Result of demonstration test for beach litter survey using UAVs

1. Purpose of the demonstration test

The purpose of the demonstration test is to ensure the practicality of Annex Section I. 1 and II of the guideline with following elements(Table 1).

Table 1. Points to ensure practicality

Concrete-ness	Make sure the procedures in the guideline are concrete enough.
Versatility	Note that the contents of the guideline need to be generalized so that it can be used as a reference even when the equipment used or the research environment is different.
Novelty	Verify whether the guideline can solve the problems of efficiency, accuracy, and reproducibility of the existing surveys to be verified.

2. Demonstration test outline

Table 2 shows the outline of the demonstration test.

Table 2. Demonstration test outline

Items	Outline
Survey period/ Frequency	23–29th July 2023 Once at each beach
Survey points	A: Gravel beach in Iyo city, Ehime, Japan (see Figure 1) B: Gravel beach in Uwajima city, Ehime, Japan (see Figure 2)
Survey area	A: 50 x 17.1 m B: 20 x 4.3 m (Longshore x cross-shore)
Survey method (See Appendix A for detailed information)	I. Drone survey with automatic detection of beach litter by AI II. Drone survey with manual detection of beach litter from images III. On-site visual inspection (implemented with reference to the "Index Evaluation Method for Waterside Scattered Debris (Coastal Version)" (Tohoku Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism, etc.)) IV. Collection survey (with reference to the “Guidelines for Investigating the Composition of Drifted Debris for Local Governments (June 2020, 2nd edition)”) * Methods III and IV can be performed by the general public with the guidance of an experienced person.
Survey target	I number and volume of beach litter (including driftwood (non-processed))

	II-III volume of beach litter (including driftwood (non-processed)) IV number, volume, and weight of beach litter (including driftwood [non-processed])
Researcher	Dr. Kako lab, JANUS, Futaba Inc.
Image Processor/Analyst	Image process: Futaba Inc. Image analysis: Dr. Kako
Method of Organizing Results	- Comparisons of the amount of beach litter estimated by each survey method (size detectable by drone and AI / all litter size) - Verification of human error in visual surveys (reproducibility) - Comparison of time spent on survey - Comparison of survey cost

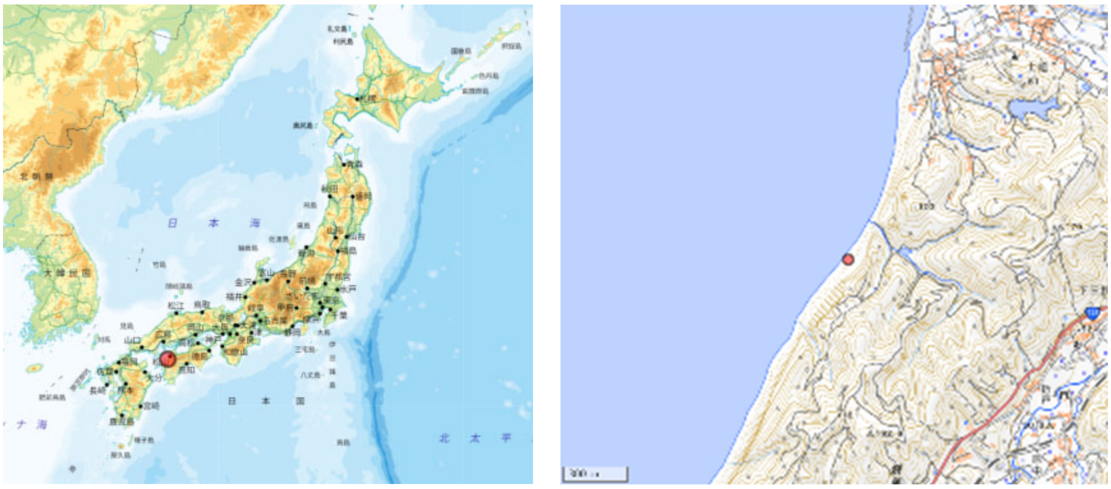


Figure 1. Location of Mori beach in Iyo city, Ehime, Japan (A)

(Source: GSI map)

Figure 2. Location of Hirai beach in Uwajima city, Ehime, Japan (B)

(Source: GSI map)

3. Results of the demonstration test

3.1 Results of comparisons of the amount of beach litter estimated by each survey method

3.1.1 Comparison of survey and estimation results limited to size detectable by drone and AI

Since the resolution of the objects that the image analysis model used in this demonstration can detect is about 30 pixels (5 x 6 cm), the result of the drone and AI method was first compared to the ground truth data of the beach litter volume, the size of which is larger than the approximate detectable size (5 x 6 cm, or 100 cm^3).

As shown in Table 3, approximately 66–82% of the man-made object volume could be detected if survey targets were limited to sizes detectable by drones and AI. As shown in Table 4, The same can be said for the number of pieces of the man-made object. The reason why the detection rate at location B is lower than that at location A is that the man-made objects were covered by driftwood washed ashore, making detection at location B more difficult (see Figure 3).

Table 3. Results of volume comparison between drone and AI estimates and the ground truth for man-made objects larger than detectable size (unit: m^3)

Location	Drone and AI	Ground truth
A (Iyo)	0.04	0.049
B (Uwajima)	0.19	0.288

Note:

1. Values of the ground truth are rounded to the fourth decimal place.
2. These results include the uncertainty associated with each estimate, including detection of non-litter as litter or failure to detect litter.
3. The amount of wood (lumber, etc.) from man-made objects was excluded because the item is difficult to distinguish from driftwood (natural objects).
4. The estimated volume of man-made objects at location A detected by the drone and AI method was 0.11m^3, but a later review revealed that 0.07m^3 of driftwood was incorrectly detected as a man-made object, so the estimated value of man-made objects was 0.04m^3.
5. See IV. Collection survey in Appendix A for the method to investigate the ground truth.

Table 4. Results of piece count comparison between drone and AI estimates and the ground truth for man-made objects larger than detectable size (unit: pieces)

Location	Drone and AI	Ground truth
A (Iyo)	61	67
B (Uwajima)	517	625

Note:

1. The amount of wood (lumber, etc.) from man-made objects was excluded because the item is difficult to distinguish from driftwood (natural objects).
2. As for the ground truth data, pieces of item types of which the average volume is more than 100 cm^3 were counted. Therefore, pieces of litter that are undetectable by drones and AI are included in the above ground truth.
3. The drone and AI method could count multiple objects as one.
4. These results include the uncertainty associated with each estimate, including detection of non-litter as litter or failure to detect litter.

