is in shadow due to trees in the hinterland of beach, or if the sunlight is so strong that litter reflects the sunlight and glows white, litter identification may be affected. In the past, some surveys have been conducted at noon to reduce shadows, or in the morning or evening to minimize the effects of sunlight reflection.
- The time of high and low tides and the width of the tidal range should be confirmed in advance, as they are relevant to the location of the survey equipment and the survey area. For example, if the survey is to be conducted between low and high tides, placing survey equipment near the water's edge may result in submersion due to the rising tide during the survey. In addition, depending on the survey purpose, the survey may be conducted at low or high tide.
- The results of the survey time and tide questionnaire are shown in Table 6.

Table 6. The inquiry results _ Survey time of the existing research cases

Case No.	The time of the survey and the reason for selecting that time.	Tide
1	Combining maximum solar height to minimize shadows with low tide to have the largest area of beach available.	At low tide
2	Time was just selected based on low tide, even though it was not mandatory. It was important for us not to do the survey during high tide.	At low tide
3	No preference	Not taken into account
4	10:00-14:00. For light and work permit convenience	Not taken into account
5	Most of the time it is around 8 or 9 am. The survey of elementary school students starts around 9-10 a.m., so I choose a time when there are no children.	Not taken into account
6	All day long	Not taken into account
7	-	At low tide
8	The central hours of the day are chosen to reduce the presence of shadows.	Not taken into account
9	Noon is a good time to do this without the influence of shadows.	Not taken into account
10	Time was selected to be as close as possible to sun-noon.	At low tide
11	Not midday because of the angle of incidence of sunlight.	At low tide
12	Beach - low tide. Sunlight to decrease reflection.	At low tide
13	-	Not taken into account
14	Midday to maximize incident solar radiation and get good SNR[*1].	At low tide
15	The time considered 10 am to 3 pm was the time considered to obtain the clearest EMR[*2] spectrum.	At high tide, At low tide
16	-	Not taken into account

Notes:
*1 Signal to noise ratio
*2 Electromagnetic Radiation

(6) Legal considerations and requirements

- Apply for permits for UAV flights and use of the beach. Since there are different laws and regulations by national and local governments, etc., and the applications required differ depending on the weight of the UAV to be used, the flying method, and the flying location (on the sea or on land), the necessary applications should be made after confirming in advance what type of application is required, and surveys should be conducted in accordance with the laws and regulations. If registration of the UAV vehicle is required, it must be pre-registered.
- Examples of past permit applications are shown in Table 7.
- In some cases, the survey can be conducted smoothly by informing local residents, such as those involved in the fishing industry, in addition to the national or regional application, of the survey plan in advance.

Table 7. The inquiry results _ Legal considerations and requirements (1/2)

Case No.	Purpose of the procedure	Destination institution	Specific name of institution in case of "public institution" answer.	Points that were or should be noted in the permit application process.
1	To obtain permission to fly a UAV, To obtain permission to use the beach	Public institution	University of Coimbra and Institute for Engineering Systems and Computers at Coimbra (INESC-Coimbra)	The weight of the drone and its flying class. Current EU certification can place many limitations on the use of this technology for research purposes. Flying outside classes A1-A3*1 may be practically impossible for research purposes.
2	To set up the technique	Public institution, scientific publications	INESC Coimbra, University of Coimbra, Portugal	I prefer to leave the answers an expert in UAV set up.
3	To obtain permission to fly a UAV, To obtain permission to use the beach	Public institution	University of the Aegean	Regular national regulations
4	To obtain permission to fly a UAV, To obtain permission to use the beach, To inform all parties concerned of the work	Public institution, Fishery organization	Town office	In addition to the usual procedures, fishery cooperatives in particular needed to be provided with detailed information. They had no knowledge or experience in dealing with UAVs, so we explained in detail the survey, the time and location of the work. When targeting coastal areas, it should be noted that the parties involved may differ depending on whether they are flying over the sea or only over land. In addition, UAVs will be flown in the area near fishery-related facilities, so we think it is important for smooth operations to thoroughly inform local residents, especially those involved in the fishery industry.
5	To obtain permission to fly a UAV	Public institution	West Japan Civil Aviation Bureau	We had difficulty in obtaining an approval letter for flying out of sight flights under DIPS 2.0*2 Since our organization uses rental UAVs, we could not proceed with the application process under DIPS 2.0 without having the rental company, the owner, go through the "Procedures for sharing aircraft information". It took us some time to realize this.
6	To obtain permission to fly a UAV	Public institution	Research in Svalbard portal	Avoid interactions with birds and other fauna.
7	-	-	-	-
8	To obtain permission to fly a UAV, To obtain permission to use the beach	Public institution	Istituto di Scienze Marine e Istituto di Fisiologia Clinica, both of CNR (Italian Council of Research)	Adhere to the flight rules and procedures for the operation of unmanned aircraft (ENAC*3 on 4 January 2021 published the UAS-IT Regulation, applicable from 31 December 2020, which regulates what is the responsibility of the Member States). Consider the distances to built-up areas, and based on this decide the (permitted) heights of flight. Check whether there are sensitive activities in the area (military bases, etc.).
9	To obtain permission to fly a UAV, To obtain permission to use the beach	Public institution	Ministry of Land, Infrastructure, Transport and Tourism	There are guidelines from the Ministry of Land, Infrastructure, Transport and Tourism, so follow them. https://www.mlit.go.jp/koku/drone/ https://www.ossportal.dips.mlit.go.jp/portal/top/
10	To obtain permission to fly a UAV, to obtain permission to use the UAV to collect imagery	Public institution, R&D unit and EU projects	Universidade da Madeira, Regional Directorate of Environment and Climate Change, MARE-Madeira R&D unit	Consult current restrictions to flights and provide adequate justification when asking for permits. include pilots credentials, insurance policies and UAV registry.
11	To obtain permission to fly a UAV	Public institution	ANN - Autoridade Aeronáutica Nacional	Please note that the location requested to carry out the survey is not a no fly zone.
12	To obtain permission to fly a UAV, To obtain permission to use the beach	Public institution	Government, Research entities	-

Table 7. The inquiry results _ Legal considerations and requirements (2/2)

Case No.	Purpose of the procedure	Destination institution	Specific name of institution in case of "public institution" answer.	Points that were or should be noted in the permit application process.
13	-	-	-	-
14	To obtain permission to fly a UAV	Landowners, Local Airport authority	-	Risk assessement is usually needed.
15	To obtain permission to fly a UAV, To obtain permission to use the beach	Government research institute	-	We followed the DGCA*4-Civil Aviation guidelines to protect national security.
16	To obtain permission to fly a UAV, To obtain permission to use the beach	Public institution	NASA, USGS, UoG	-

*1 EU Regulations 2019/947 and 2019/945 set out the framework for the safe operation of civil UAVs in the European skies. It defines three categories of civil UAV operations: the ‘open’, the ‘specific’ and the ‘certified’ category. The ‘open’ category addresses the lower-risk civil UAV operations in , where safety is ensured provided the civil UAV operator complies with the relevant requirements for its intended operation. This category is subdivided into three subcategories, namely A1, A2 and A3. (European Union Aviation Safety Agency “Operating a drone” https://www.easa.europa.eu/en/domains/drones-air-mobility/operating-drone)
*2 Drone/UAS Information Platform System 2.0
*3 Italian Civil Aviation Authority
*4 Directorate General Civil Aviation

(7) Researcher

- The survey requires the following division of roles. The same person may take on multiple roles, but care should be taken not to overburden each worker. A minimum of two surveyors is required due to the need to constantly monitor the UAV aircraft for safety reasons.
  - Supervisor: Responsible for work in the survey. Understands and manages the work and deployment of workers in the field, and gives instructions and takes action according to the situation.
  - UAV operator: Operates the UAV in accordance with the Supervisor's instructions.
  - Maintainer: Maintains the aircraft before and after the UAV's flight and replaces parts as required.
  - Monitor observer: Constantly monitors the UAV status during the UAV flight using a monitor to check any abnormalities in the UAV's flight position, rotor blade status, remaining battery level, GPS signal reception, etc.
  - UAV observer: Monitors the aircraft and weather conditions while the UAV is in flight.
  - Security officer: Monitors the flight route of the UAV and the surrounding area for third parties. If a third party attempts to enter the flight range, a security officer will stop them.
- If a pilot permit or flight license is required by national or local government regulations, it should be obtained in advance.
- Even if a license is not required to operate a UAV, it is recommended to conduct UAV pilot training, learn how to set up an autonomous flight configuration, and confirm safety management in advance.
- Table 8 shows the results of the inquiry regarding the number of people surveyed and their role assignment. The minimum number of people surveyed was one and the maximum was 10.