Figure 3 Man-made objects covered by driftwood washed ashore at location B

3.1.2 Comparison of survey and volume estimation results including all litter size

Next, for beach litter larger than 2.5cm, including sizes undetectable by drone and AI, estimates (Table 5, 7) and ground truth data (Table 6, 8) of beach litter volume were compared by each survey location. Estimates including beach litter of undetectable size differed more from the ground truth data than estimates excluding it. This is because smaller litter is more affected by resolution and driftwood cover (see Figure 3). Although this is considered a limitation of the remote sensing technology, future improvements in drone resolution and image analysis technology are expected to improve the drone survey problem.

On a beach with a high density of litter, such as Location B, it was difficult to accurately quantify each of the man-made and natural objects for the reasons mentioned above, but the total amount was estimated to be 1.243 m^3 (see Table 8), which is relatively close to the ground truth (1.55 m^3 (see Table 7)).

Table 5. Results of volume estimates at location A (unit: m^3)

Objects	Drone and AI	Drone and manual	On-site visual inspection
Man-made	0.04	0-0.1	0.058
Natural	0.66	0.8-6.4	1.875

Note:

1. Values of on-site visual inspection are rounded to the fourth decimal place.
2. These results include the uncertainty associated with each estimate, including detection of non-litter as litter or failure to detect litter.
3. The estimated volume of man-made objects at location A detected by the drone and AI method was 0.11m^3, and that of natural objects was 0.59m^3. However, a later review revealed that 0.07m^3 of driftwood was incorrectly detected as a man-made object, so the estimated value of man-made objects was 0.04m^3, and that of natural objects was 0.66m^3.
4. Taking into account the uncertainty of detection by the human eye from aerial images, the estimates for the drone and manual method are estimated using a method that provides a range of estimates (see Table 20).
5. On-site visual inspection estimates are the average of the survey results from each of the two surveyors on the same survey area (see Table 10 for detailed results).
6. See I-III in Appendix A for the methods to conduct surveys and estimates.

Table 6 Ground truth data of beach litter volume at location A (unit: m^3)

Objects	Ground truth
Man-made	0.115
Natural	3.854

Note:

1. Values are rounded to the fourth decimal place.
2. See IV. Collection survey in Appendix A for the method to investigate the ground truth.

Table 7 Results of volume estimates at location B (unit: m^3)

Objects	Drone and AI	Drone and manual	On-site visual inspection
Man-made	0.19	0.04-0.32	0.223
Natural	1.36	0.32-2.56	0.795

Note:

1. Values are rounded to the fourth decimal place.
2. These results include the uncertainty associated with each estimate, including detection of non-litter as litter or failure to detect litter.
3. Taking into account the uncertainty of detection by the human eye from aerial images, the estimates for the drone and manual method are estimated using a method that provides a range of estimates (see Table 20).
4. On-site visual inspection estimates are the average of the survey results from each of the two surveyors on the same survey area (see Table 10 for detailed results).
5. See I-III in Appendix A for the methods to conduct surveys and estimates.

Table 8 Ground truth data of beach litter volume at location B (unit: m^3)

Objects	Ground truth
Man-made	0.469
Natural	0.774

Note:

1. Values are rounded to the fourth decimal place.
2. See IV. Collection survey in Appendix A for the method to investigate the ground truth.

3.1.3 Comparison of survey and pieces of number estimation results including all litter size

Next, for beach litter larger than 2.5 cm, including sizes undetectable by drone and AI, estimates and ground truth data of the beach litter number were compared with each other by survey location.

The gap was even larger when the estimates were compared with ground truth data including beach litter of undetectable size (see Table 9). This is because smaller litter is more affected by resolution and driftwood cover (see Figure 6). In addition, this is because it is considered that the method of image analysis used in drone and AI (semantic segmentation), unlike object detection, is not suitable for counting the number of pieces. In the case of semantic segmentation, the number of pieces of beach litter tends to be underestimated in the high-density area of beach litter, such as the demonstration site. Conversely, the automatic detection method 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 item.

Table 9 Results of piece count comparison between drone and AI estimates and ground truth for man-made objects (unit: pieces)

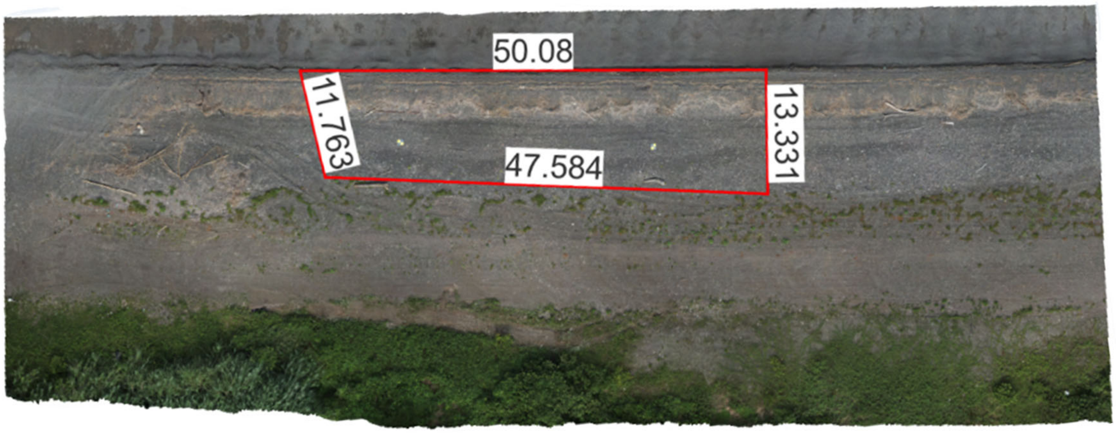
Location	Drone and AI	Ground truth
A (Iyo)	61	2,027
B (Uwajima)	517	2,477

Note:

1. The drone and AI method could count multiple objects as one object.
2. These results include the uncertainty associated with each estimate, including detection of non-litter as litter or failure to detect litter.
3. As for ground truth, litter fragments, including natural objects, were not counted. Only pieces of hard plastic were counted.

Before collecting

After collecting

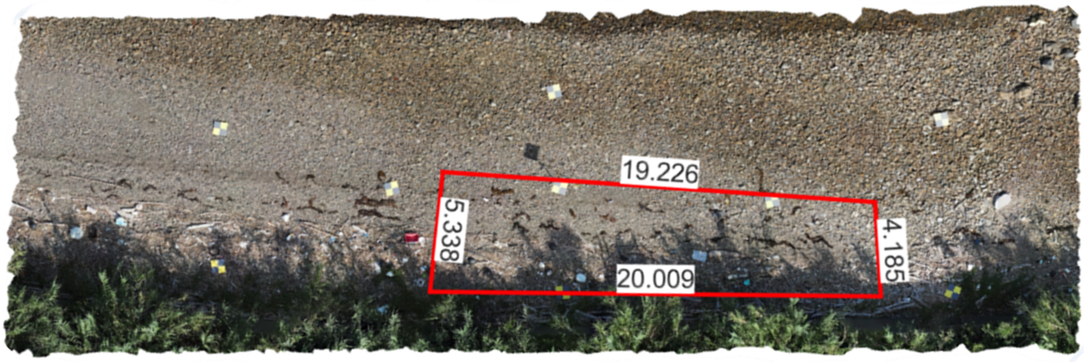


Orthoimage of location A (red square is survey area, values represent length (m))

Figure 4 Pictures of survey area (A)

Before collecting

After collecting



Orthoimage of location B (red square is survey area, values represent length (m))

Figure 5 Pictures of survey area (B)

3.2 Results of human error verification for visual inspection

Table 10 Inter-observer variability of on-site visual inspection (method III) results

Survey location	Researcher	Man-made objects (m^3) visual inspection	Man-made objects (m^3) ground truth	Natural objects (m^3) visual inspection	Natural objects (m^3) ground truth
A 50m longshore	α	0.05	0.115	1.5	3.854
	β	0.065		2.25	
B 20m longshore	α	0.175	0.469	0.83	0.774
	γ	0.27		0.76	

Note:

1. Values are rounded to the fourth decimal place.
2. Calibration was conducted at location B.

Table 11 Inter-observer variability in drone and manual (method II) results

Survey location	Researcher	Man-made objects (m^3) visual inspection	Man-made objects (m^3) ground truth	Natural objects (m^3) visual inspection	Natural objects (m^3) ground truth
A 50m longshore	α	0.045 (0-0.1)	0.115	2.5 (0.8-6.4)	3.854
	β	0.035 (0-0.1)		6.383 (0.8-6.4)	
B 20m longshore	α	0.265 (0.04-0.32)	469	1 (0.32-2.56)	0.774
	β	0.231 (0.04-0.32)		1.4 (0.32-2.56)	

Note:

1. Values in parentheses indicate estimated quantities using a rank table (see Table 20).
2. Values are rounded to the fourth decimal place.

3.3 Comparison of time spent on survey

Table 12 Time spent on survey in location A (Iyo)

Survey methods		Data sampling (unit: hour)			Data processing/analysis (unit: hour)		Total person-hour
		Preparation	Measurement	Sampling	Processing	Detection, classification, quantification	
I	Drone and AI	2 (3 workers)	1 (3 workers)	1 (3 workers)	8.2 (1 worker)	10 (1 worker)	30.2
II	Drone and manual detection					0.63 (1 worker)	20.82
III	On-site visual inspection	0.5 (7 workers)	0	0.2 (1 worker)	0	0	3.7
IV	Collection survey		0	2.25 (13 workers)	0.25 (2 workers)	2.66 (12 workers)	65.17

Note:

1. The quantification effort for the collection survey includes not only volume measurements, but also counts and weights of beach litter.
2. Data processing time does not include automatic processing time, only manual processing time.
3. Collection survey classified litter into 42 items; other survey methods used 2 types (natural/man-made).
4. If each worker performed a different task, describe as 1 worker.
5. In Japan, it takes about 20 hours to learn how to operate a drone if you go to drone training school. In one case, it took about two months and 15 people to prepare a beach litter dataset of 3,500 images for semantic segmentation, classifying man-made and natural litter pixel by pixel. Therefore, it is practical to use publicly available existing data.

Table 13 Time spent on survey in location B (Uwajima)

Survey methods		Data sampling (unit: hour)			Data processing/analysis (unit: hour)		Total person-hour
		Preparation	Measurement	Sampling	Processing	Detection classification quantification	
I	Drone and AI	2 (3 workers)	1.5 (3 workers)	0.33 (3 workers)	8.21 (1 worker)	14.5 (1 worker)	34.19
II	Drone and manual detection					0.48 (1 worker)	20.16
III	On-site visual inspection	1.05 (3 workers)	0	0.23 (2 workers)	0	0	3.61
IV	Collection survey	0.5 (2 workers)	0	3.25 (4 workers)	0.25 (2 workers)	4.5 (7 workers)	46

Note:

1. The quantification effort for the collection survey includes not only volume measurements, but also counts and weights of beach litter.
2. Data processing time does not include automatic processing time, only manual processing time.
3. Collection survey classified litter into 42 items, other survey methods used 2 types (natural/man-made).
4. If each worker performed a different task, describe as 1 worker.
5. In Japan, it takes about 20 hours to learn how to operate a drone if you go to drone training school. In one case, it took about two months and 15 people to prepare a beach litter dataset of 3,500 images for semantic segmentation, classifying man-made and natural litter pixel by pixel. Therefore, it is practical to use existing publicly available data.

3.4 Comparison of survey cost

Table 14 Survey cost of location A (Iyo)

(unit：USD)

<table>
<tr><th colspan="2" rowspan="2">Survey method</th><th colspan="3">Initial cost</th><th colspan="6">Operating cost</th><th rowspan="2">Total</th></tr>
<tr><th>Equipment including rental</th><th>Software</th><th>License, registration of drone, training</th><th>Equipment transportation</th><th>Travel expenses</th><th>Maintenance cost</th><th>Labor cost</th><th>Waste disposal</th></tr>
<tr><td>I</td><td>Drone and AI</td><td rowspan="2">469
~1,675</td><td>6,738</td><td rowspan="2">1,424
~2,134</td><td rowspan="2">482</td><td rowspan="4">982</td><td>1,205
~2,623</td><td>1,154</td><td rowspan="2">0</td><td>12,454
~15,788</td></tr>
<tr><td>II</td><td>Drone and manual detection</td><td>3,546</td><td>709
~2,127</td><td>795</td><td>8,407
~11,741</td></tr>
<tr><td>III</td><td>On-site visual inspection</td><td>391</td><td>0</td><td>0</td><td>0</td><td>0</td><td>141</td><td>0</td><td>1,514</td></tr>
<tr><td>IV</td><td>Collection survey</td><td>1,488</td><td>0</td><td>0</td><td>114</td><td>95</td><td>2,490</td><td>469</td><td>5,638</td></tr>
</table>

Note:

1. 1 USD = 140.97 yen (To convert yen to USD, we used the table of exchange rates for yen (TTM) on July 31, 2023. Decimal values resulting from the conversion were rounded off.)
2. Drone prices are listed for a one-week rental. Costs vary by model and rental company. If the drone is purchased, the cost ranges from approximately 7,094 to 21,281 USD.
3. Drone with RTK capabilities was used, and the cost of related equipment (e.g., RTK base station) is included in “Equipment including rental”.
4. Operating cost excludes daily allowance and accommodation costs.
5. The demonstration test included two software costs because image processing and image analysis were performed by different parties, but the actual costs are expected to be lower.
6. Only travel expenses within Ehime Prefecture are included.
7. Insurance costs for the drone, which are included in maintenance costs, reflect amounts for plans with 200 million yen for bodily injury and 500 million yen for property damage.
8. Maintenance costs include the cost of consumables.
9. The labor cost was calculated based on the unit cost of a survey engineer applied by the Japanese Ministry of Land, Infrastructure, Transport and Tourism in 2023. The labor cost per hour is approximately 38 USD. This labor cost does not include overhead costs.