Table 8. The inquiry results _ Number of researchers and assignment of roles

Case No.	Number of Researchers	Roles
1	1-2	(1) UAV operator, (2) Marine litter surveyor for perform field validation.
2	2	(1) UAV set up and flight, Site inspection, GPS surveys, (2) Assistance, Site inspection, GPS surveys
3	1	Associate Professor
4	4	(1) Operator, (2) Maneuvering assistance/surveillance, (3) Grading point surveying, Surveillance
5	2	(1) UAV pilot, (2) Assistants who visually check the surrounding area for safety
6	3	(1) UAV pilot, (2) Data and video analyzer, (3) Principal investigator, (4) Expedition leader
7	-	-
8	2	(1)The UAV pilot, (2) A support person (researcher director)
9	3-5	(1) Pilot, (2) Perimeter monitoring, (3) setting up of fixed points, (4) field surveying.
10	1-2	(1) Pilot and planning, (2) Planning and flight operations "assistance"
11	Minimum 2	(1) Pilot focused on the flying procedures, (2) Co-pilot never lose sight of the UAV
12	2-4	(1) Pilot, (2)Co-pilot, (3)Security of the area.
13	1	Flying UAV
14	2 minimum, ideally 3	(1) Pilot, (2) co-pilot, (3) observer
15	10	Capturing the beach litter using UAVs, collection, segregation, and litter quantification.
16	10	-

(8) Survey equipment

(A) UAV and camera

- Prepare a UAV and a camera to be used for image capturing. In order to capture images from a camera mounted on the UAV, it is necessary to select a model that comes with or can mount a camera on the UAV in advance. Which UAVs and cameras are to be used should be decided in consideration of the following Table 9.
- Table 10 shows the UAVs that have been used in existing surveys.

Table 9. Considerations for UAV and camera selection

Item	Selection Considerations
Sensor Type	When conducting a UAV survey of marine litter according to the guideline, an RGB camera should be used. Although it may be possible to classify plastic litter and other materials based on their wavelength characteristics using a multispectral and hyperspectral sensor in the future, the identification of litter using those sensors is currently in the research phase.
Image resolution	In general, the higher the resolution, the clearer the image obtained from the same altitude, but the larger the image capacity per image. For the relationship between the size of the observation target and resolution, see (A) Ground Sampling Distance in 1.1.1, (9).
Relationship between flight time and survey area	The standard model of UAVs suitable for measurement can fly for roughly 15–30 min on a single battery and can capture an area in the order of 10^4 m^2 (Kako et al. 2024). When photographing a wide area, it is easier to take pictures with an aircraft that can fly for a long time per flight. If the survey area is broader than 10^4 m^2, multiple sets of batteries should be prepared.
UAV size	Confirm that the UAV can be transported to the survey site. Note that the UAV's lithium-ion battery cannot be transported by air or sea, so it must be transported by land. In addition, if the survey site needs to be accessed on foot, it may be difficult to carry a large UAV, so it is recommended that the accessibility of the survey site be checked in advance before selecting the equipment.
Autopilot function	This refers to a function in which a UAV uses GPS mounted on the aircraft to determine location information, etc., and flies autonomously according to a route planned in advance. Since the use of the autopilot function enables accurate and safe imaging of a wide area, it is recommended that UAVs be flown with the autopilot function.

Table 10. UAVs in the existing research cases and the inquiry results

The model of the UAV	The manufacturer
Inspire	DJI
Matrice 210 RTK	DJI
Matrice 210 RTK V2	DJI
Matrice 210 RTK V2	DJI
Matrice 300 RTK	DJI
Mavic 2 Zoom	DJI
Phantom 2 Vision	DJI
Phantom 3 Advanced	DJI
Phantom 3 Professional	DJI
Phantom 4	DJI
Phantom 4 Pro	DJI
Phantom 4 Pro V2.0	DJI
Phantom 4 RTK	DJI
WingtraOne Rededge MX	Wingtra

(B) Location measurement equipment

- For accurate estimation of litter volume, precise location measurements should be taken.
- Note that many UAVs, as a technical specification, have an error of a few centimeters to several meters in acquiring positional information. In past surveys, an error of 1 m per 20 m has actually been observed (Kako et al. 2024). It is necessary to eliminate this error for accurate estimation of litter volume, and the following two methods can be considered for this purpose. Note, it is not necessary, for other survey purposes, to obtain accurate location information.

(i) Use ground control points and total stations for precise location measurements. The details of the total station and preparation of the target point will be introduced in the section (C) Other survey equipment. However, the survey time will be 1-2 hours longer than (ii) because of the time required to set up the total station and other preparations.
(ii) Use UAVs with real-time-kinematic (RTK) for more precise location acquisition. RTK is centimetre-level accuracy positioning in real-time based on GPS measurements (or more generally on Global Navigation Satellite System (GNSS) measurements) (source:IAG website). RTK positioning is divided into two categories. The first type is a method in which users set up RTK base stations by themselves. Although this method requires transporting a base station to observation sites, it can be employed globally, obtaining GNSS information. The second type is a network method that uses the services of private companies that provide location correction information. This method relies on private operators' data, incurring a communication fee of approximately $1 per min (this is the rate of a company in Japan). However, the method eliminates the need for on-site base station setup. Nonetheless, it is important to acknowledge that the feasibility of the method hinges on the network environment in the vicinity, which may render it unviable for certain coastlines.

(C) Other survey equipment

- Although there is no equipment other than UAVs and cameras that must be used, the equipment listed in Table 11 may be used depending on environmental conditions and image processing.
- When using ground control points, maximum 10 signs should be placed within the survey area to ensure that there is no bias (Figure 3). In the demonstration test shown in Appendix 1, six points were set up in a 20 x 4.3 m survey area. Use ground control points targets for ground control points. Colored ground control point targets are better than black and white for smooth image analysis. When a 3D model is created from the image to estimate the volume, it is advised to place 2 to 3 targets as stereo ground control point targets for height compensation, about 2 m higher than the other targets. The stereo ground control point targets should be set up using a tripod or similar device. Note that the placement of ground control point should not be too linear. Figure 4 shows an example of the location of ground control point , and Figure 4 shows an example of how stereo ground control point targets are installed.