Table 15 Survey cost of location B (Uwajima)

（unit：USD）

Survey method		Initial cost			Operating cost					Total
		Equipment including rental	Software	License, registration of drone, training	Equipment transportation	Travel expenses	Maintenance cost	Labor cost	Waste disposal	
I	Drone and AI	469 ~1,675	6,738	1,424 ~2,134	482	1,123	1,205 ~2,623	1,306	0	12,747 ~16,081
II	Drone and manual detection		3,546				709 ~2,127	770		8,523 ~11,857
III	On-site visual inspection	432	0	0	0		0	137	9	1,701
IV	Collection survey	1,408	0	0	114		151	1,757	51	4,604

Note:

1. 1 USD = 140.97 yen (To convert yen to USD, we used the table of exchange rates for yen (TTM) on July 31, 2023. Decimal values resulting from the conversion were rounded off.)
2. Drone prices are listed for a one-week rental. Costs vary by model and rental company. If the drone is purchased, the cost ranges from approximately 7,094 to 21,281 USD.
3. Although the total station was used for the measurements, the cost of related equipment is not included because it is not realistic to purchase a total station, which costs approximately $10,640, for a single survey.
4. The demonstration test included two software costs because image processing and image analysis were performed by different parties, but the actual costs are expected to be lower.
5. Operating cost excludes daily allowance and accommodation costs.
6. Only travel expenses within Ehime Prefecture are included.
7. Insurance costs for the drone, which are included in maintenance costs, reflect amounts for plans with 200 million yen for bodily injury and 500 million yen for property damage.
8. Maintenance costs include the cost of consumables.
9. The labor cost was calculated based on the unit cost of a survey engineer applied by the Japanese Ministry of Land, Infrastructure, Transport and Tourism in 2023. The labor cost per hour is approximately 38 USD. This labor cost does not include overhead costs.

4. Inter-lab demonstration

Dr. Topouzelis' beach litter detection method (object detection by bounding box) can also work well with images taken according to international guidelines (Annex).

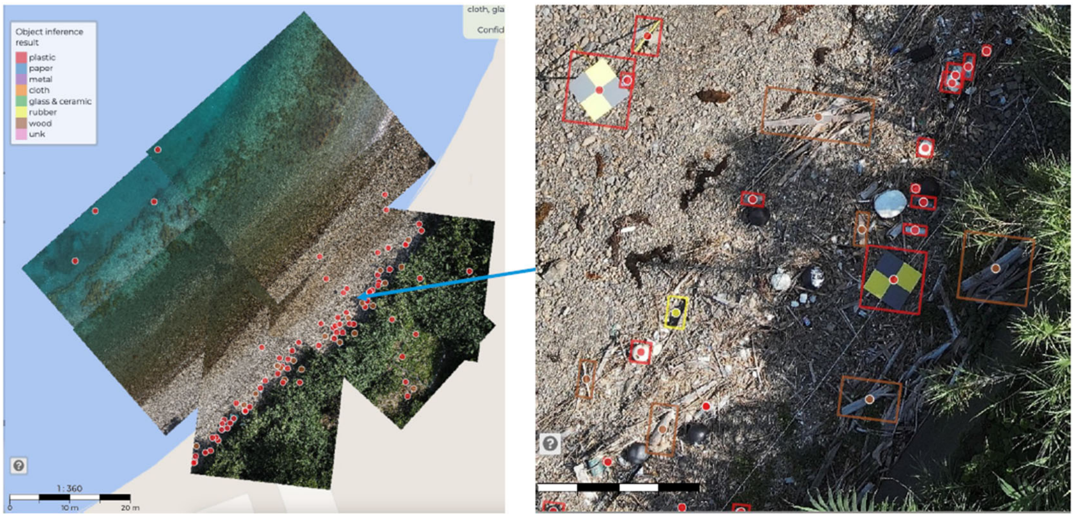


Figure 6 Object detection from the images taken in the demonstration test

Source: Coastal Marine Litter Observatory (CMLO) https://cmlo.aegean.gr/: Case study in Japan (August 2023, Konstantinos Topouzelis and Shin'ichiro Kako)

5. Conclusion

We demonstrated that data sampling of beach litter using drones according to the guidelines worked well (see Table 16). These findings have been added to Section II of Annex.

The results of the survey cost comparison show that the drone-based methods are more expensive than the manual methods due to the high initial cost, but considering that the cost gap between the drone-based methods and the manual methods diminishes as the survey coverage increases, the drone survey can survey a larger area, and the workload and cost of a drone and AI survey is expected to decrease more than that of a manual survey and analysis over a larger survey coverage.

In addition to Table 16, several items were identified that should be added to Annex of the guidelines as the survey was planned, prepared, and conducted (see Table 17).

Table 16 Matters that drone and AI can achieve for beach litter survey

<table>
<tr><th>What drone and AI can do for beach litter survey</th><th>Current technology limitations</th></tr>
<tr><td>Quantification* of detectable size man-made objects
*Semantic segmentation is more suitable for volume estimation on beaches with high litter density. Object detection by bounding box is more suitable for detecting individual pieces of litter on beaches with low litter density.</td><td rowspan="2">There is a minimum size of litter that can be detected by drones and AI. In this demonstration test, the lower limit of detection was about 5x6 cm. This depends on the resolution of the camera and the AI. It is assumed that beach litter higher than 2–3 cm was generally detectable given the range of height error in the demonstration test area (see Table 19).
In addition, it is difficult for drones to detect beach litter if the litter is not visible because it is piled on top of each other.</td></tr>
<tr><td>Identification of the distribution of beach litter on a per-item basis automatically using object detection by bounding box (see Figure 7)</td></tr>
<tr><td>Quantification of beach litter volume automatically using semantic segmentation</td><td>If smaller beach litter is deposited at low height and low density, the error will be greater. On the other hand, when litter is densely drifted ashore, it is difficult to separate and quantify the different types of litter for the reasons described above.</td></tr>
</table>

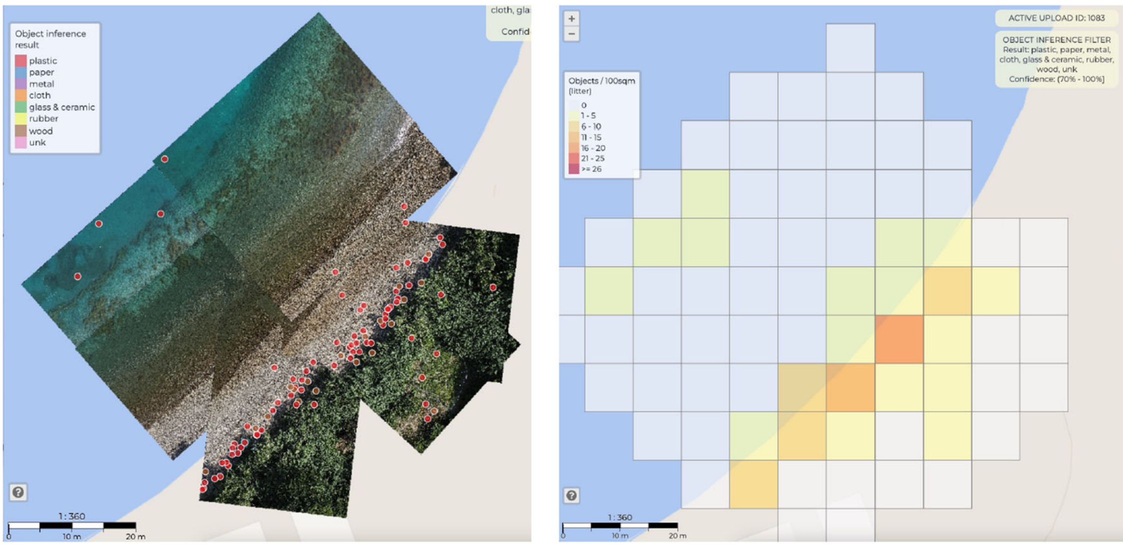


Figure 7 Identification of the distribution of beach litter on a per-item

Source: Coastal Marine Litter Observatory (CMLO): Case study in Japan (August 2023, Konstantinos Topouzelis and Shin'ichiro Kako)

Table 17 Several items were identified that should be added to ANNEX of the guidelines

1. Selection of survey points

- The beach within the survey area must be free of third-party use at the time of the survey (security must be ensured by restricting access to the survey area, etc.).
- If there is a cliff behind the beach, it is not a suitable location because radio waves may be blocked. Also, for safety reasons, fly 10 to 20 meters away from the cliffs.
- If there is vegetation directly above the target, it may not be possible to photograph the target from the sky.

2. Flight plan

- Since a 3D model is made to estimate the volume of beach litter, it is necessary to take oblique shots (-70° angle) as well as -90°.

Figure 8 Oblique shots (left: vertical direction of shoreline, right: horizontal direction of shoreline)

- If the number of photos is too small for the flight route, there is little information about the position of the camera, which reduces the accuracy of the position correction. Also, if there is little overlap, there will be blank areas in the orthoimage. It is better to combine flights parallel and vertical to the shoreline to increase the number of photos.

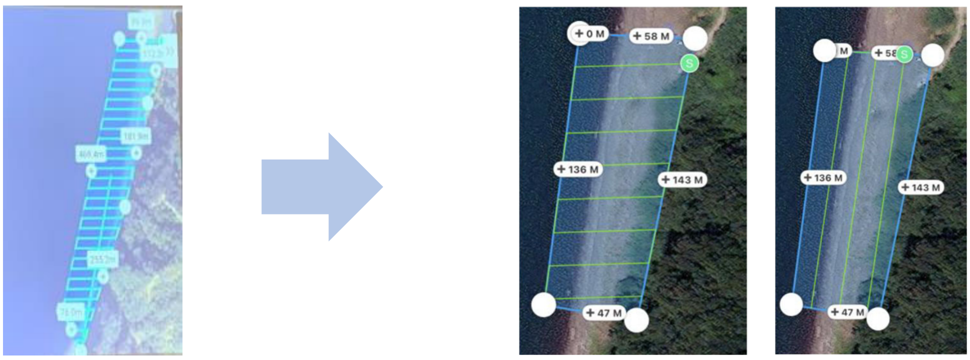
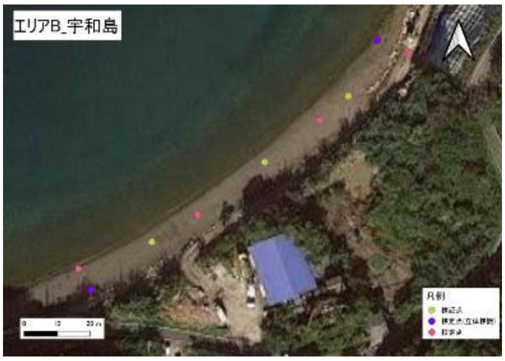
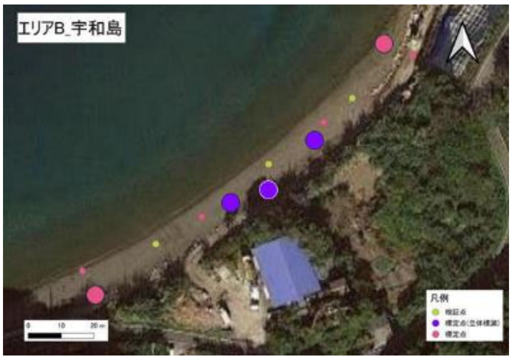


Figure 9 Flight routes (left: before change, right: after change)

- Regarding the placement of ground control points (GCPs), the placement should not be too linear.



Placement of GCPs (before)



Placement of GCPs (after)

Figure 10 Placement of GCPs (purple circle)

3. Drone setting

- The altitude of the drone 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 drone should be set to consider the difference in height.
- The drone's camera settings are basically optimized automatically, but if the operator notices that the image is too dark to clearly see the target litter while shooting, the operator may want to temporarily stop shooting and change the camera settings manually.

4. Safety check

- 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.
- Check the propeller of the drone 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.

5. Flight conducting

- 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 be well visible.
- When the battery reaches approximately 25%, end the flight as a safety precaution.

6. Others

- Drone air transport may not be possible for high-capacity batteries, so they must be transported by land, which takes time to arrive, so it is necessary to schedule transportation well in advance.