Table 11. Examples of equipment other than UAVs and cameras (1/2)

Equipment	Uses	Photograph
GNSS surveying equipment	To measure the positional information of ground control points and total stations. To perform detailed positional information correction.	
Cameras for ground photography	To record the situation of the site from the ground, etc. To compare the images taken by UAV with the situation on the ground, etc.	
Polarizing filters	To reduce reflected light in the image. Used when reflected light affects image discrimination.	 Citing from photoAC (https://www.photo-ac.com/)
Neutral density filters	To reduce the amount of light coming through the lens and adjust the brightness of the image. Used to correct the brightness of an image.	 Photo by João Monteiro.
Wind anemometers	Wind speed is measured before and during UAV flight for safety. Note that the wind speed on the ground may be different from the wind speed in the sky.	 Citing from AcuRite.com, "How Does an Anemometer Measure Wind Speed?". (https://www.acurite.com/blog/how-does-an-anemometer-measure-wind-speed.html)

Table 11. Examples of equipment other than UAVs and cameras (2/2)

Equipment	Uses	Photograph
Base station receiver for RTK operations	This is used as a reference for correcting positional information when using RTK-UAV.	
Ground control point targets	It is installed within the survey area as a ground control point. It is necessary when RTK-UAV is not used for detailed positional information correction. Even when RTK-UAV is used or detailed positional information correction is not required, ground control point targets can be installed to serve as a landmark for image processing.	
Total station	An instrument used to survey ground control points. It corrects the positional information of the image based on the surveying information.	

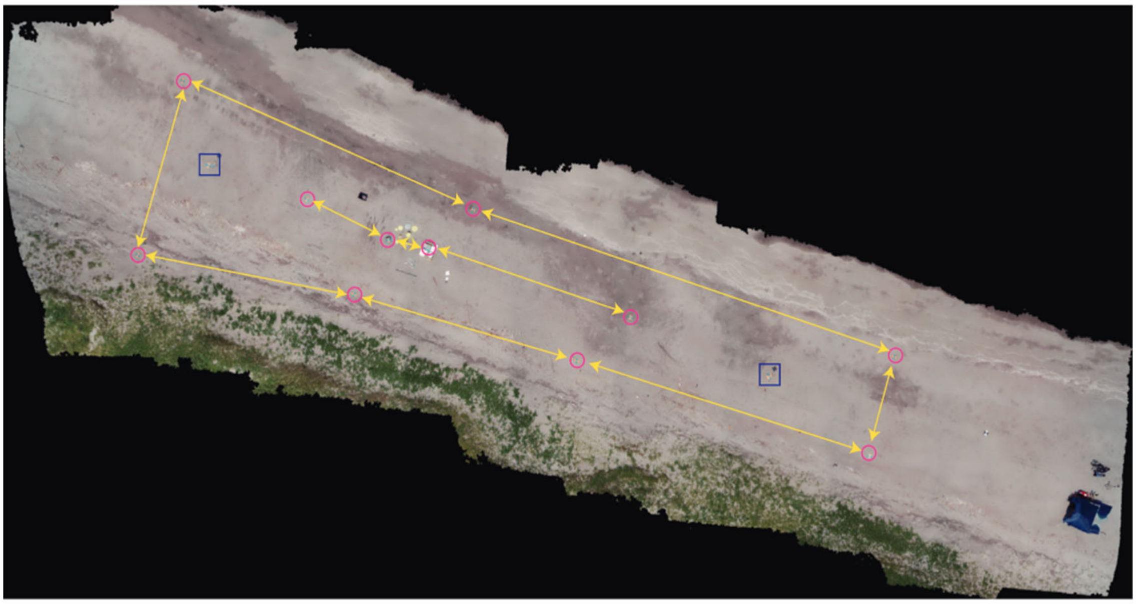

Figure 3. Example of placement of ground control points.
An Orthoimag of Fukiage Beach. Antiaircraft beacons are surrounded by pink circles. Distances between antiaircraft beacons measured by Total Station (TS) are indicated by yellow numbers. Stereo antiaircraft beacons used to calibrate altitude data are surrounded by blue squares. Antiaircraft beacon number 9 was original point placed on TS. (For interpretation of the referencese to color in this figure legend, the reader is referred to the web version of this article.) (Partially processed from Kako et al. 2020)

Figure 4. Example of installation of a stereo ground control point targets

(9) UAV setting

(A) Ground Sampling Distance

- Ground Sampling Distance (GSD) is the size of each pixel (Kako et al. 2024, Figure 5). The GSD determines the image resolution, thus the detectable size of litter items (Andriolo et al. 2023). The smaller the GSD is, the finer the discrimination of litter becomes. Based on the minimum size of the target litter, the necessary GSD is calculated with reference to Figure 6.
- In Figure 6, a), the vertical axis shows the GSD (cm/pix) and the horizontal axis shows the number of pixels constituting one side of the litter. The blue, orange, and yellow curves indicate the minimum size of the litter to be detected: 2.5 cm, 5 cm, and 10 cm, respectively. Since one side of the litter should consist of a minimum of 4 to 5 pixels, the GSD where the blue, orange, and yellow curves are located at 4 and 5 on the horizontal axis is the minimum GSD required. For example, if the minimum size of the target litter is 2.5 cm, a ground resolution of 0.5 cm/pix is recommended.
- Examples of litter visibility and litter detection at GSD of 0.5 cm/pix, 1.25 cm/pix, and 1.85 cm/pix are shown in Figure 7.
- Note that even when the lower limit of the target size is set at 2.5 cm, the lower limit may be larger than 2.5 cm in image detection by the AI. In the demonstration test shown in Appendix 1, only litter larger than about 10 cm could be detected by AI. Since this depends on the size of the litter in the AI training data, it is necessary to separately check the lower limit of AI detection beforehand or after detection. However, even if the lower limit of AI detection is larger than 2.5 cm, there is no need to set the GSD of the image smaller, since it may be possible to discriminate litter from the image again in the future using more accurate image detection technology in the future.