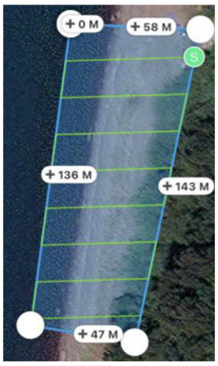
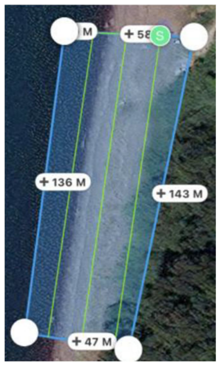
Detailed information regarding each survey method

I (and II). Drone survey

Figure 11 Pictures of drone survey at location A

Figure 12 Pictures of drone survey at location B

Table 18 Metadata of drone survey

Survey plan and preparation	Survey timing (flight date)	A: 8 a.m., 24th July 2023 The weather is sunny. (Low tide time: 6 a.m.) B: 9 a.m., 27th July 2023 (Low tide time: 7 a.m.) The weather is sunny.
	Survey target	Man-made objects over 2.5 cm (including "small pipe for oyster culture [1.5 cm in length] and cigarette butt [filter] under 2.5cm) and driftwood
	Flight regulations and legislation	- registration of drone number - prohibited from flight when third party exists in survey area - submit flight plan to coastal administrator (not required legally)
	Roles of researcher	Drone operator: 1 person Monitor observer: 1 person Drone observer: 1 person
	Flight route	 
Drone setting	Flight altitude	Appx. 40 m (A: 39.4 m B: 41 m)
	Size per pixel (Ground Sampling Distance)	A: 4.99 mm/pix B: 5.13 mm/pix
	Number of pixels per image	8,192 x 5,460 pix
	Gimbal angle	-90° (and -75° for volume estimation)
	Overlap ratio	Front overlap ratio : 80 % (20 % for Dr. Topouzelis method) Side overlap ratio : 60 % (20 % for Dr. Topouzelis method)
	How to take pictures	☐ Pause when taking a picture ■ Takes pictures at equal-second intervals while moving

	How to set up the camera	■ Auto setting ☐ Manual setting
	Camera settings	ZenmuseP1 (35mm) - Shutter speed：1/1000 - F-value：5.6 - ISO：100-800
Survey implementation	Installation of survey equipment (grand control point, RTK equipment)	Deployment of Ground Control Points (GCPs) and validation points is described in Figure 13. Root Mean Square Error (RMSE) of GCPs and validation points is described in Table 19. RTK was used for measurement in A; total station was used for measurement in B.
	Number of pictures	A: 560 B: 319
	Photographing area	A: 5,180 m^2 B: 706 m^2
Image processing	Software	Agisoft Metashape Professional
	Software version	1.8.4 build 14856
	OS	Windows 64 bit
	RAM	127.92 GB
	CPU	Intel(R) Xeon(R) CPU E5-2699 v4 @ 2.20GHz
	GPU	Quadro P6000
Image analysis	I. AI detection	AI developed by Dr. Kako was used for the beach litter detection. Terra Mapper (the software for creating 3D data from orthoimages) was used as the software for beach litter volume estimation (see Figure 14).
	II. Manual detection	Since volume estimation using orthoimages is challenging, the estimation was conducted using a "rank table", which corresponds to the amount of litter in terms of number of bags. The simplified rank table from the original version was used considering the difficulties described above, which refers to the previous study of the Ehime prefectural government (see Table 20).

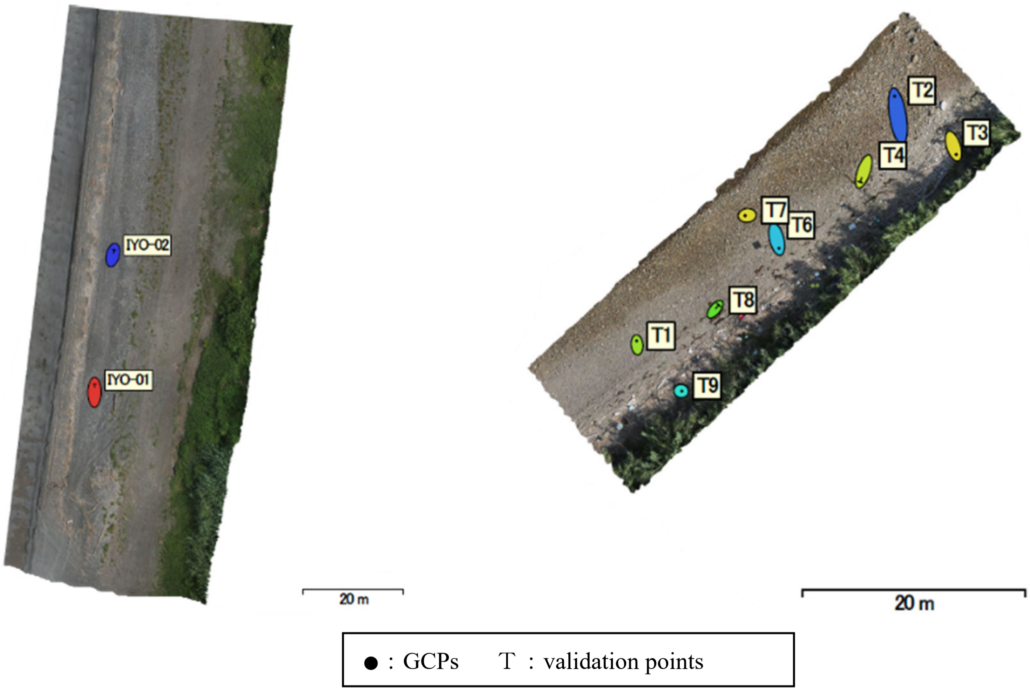


Figure 13 GCPs and validation points of each site (left location A, right: location B)

Table 19 RMSE of GCPs and validation points

Location	Number of GCPs/validation points	X error (mm)	Y error (mm)	Z error (mm)	XY error (mm)	Total (mm)
A	2 validation points	0.0189119	0.13978	0.387375	0.141053	0.412257
B	6 GCPs	1.95466	8.76064	22.631	8.97606	24.3461
	2 validation points	3.2263	7.24915	12.4205	7.93469	14.7387

Note: X - East longitude, Y - North latitude, Z - Altitude.

Table 20 Rank table for method II

Rank for volume estimation	Number of 20L garbage bags	Estimated volume (m^3/10m)
0	0	0
1	0~1	0~0.02
2	1~8	0.02~0.16
3	8~64	0.16~1.28
4	64~	1.28~ (*)

* Based on the same report, the maximum volume was set at 2.2 m^3.