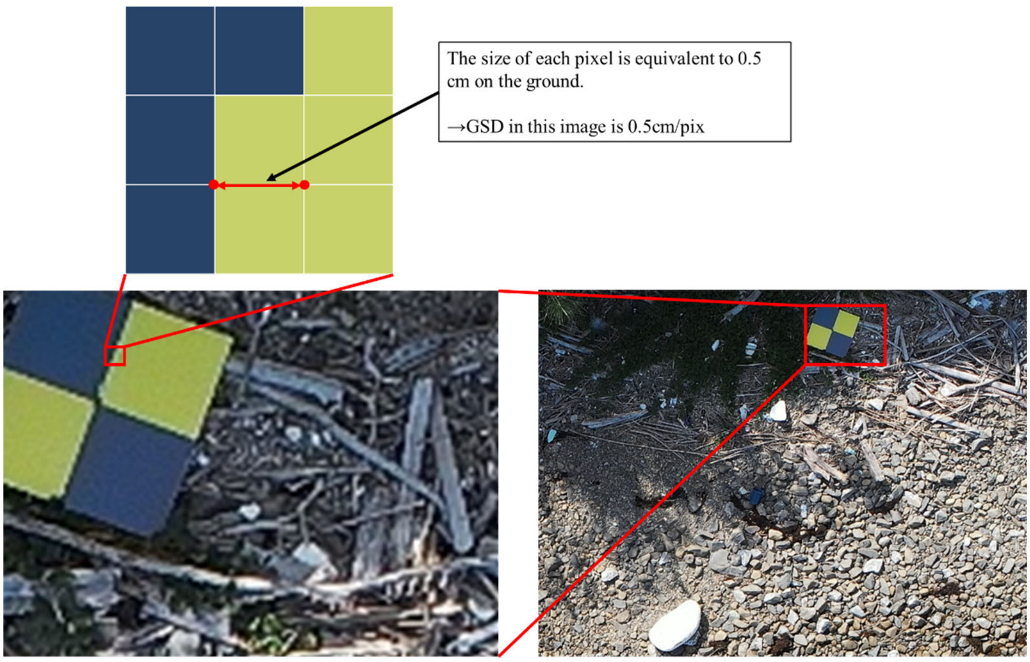

Figure 5. GSD concept

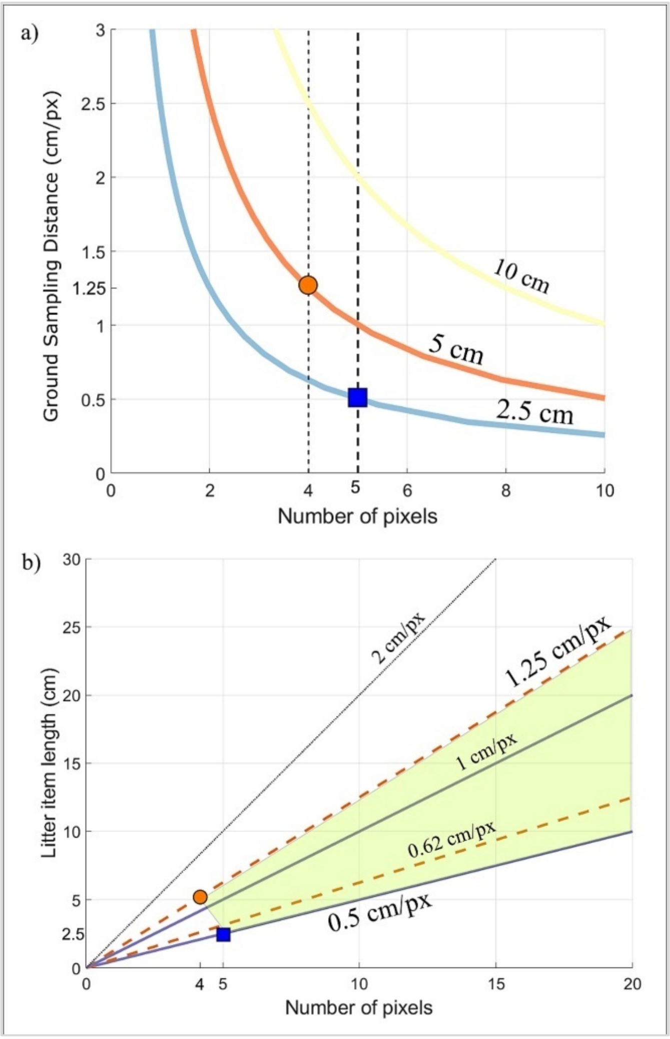

Figure 6. Relationship between GSD and discernible litter size

Relation between Ground Sampling Distance (GSD) and size of litter (Sz). a) Blue and orange curves represent the litter size Sz (2.5 cm and 5 cm, respectively) in the graph GSD-number of pixels (Npx). The yellow curve shows a 10-cm litter size in the graph GSD-number of pixels. Black shaded lines indicate the adopted thresh-olds of Npx = 4 and Npx = 5; b) GSD represented in the graph litter size Sz – number of pixels (Npx). Thick blue lines indicate GSD of 0.5 cm/px and 1 cm/px, and dashed orange lines indicate GSD of 0.62 cm/px and 1.25 cm/px. For comparison purposes, dotted black lines show the GSD of 2 cm/px. Shaded area delimitates the suitable GSD range. In both graphs, the blue square indicates the intersection between Npx = 5 and Sz = 2.5 cm, while the orange circle indicates the intersection between Sz = 5 cm and Npx = 4 . (Andriolo et al. 2023)

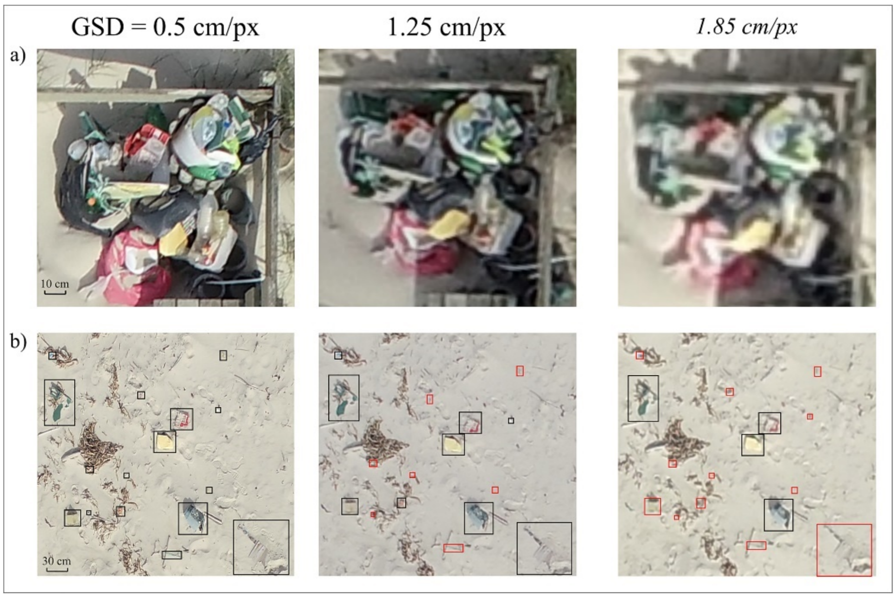

Figure 7. Image visibility per GSD

Example of drone images with different Ground Sampling Distance (GSD). a) aerial picture of a recollection point close to the beach, with bins and garbage bags. Different types of plastic bottles are distinguishable on the image with GSD = 0.5 cm/px (left). On the image with GSD = 1.25 cm/px (central), items can still be counted but not recognized, whereas it is difficult to count litter on the image with GSD = 1.85 cm/px (right); b) operational assessments of litter items marked on images. On the image with GSD = 0.5 cm/px (left), several items were detected, and their material and/or category can be recognized (black boxes). On the image with GSD = 1.25 cm/px (central), the smallest items could not be detected (red boxes), while only the four biggest items could be spotted on the image with GSD = 1.85 cm/px (right). Overall, in b), black boxes bound the detected items, whereas red boxes missed the items. (Andriolo et al. 2023)

■ Point

For comparability with existing surveys, it is recommended that the litter to be studied be at least 2.5 cm, in which case the GSD would be 0.5 cm/pix.

(B) Flight altitude

- The appropriate flight altitude is calculated as :

  [(GSD) / (size of one pixel of the digital camera used) x (focal length)]

- For example, in the case of the demonstration test shown in Appendix 1, the GSD was 0.5 cm, the size of one pixel of the digital camera used was 4.4 μm, and the focal length was 35 mm,

  0.5 cm/4.4 μm x 35 mm≒39773 mm≒40 m

  and the flight was made at an altitude of 40 m.
  However, if you use an application to set up the UAV, the appropriate flight altitude may be calculated automatically when the GSD is given to the application.
- The altitude of the UAV is set from the take-off point, so if the height of the beach is different

from the take-off point, the altitude of the UAV should be set to consider the difference in height.

(C) Gimbal angle (Camera angle)

- In many cases, the gimbal angle is set at -90°. However, when creating a 3D model to estimate litter deposition from the images taken, it is necessary to also take images from an angle such as -70° to create a more accurate 3D model.

(D) Image overlaps

- The image overlap ratio is determined by the way the image is processed. To create an orthoimage from an image taken, it is recommended that the front overlap (percentage overlap of images in the UAV's direction of motion) be set above 80-90% and the side overlap (percentage overlap between left and right when the direction of motion is assumed to be forward) be set above 60%. On the other hand, if not creating an orthoimage, the image may be taken with a lower front-side overlap to reduce the imaging time.
- In the demonstration test, when photographing a 50 x 17.1 m survey area, it took approximately twice as long to photograph the area with 80% front overlap and 60% side overlap as it did with 20% front overlap and 20% side overlap.
- If the number of photos taken is very minor due to a narrow shooting range or high flight altitude, there is very little camera position information and the accuracy of position correction will be reduced. Also, if the overlap is very small, there will be blank spaces in the ortho image. If the number of photos taken is likely to be small, it is recommended that a surveyor increases the number of locations photographed by combining flights parallel and perpendicular to the coastline.

(E) Shooting methods

- UAVs have two imaging methods: one is to take photographs at equal second intervals while moving, and the other is to stop moving and take photographs once when taking photographs. The characteristics of each are shown in Table 12, and either of the shooting methods can be investigated.