Source: Beach litter spatial distribution survey report (2023, Ehime prefectural government and JANUS)

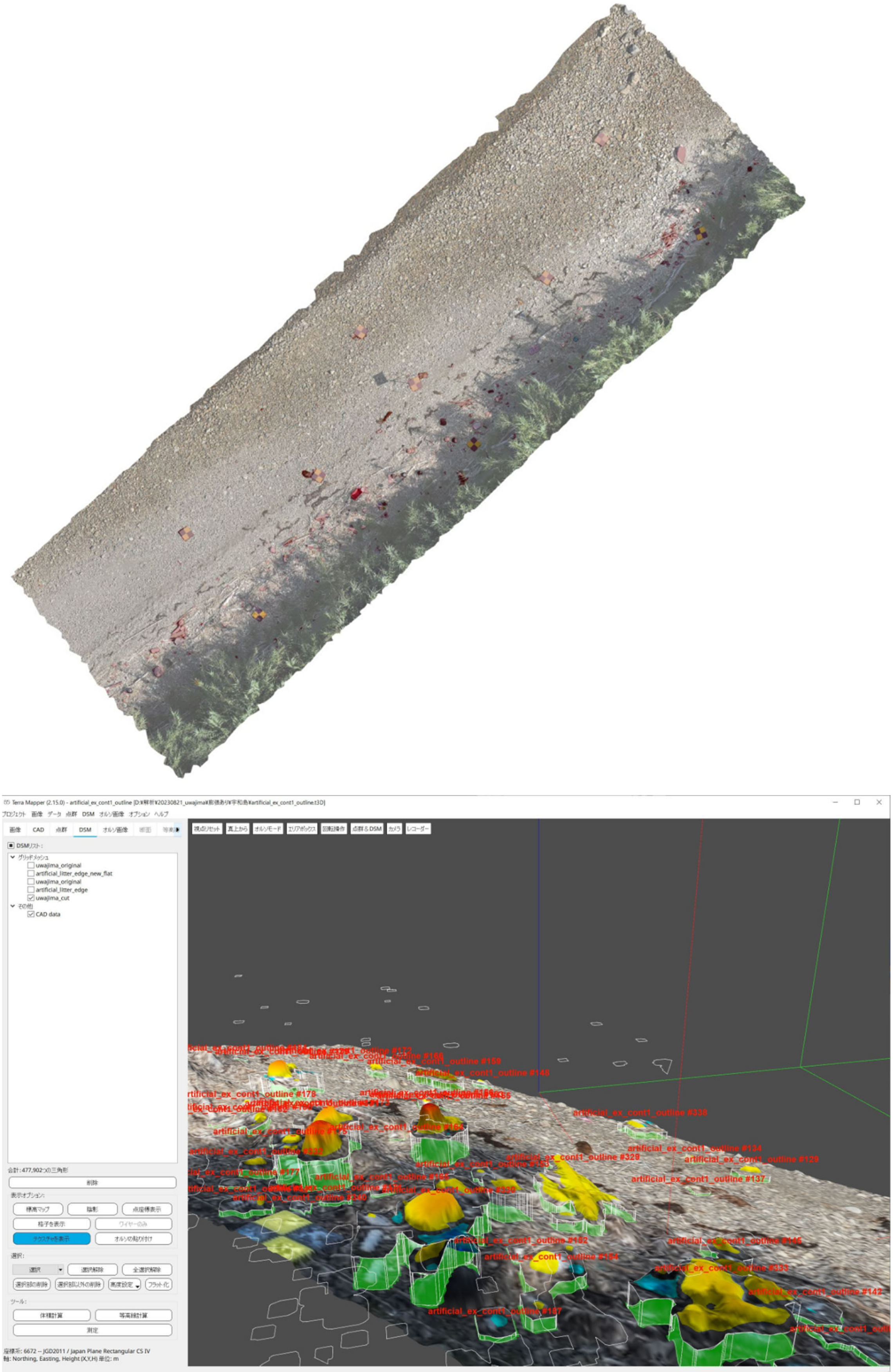


Figure 14 Images of AI-based litter detection and quantification

Source: Dr. Kako

III. On-site visual inspection

(1) Calibration

A person experienced in cleanup activity conducts on-site visual inspection. If an inexperienced person conducts the on-site visual inspection, conduct a test litter evaluation under the instruction of an experienced person for calibration. As for location B, the researcher γ conducted the calibration.

Table 21 Result of calibration

Survey location	Researcher	Man-made objects (L) on-site visual inspection	Man-made objects (L) ground truth	Natural objects (L) on-site visual inspection	Natural objects (L) ground truth
B (5 m longshore)	α	81	50	338	258
	γ (inexperienced)	20		35	

Figure 15 Collected beach litter for the calibration

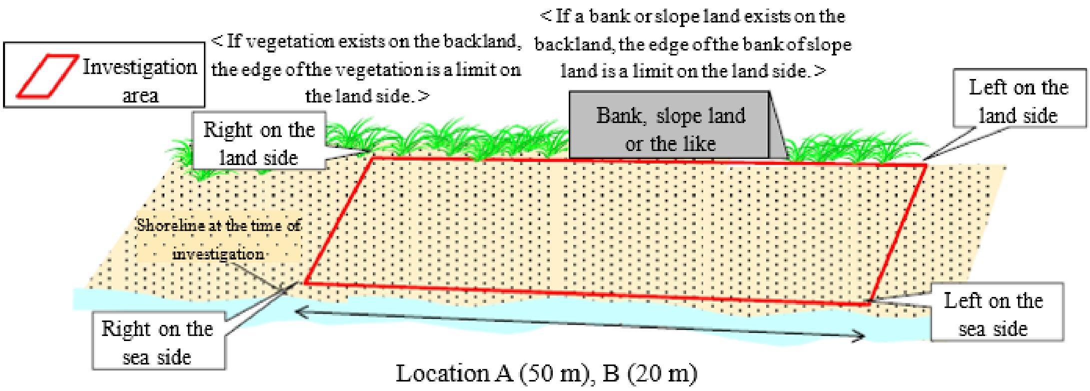
(2) Evaluation methods

We evaluated the volume of beach litter as "the number of 45L bags filled with litter within (A site) 50m of the shoreline at 10m intervals and (B site) 20m of the shoreline at 5m intervals". To verify the above human bias (see 3-2), the volume of beach litter was estimated without the rank table.