Table 12. Advantages and disadvantages of each imaging method

Shooting Method	Advantages	Disadvantages
Shooting at equal second intervals while moving	Takes a short time to take a picture.	Since the aircraft continues to move during shooting, images may be blurred when shooting from a low altitude such as 10m or lower.
Stop moving and take a picture	Since the aircraft is paused when shooting, images are less blurred even when shooting from a low altitude.	Takes a long time to take pictures.

(F) Brightness of the image (shutter speed, F-value, ISO and other factors)

- Camera settings such as shutter speed, F value, ISO, etc. are basically optimized automatically and do not need to be changed if there are no problems with image brightness.
- If the image brightness is too dark and debris cannot be seen clearly, adjust these settings manually. However, care should be taken not to use a very slow shutter speed, as this can result in blurred images. A preliminary flight may be conducted in advance to search for appropriate settings.

(G) Image storage format

- There is not a specific format for saving captured images, but it should be noted that saving images in a format with a high compression ratio may degrade image quality.

(10) Survey implementation

(11) Determination of the survey area

- Although a rough survey area has been determined at the planning stage, on the day of the survey, check the coastal conditions from the following perspectives to confirm that the survey area is safe for UAV flights.
  - The state of litter: For example, if the survey is to be conducted at a location where the quantity of litter is average among beaches, or at a location where litter has accumulated, the actual litter drift situation should be checked and adjusted to a suitable area.
  - Surrounding topography: If the beach has cliffs in the hinterland, the actual condition of the cliffs should be confirmed on-site, and the survey area should be adjusted so that the flight range is at least 10-20 m away from the cliffs and that the survey can be conducted safely.
  - Vegetation: If there is a risk that trees in the hinterland may protrude onto the beach, making it impossible to see the beach from directly above, the survey area should be changed to an area with no trees, or change to shooting from an oblique direction instead of directly above.
  - Presence of obstructions: Check to see if there are any tall structures in the vicinity of the survey area that could potentially come into contact with the UAV. Adjust the survey area to be at least 10-20 m away from tall structures.

(12) Weather conditions

- UAV flights shall be conducted when the weather is clear or cloudy and the wind is calm. Under the following weather conditions, the UAV should not be flown because it may be dangerous or it may not be possible to acquire clear images.
  - Wind speed 5 m/s or higher (This is only a guideline, as each UAV model has a different wind resistance performance. The wind resistance performance of the model to be used should be confirmed in advance, and the survey should be conducted only when the wind speed is sufficiently slower than the wind resistance limit.)
  - Rainy weather
  - Snowfall
  - Fog
  - Lightning
  - Hail
- Note that on sunny days, the camera settings may be adjusted manually or polarizing lenses may be used if necessary, as sunlight may reflect strongly off the ground or debris, or shadows cast by surrounding vegetation or debris may affect image analysis.

(13) Installation of survey equipment

- If there is any equipment other than the UAV and camera to be used, it should be installed prior to the flight.
- When using a total station, the coordinates of the base point must be obtained in advance. In addition, the tripod should be firmly fixed so that it does not move during measurement, and the equipment should be installed horizontally. For detailed instructions on how to use the total station, refer to the instructions for the equipment used.
- When using stereo ground control point targets, note that targets should be placed horizontally. Stereo ground control point targets should be mounted using a tripod or similar device. An example of a stereo ground control point targets is shown in Figure 4.
- In the case of sandy beaches, it may be difficult to fix a reference point (e.g., tacks). Therefore, if there is a ground object (e.g., concrete), it is recommended to place it there.

(14) Safety management

- If the country or region where the survey is conducted has regulations on UAV flight safety management, the survey should be conducted accordingly.
- Other examples of safety management practices that have been implemented in existing studies and surveys are listed below.
  - Check for obstacles in the route
  - Check for safe takeoff and landing sites
  - Calibration of inertial measurement units (IMU) on a UAV (Perform as necessary according to the UAV instructions (Figure 8).)
  - GNSS reception status
  - Confirmation that the controller and UAV aircraft are in good working order
  - Confirmation that there is no intrusion of the general public within the flight envelope
  - Check aviation safety information
  - Check weather conditions such as temperature, wind speed, cloud cover, etc.
  - Wear clothing appropriate for the weather conditions and research location
  - Check the geomagnetic storm index (related to GPS and the connection between the UAV and the controller)

Figure 8. Calibration of IMU

(15) Measurement

- Follow the instructions for the equipment to use when operating the UAV.
- The flight is carried out according to the following procedure.

[Flight procedure]

(i) Check the safety of the flight route. Visually check the flight route for the presence of third parties and obstacles (tree branches, etc.) along the route. The takeoff site should be selected where sand roll-up is unlikely to occur (ideally on paved ground) to prevent breakdowns. Also, the sky above the site should have good visibility.

(ii) Attach cameras and other necessary equipment to the UAV's fuselage and prepare the propeller and other equipment for flight.

(iii) Check the propeller of the UAV for damage. Also, turn the propeller by hand to check if there are any abnormalities in the joints, or if there is any abnormal noise from the motor, etc.

(iv) Turn on the power of the transmitter and then the UAV. (When using an RTK base station, power them on before the UAV.)

(v) Confirm that the transmitter is properly connected to the network and the UAV body, and load the preset flight route.

(vi) Confirm the following points for flight preparation.

- Is there sufficient remaining battery power in the transmitter and UAV body?
- Is the location information acquisition such as GPS performing normally?
- Is the camera working properly?
- Is there not an error message?

(vii) Check the machine settings as follows.

- Is the altitude for automatic return set to an altitude where there are no obstacles?
- Is the upper limit of the altitude within the range of the regulations?
- Is there no problem with the settings when the signal with the transmitter is lost (hovering)?
- Check for flight route errors.

(viii) Calibrate the compass. The calibration method must be performed immediately before the flight according to the manual of each UAV. In addition, the IMU will be calibrated as necessary.

(ix) Check the connection of equipment other than UAVs (RTK base stations, etc.) to be used in connection with the transmitter. When using an RTK base station, check the following points.

- Are the coordinates displayed correctly?
- Is the remaining battery power sufficient? Also, is it set to warn when the remaining amount is insufficient?
- Are all satellites, a system control software, transmitters, and RTK base stations properly connected?

(x) After completing flight preparations, reconfirm that there are no abnormalities in the UAV and transmitter, etc., and that no errors are displayed on the screen, and then start flying.

(xi) After takeoff, confirm that the UAV is hovering stably and that there are no abnormalities in the propeller or motor noise. In addition, check whether the UAV aircraft can move forward and backward, left and right, and turn left and right normally by manual operation. If it is confirmed that there is no abnormality, the predefined flight mission is initiated.

(xii) When the battery reaches approximately 25%, end the flight as a safety precaution.

(xiii) After the flight, immediately turn off the UAV's power for safety.

(16) Record

- After survey, immediately confirm that there are no abnormalities in storage conditions, etc.

Section II. Survey data analysis and publication

2.1 Data analysis

2.1.1 Detection of beach litter from images

(1) Manual detection
Manual detection of beach litter from images requires less expertise and skill than automated detection. In previous studies (Deidun et al. 2018; Andriolo et al. 2020; Escobar-Sánchez et al. 2021; Andriolo et al. 2021; Taddia et al. 2021), the images displayed on the monitor screen were zoomed in and beach litter was visually counted, such as left-to-right and top-to-bottom, marking and adding litter classification information. According to the previous studies, detection rates are valuable for several factors (see Table 13).

Table 13. Several factors related to detection rates

Factor *1,2	Note
Image resolution (GSD)	200 pix/m (GSD = 0.5 cm) is a good solution to map plastic debris. *3 RGB cameras with the highest possible resolution can make the GSD smaller.
Experience of the operator	Operator training should be required in order to improve their confidence with UAV-based mapping. *3
Image background	Sand, vegetation, footprints, etc. *1
Conditions of beach litter	Fully visible, partially buried, broken, placed close to each other etc. *1,2
Beach litter size	Larger items (2.5 cm <) are easier to find. *2
Beach litter color	White, black, brown, and transparent are harder to find, while unnatural colors on the beach such as yellow, blue, pink, orange, red, and bright green are easier to find. *2
Beach litter shape	String/cord, lines, and squares are harder to find.*2
Environmental conditions	Coastal hinterland vegetation, weather etc.

Notes:
*1 Andriolo et al. 2020b
*2 Escobar-Sánchez et al. 2021
*3 Taddia et al. 2021

Some studies used other information to assist with beach litter detection. For example, multispectral data (near-infrared (NIR) and Normalized Difference Vegetation Index (NDVI)) were used to distinguish vegetation from AMD (Taddia et al. 2021). There was also a research case study using a mobile GIS application to confirm beach litter of uncertain category in manual image screening, the result of which was edited on the mobile application during in-situ visual inspection, updating the item attributes with the category/material and color detected in-situ (Andriolo et al. 2020).

The previous studies used existing manual survey item lists (e.g., the OSPAR objects list (OSPAR Commission, 2010) and the Master List of Categories of Litter Items (European Commission, 2013)) to classify beach litter.

(2) Automated detection
There are two main automated data analysis methods for detecting beach litter from images: Object detection by bounding box (hereafter, shortened as object detection), which detects and classifies objects by bounding box, and image segmentation, which classifies objects by pixel unit of the image.

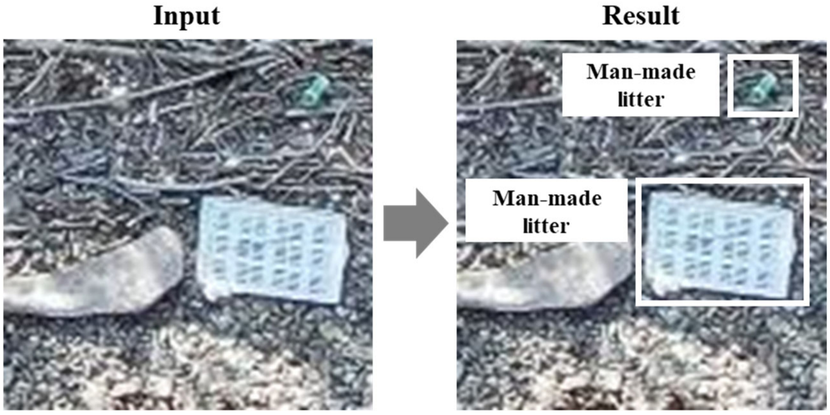

Figure 9. Object detection

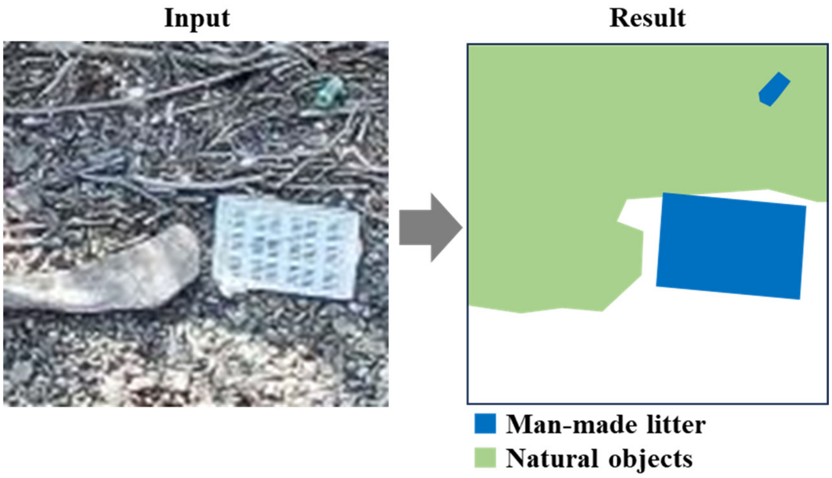

Figure 10. Image segmentation

Considering the characteristics of each method, the data analysis method should be selected based on the status of litter washed ashore. Object detection can estimate the total number of pieces of beach litter by detecting each individual piece of litter. It is suitable for cases where the pieces of litter are not close to each other, because the boundary of each piece of litter is clear enough to identify each individual piece.

Since semantic segmentation, a type of image segmentation can detect beach litter at the pixel level, its area [m^2] and volume [m^3] can be estimated by combining it with aerial images taken by UAVs and orthorectified. This method is suitable for cases where beach litter is accumulated, and it is difficult to identify individual items (see Appendix 1).

Instance segmentation, which is also a type of image segmentation, can estimate the total number of pieces of beach litter like object detection and can detect beach litter at the pixel level, its area [m^2] and volume [m^3] can be estimated by using orthoimages like semantic segmentation.

For both object detection and image segmentation, image analysis techniques based on deep learning (hereinafter referred to as deep learning models) have recently been applied (e.g., Kako et al. 2020; Hidaka et al. 2022; Martin et al. 2021). The development of deep learning models requires expertise, a high-end GPU-enabled computer, and the preparation of training data (annotation work) necessary to train the models.

In particular, training data preparation is a time-consuming task and requires many images. In the case of Sugiyama et al. (2022), it took about two months and 15 staff members to prepare a Beach Litter Dataset of 3,500 images for semantic segmentation (a type of image segmentation), classifying man-made and natural litter pixel by pixel. There are also other databases, such as the Beach Plastic Litter

Dataset (Hidaka et al. 2023), which extracts plastic litter from beach images taken from the ground, and the TACO Dataset (Proença and Simões, 2020), which extracts litter from beaches and classifies it into 28 categories, such as beverage cans and plastic bags. Although the datasets described above are developed from photos taken from the ground, they can also be applied to aerial images taken by UAVs. Considering the workload, it is practical to use these existing public data as training data. However, the datasets might exhibit biases based on the region and/or substrate conditions of the litter images. Given the nearly infinite range of purposes for utilizing litter prediction models, custom datasets tailored to specific tasks are also essential.
The source code for the image analysis model is available for free and open source (see Table 14).

Table 14. Examples of source code and image analysis model

Method	Name	URL
Object Detection	Torchvision	https://github.com/pytorch/vision
	HRNet	https://github.com/HRNet/HRNet-Object-Detection
	YOLOv5	https://github.com/ultralytics/yolov5
Image Segmentation	Segmentation Models	https://github.com/qubvel/segmentation_models.pytorch
	HRNet	https://github.com/HRNet/HRNet-Semantic-Segmentation

The Japan Agency for Marine-Earth Science and Technology (JAMSTEC) is developing a web application (will open to the public in 2024) using the semantic segmentation model developed by Hidaka et al. 2022. Since it uses a pre-trained model, it does not require coding and training of training data and models, and can detect litter in images simply by loading images using drag-and-drop operations on a web browser, making it possible to analyze images without expertise in deep learning models. Such an application has the potential to significantly reduce labor costs compared to visual image analysis (manual detection of beach litter from images).
The resolution of objects that a deep learning model can detect from images taken by a UAV is different from that of a visual inspection (see Appendix 1). It also depends on the training data used to train the model. For example, in the case of the semantic segmentation model of Hidaka et al. 2022, the resolution is about 30 pixels (5 cm x 6 cm) when the GSD of the image taken by a UAV is about 1 cm (see Appendix 1). It is assumed that beach litter higher than 2-3 cm was generally detectable given the range of height error in the demonstration test cases (see Appendix 1). Regardless of the resolution, it is difficult for UAVs to detect beach litter if the litter is not visible because it is piled on top of each other.