Figure 16 On-site visual inspection

IV. Collection survey

(1) Surrounding survey area by rope



(2) Collecting beach litter

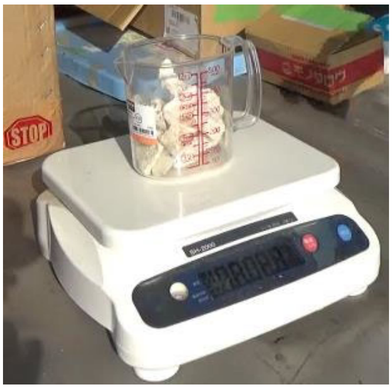
Collect man-made objects over 2.5 cm (including "small pipe for oyster culture [1.5 cm in length] and cigarette butt [filter] under 2.5cm) and driftwood manually. In the case where such a large marine litter that cannot be collected by human power is found in the investigation area, measure the dimensions of the marine litter to estimate the volume.

(3) Classification of beach litter

Classify beach litter based on item list (see Table 22).


(4) Measurement for quantification

Measure the number, volume, and weight of each item (See Table 23,Table 24).



(5) Record the survey result

Take pictures of each item. And the number, volume, and weight of each item are recorded in the data sheet with meta data (e.g., survey date, matrix of shore, survey point coordinates).

Table 22 Classification list for demonstration test

material	item type	
plastic	bottle cap and lid	
	plastic bottle	for drink
		other
	straw	
	cutlery	
	food containers incl. fast food cup etc.	
	plastic bag	
	lighter	
	tape incl. package band	
	pieces of sheet/bag	
	pieces of hard plastic	
	sponge	
	buoy (fishing gear)	
	rope, string (fishing gear)	
	conger tube (lid, cylinder)	
	small pipe for oyster culture (1.5cm in length)	
	pipe for oyster culture (10 to 20cm in length)	
	fishing net	
	other fishing gear	
	fishing tackle (for recreation)	
	cigarette butt/filter	
	household goods incl. tooth brush	
	seeding pot	
	other plastic	

material	item type
foamed plastic	float/buoy made of foamed polystyrene
	pieces of foamed polystyrene
	other foamed polystyrene
rubber	shoe incl. flip-flops, shoe sole
	pieces of rubber
	other rubber
glass, ceramic	pieces of glass/ceramic
	other glass/ceramic
metal	can
	pieces of metal
	other metal
paper, cardboard	paper containers incl. paper pack for drink
	pieces of paper
	other paper
fabric	fabric
wood	wood (lumber etc.)
driftwood	driftwood (not processed)
other	other
large marine litter that cannot be collected by man power	coordinates item type ( )

Table 23 Result of collection survey in A

material	item type		number	volume（L）	weight（kg）
plastic	bottle cap and lid		94	1.9	0.23
	plastic bottle	for drink	44	36	1.6
		other	2	1.5	0.32
	straw		11	0.05	0.008
	cutlery		0	0	0
	food containers incl. fast food cup etc.		11	0.75	0.075
	plastic bag		30	1.8	0.043
	lighter		6	0.2	0.064
	tape incl. package band		0	0	0
	pieces of sheet/bag		128	10	0.118
	pieces of hard plastic		277	4	0.57
	sponge		5	2.5	0.098
	buoy (fishing gear)		2	0.15	0.032
	rope, string (fishing gear)		21	1.5	0.036
	conger tube (lid, cylinder)		0	0	0
	small pipe for oyster culture (1.5cm in length)		956	4	0.683
	pipe for oyster culture (10 to 20cm in length)		183	10.5	1.245
	fishing net		0	0	0
	other fishing gear		67	0.2	0.058
	fishing tackle (for recreation)		2	0.02	0.015
	cigarette butt/filter		1	0.01	0.002
	household goods incl. tooth brush		28	1.8	0.172
	seeding pot		1	1	0.011
	other plastic		26	0.5	0.024
foamed plastic	float/buoy made of foamed polystyrene		0	0	0
	pieces of foamed polystyrene			21	0.212
	other foamed polystyrene		97	7	0.049
rubber	shoe incl. flip-flops, shoe sole		1	0.8	0.091
	pieces of rubber			0.02	0.003
	other rubber		0	0	0
glass, ceramic	pieces of glass/ceramic			0.072	0.063
	other glass/ceramic		4	3	0.676
metal	can		10	4	0.25
	pieces of metal			0.02	0.011
	other metal		2	0.05	0.009
paper, cardboard	paper containers incl. paper pack for drink		0	0	0
	pieces of paper			0	0
	other paper		0	0	0
fabric	fabric		1	0.01	0.002
wood	wood (lumber etc.)		1	0.1	0.027
driftwood	driftwood (not processed)			3594.05	253.635
other	other		15	0.3	0.087
large marine litter that cannot be collected by man power	coordinates item type（　　　　　　）		1	260	96.2
			2027	3968.802	356.719

Table 24 Result of collection survey in B

material	item type		number	volume（L）	weight（kg）
plastic	bottle cap and lid		150	2.6	0.41
	plastic bottle	for drink	32	40	1.2
		other	22	25	0.65
	straw		40	0.4	0.018
	cutlery		12	0.15	0.022
	food containers incl. fast food cup etc.		40	1.45	0.284
	plastic bag		72	7	0.088
	lighter		7	0.21	0.07
	tape incl. package band		32	1.6	0.024
	pieces of sheet/bag		183	9	0.136
	pieces of hard plastic		612	30	3.03
	sponge		28	5	0.042
	buoy (fishing gear)		20	100	8.7
	rope, string (fishing gear)		107	11	1.014
	conger tube (lid, cylinder)		1	1	0.056
	small pipe for oyster culture (1.5cm in length)		302	1.3	0.21
	pipe for oyster culture (10 to 20cm in length)		190	11	1.402
	fishing net		3	0.1	0.006
	other fishing gear		47	0.6	0.079
	fishing tackle (for recreation)		9	0.3	0.051
	cigarette butt/filter		0	0	0
	household goods incl. tooth brush		34	0.61	0.192
	seeding pot		5	0.8	0.016
	other plastic		251	24	1.315
foamed plastic	float/buoy made of foamed polystyrene		7	52	0.78
	pieces of foamed polystyrene			40	0.55
	other foamed polystyrene		53	7	0.072
rubber	shoe incl. flip-flops, shoe sole		6	1	0.191
	pieces of rubber			0	0
	other rubber		5	6.8	0.51
glass, ceramic	pieces of glass/ceramic			0.05	0.075
	other glass/ceramic		5	1.5	0.691
metal	can		7	4	0.237
	pieces of metal			0.5	0.166
	other metal		1	0.15	0.021
paper, cardboard	paper containers incl. paper pack for drink		1	0.03	0.002
	pieces of paper			0.002	0
	other paper		0	0	0
fabric	fabric		3	2	0.106
wood	wood (lumber etc.)		94	70	11.9
driftwood	driftwood (not processed)			750	88.89
other	other		95	5.25	0.906
large marine litter that cannot be collected by man power	coordinates item type（ ）		2	29.4	9.138
			2478	1242.802	133.25