2.1.2 Quantification of beach litter

While image analysis using ordinary UAV images can only determine the number and distribution of litter, orthoimages based on RTK survey results (hereinafter referred to as orthoimages) can be used to estimate the number of density [units/ m^2], area [m^2], and volume [m^3] of litter. To implement orthorectification, it is necessary to acquire images using ground control points (GCP) or RTK equipment as described in Section I, Survey Equipment.
Orthorectification can be implemented using Pix4Dmapper (https://www.pix4d.com/jp/product/pix4 dmapper-photogrammetry-software/), Agisoft Metashape (https://oakcorp.net/ agisoft/), and OpenDr oneMap (https://www.opendronemap.org/) software, etc. Terra Mapper (https://mapper.terra-drone.n et/), a comprehensive platform software provided by Terra Drone Corporation, is capable of estimati ng the volume [m^3] of litter washed ashore in addition to orthorectification (see Appendix 1). Althou gh the remote sensing and AI survey method has lower quantification accuracy than manual surveys, it is possible to cover a larger area and achieve semi-quantification.
The flowchart below summarizes the process from image capture and surveying to detection and quantification of litter washed ashore. Solid boxes in the flowchart refer to data analysis, and dotted boxes refer to data to be output.

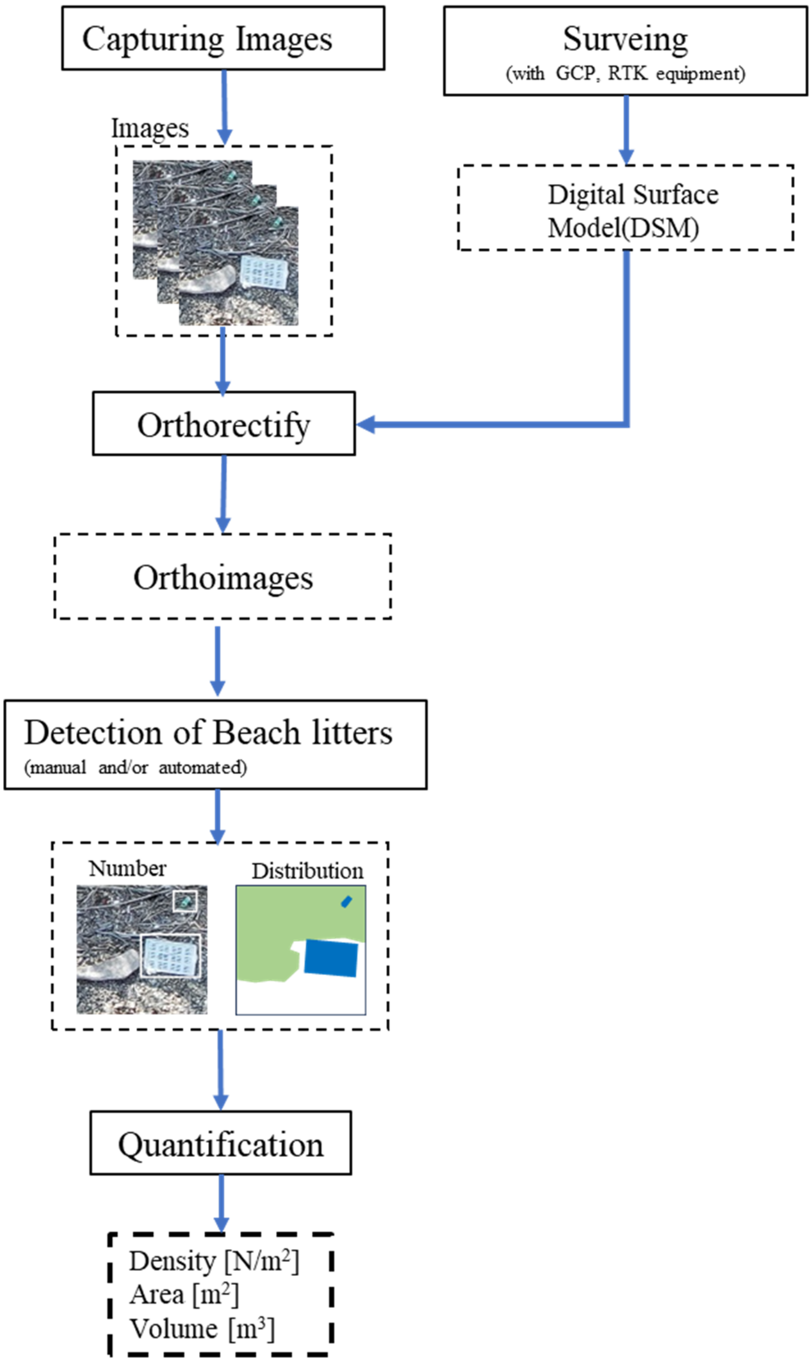

Figure 11. Flowchart of the process from image capture and surveying to detection and quantification of beach litter

2.2 Data publication

2.2.1 Data unit

According to the inquiry results, Table 15 shows the units of data used in the survey results and the reasons for selecting these units. The most common response was "the quantity of litter," followed by "Litter covered area" and "Number density of litter (see Figure 1). Using the quantity of litter per survey and survey area, a density of litter by number can be estimated. The area covered by litter is obtained by image segmentation or counting pixels of the detected litter in the bounding box. Litter volume can be estimated as the demonstration test (see Appendix 1). However, considering the purpose of estimating the flow of waste plastic, 3D information can only be obtained accurately from UAVs, a potential approach for linking the information obtained from various locations may be to select a photography method that can estimate the area covered by beach litter and the number of items per unit area in the target area.

It is important to save raw data such as orthoimages for reanalysis, as future technological developments may make it possible to estimate the amount of litter in other units.

■ Point

From the perspective of data comparison, the recommended data units are the density of litter by number, and litter coverage area. Volume is another optional data unit.

Table 15. The inquiry results _Data unit

Case No.	What are the units used to quantify litter?	Please tell us why you chose the units on the left.
1	Quantity of litter, Number density of litter, Litter covered area	Marine litter abundance, hotspots location, clean coast index, clean-up operations
2	Quantity of litter, Litter covered area, size of litter	Traditionally we worked with Quantity of litter, size of litter, area covered. I believe that drone based survey can and should also compute weight and volume (we are working to test the last two parameters)
3	Quantity of litter, Number density of litter	They are the most representative.
4	Volume, Litter covered area	For use in simulations
5	Volume, Quantity of litter	-
6	Quantity of litter, Number density of litter, Litter covered area	Weight and volume impossible to measure
7	Quantity of litter, Number density of litter, Litter covered area	-
8	Quantity of litter, Number density of litter, Litter covered area	The used units have been selected to be comparable with the ones we obtain from the “real survey” conducted on the field, from which we will compare our data. The volume or weight of the recovered material, considered all together, does not allow a subsequent classification based on type, which we are interested in doing.
9	Volume, Litter covered area	Because it is easy to calculate.
10	Quantity of litter, Number density of litter, Litter covered area	These are the most relevant ones for our purpose, which is detecting where litter accumulates and overall litter pollution.
11	Quantity of litter, Number density of litter	-
12	Quantity of litter, Number density of litter, Litter covered area	-
13	Quantity of litter, Number density of litter	Same as validation data
14	Litter covered area	Matching the artificial targets that we used in this particular experiment
15	Quantity of litter, Litter covered area	To quantify and classify the litter both spatially and temporally
16	Quantity of litter, Number density of litter, Litter covered area	-

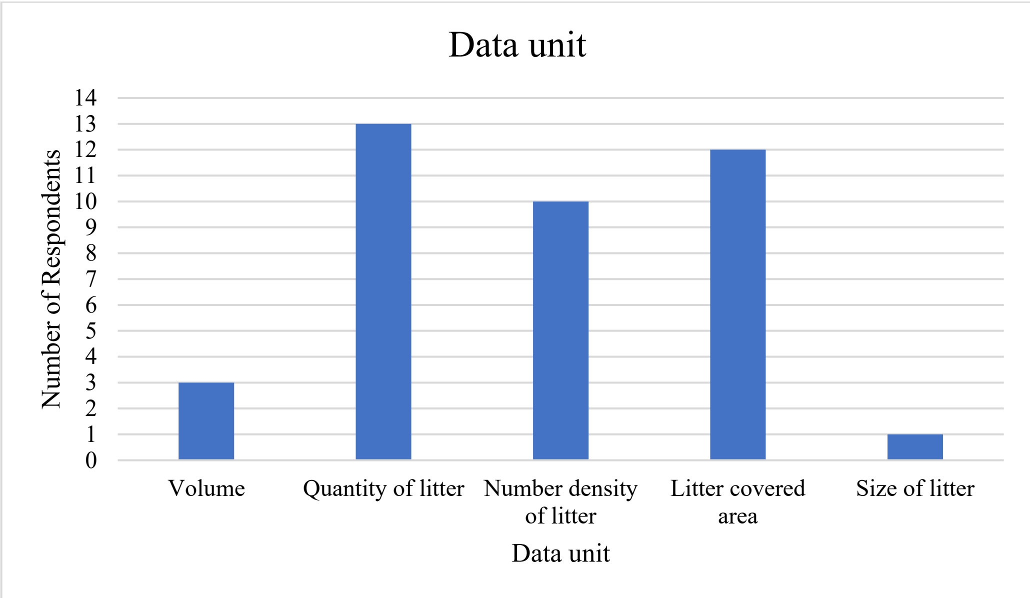

Figure 12. The inquiry results _Data unit

2.2.2 Data publication

The information published as survey results includes Quantity of litter, Percentage of litter composition, Distribution map of litter amount, Distribution map of litter types (see Appendix 1), DSM, etc. (see Table 16).
It is not a question of which is better, or which should be standardized; rather, it is important to properly quantify the information according to the purpose (Kako et al. 2024)エラー! 参照元が見つかりません。 (see Table 17).
When publishing survey data, it is useful to visualize the data so that it can be easily compared with data from other locations and easily understood by non-experts. In the case of Gonçalves et al. (2022), the density of litter by number, and litter coverage area are visualized using grid maps (see Figure 13). For publishing the grid map, web GIS services (e.g., INSPIRE (https://inspire-geoportal.ec.europa.eu/), Coastal Marine Litter Observatory (CMLO, https://cmlo.aegean.gr/)) can be useful. In terms of unifying the units for evaluating global quantities, it will be important to construct a system that allows data sharing so that such analysis can be performed in image analysis (Kako et al. 2024).エラー! 参照元が見つかりません。 There are various grid sizes (5 m x 5 m, 10 m x 10 m, etc.), but any size is considered acceptable as long as the data is compatible with other grid survey data by rescaling.
For the data publication, it is also recommended to provide information necessary for data comparison (e.g. lower detection limit of litter, etc.).

Table 16. The inquiry results _how to publish survey results

Case No.	Information published as survey results
1	Number of items per square meter
2	"Amount of litter": we used tables with number of objects and percentages. Regarding "Distribution map of litter amount", we used grids of 5m x 5m, and showed the percentages of occupancy (or number of items) in the single cells. However, this approach was just a test/example, and should be better defined.
3	10m x 10m, number of items in the area
4	-
5	g/100m2. Because the survey of beach litter is determined to be 10m x 10m and conducted.
6	Items m2
7	Amount of litter, Percentage of litter composition, Distribution map of litter amount, Distribution map of litter types, DSM
8	Amount of litter: we normally use the Quantity of litter / square meter on the surveyed area. It is also possible to calculate the linear amount of litter (Quantity of litter / /m), considering the extension of the beach. Distribution map: we divide the areas into a small "square" with a grid, and we calculate the Quantity of litter found in these sub-areas. After that, we define a graduate scale of "litter density", assigning a "scale" of color to each interval of this value. The final map visualizes the density with the intensity/nuance of the colors. It is possible to do that also for ONLY one type of litter, or type of material, so visualize difference in density distribution depending on the litter type/material.
9	Volume and Coverage Area
10	These are included in the report as average litter density for each beach and accumulation areas using heat maps. Characterization and composition are generated from an in-situ survey of a smaller area (sub-sampling and extrapolation). This characterization is in-situ as it is mandatory for compliance with EU-regulations and/or programs. Flights are used to survey larger areas and provide insight on accumulation, abundance, and density of marine litter pollution.
11	Amount of litter, Distribution map of litter amount
12	Distribution map of litter amount, Distribution map of litter types
13	Items/m2 surface
14	Percentage of litter composition
15	Percentage of litter composition, Distribution map of litter types, DSM
16	Amount of litter, Percentage of litter composition, Distribution map of litter types, DSM

Table 17. Example of how to use survey results information

Survey results information	Uses of the information (Kako et al. 2024)
Quantity of litter per item type	It facilitates formulation of policies that contribute to the reduction of plastic litter, for example, by restricting the use of certain products.
Spatial distribution of litter	It can be used to identify areas in need of intensive cleaning.
Volume and weight estimates	They provide very important information in the calculation of disposal costs.

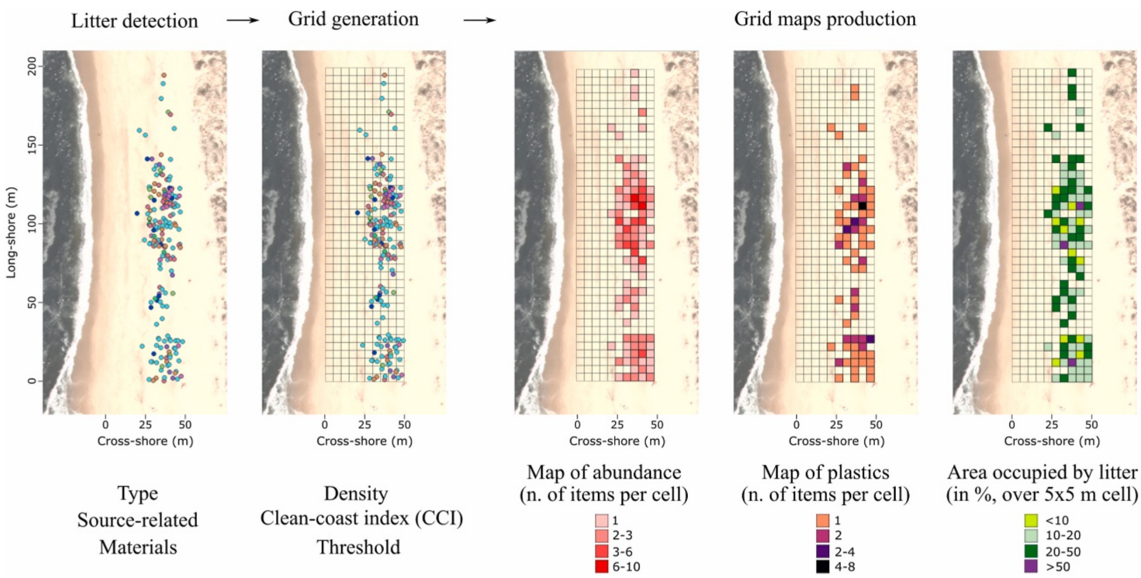

Figure 13. Example of drone-based litter survey outcomes based on grid map production.
a) Detected litter items on orthoimage. Colors can indicate different type, source and/or material; b) grid (in the example, 5 m x 5 m) generation allows counting of the desired category within each cell. For instance, thematic map of litter abundance (c), map of types and/or materials, such as plastic (d), distribution of the size and the actual area occupied by litter (e), among others, can be generated from the points dataset. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.) (Gonçalves et al. 2022)

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