

Mapping of Sicilian Pocket Beaches Land Use/Land Cover with Sentinel-2 Imagery: A Case study of Messina Province

Giovanni Randazzo^{1,2,3}, Maria Cascio¹, Marco Fontana¹, Francesco Gregorio¹, Stefania Lanza^{1,3}, Anselme Muzirafuti^{1,*}

¹ Interreg Italia–Malta–Project: Pocket Beach Management & Remote Surveillance System, University of Messina, Via F. Stagno d’Alcontres, 31–98166 Messina, Italy; giovanni.randazzo@unime.it (G.R.); maria.cascio86@gmail.com (M.C.); marco.fontana92@yahoo.it (M.F.); gregoriofrancesco92@gmail.com (F.G.); stefania.lanza@unime.it (S.L.).

² Dipartimento di Scienze Matematiche e Informatiche, Scienze Fisiche e Scienze della Terra, Università degli Studi di Messina, Messina, Via F. Stagno d’Alcontres, 31–98166 Messina, Italy

³ GeoloGIS s.r.l. Spin Off of Università degli Studi di Messina, Via F. Stagno d’Alcontres, 31–98166 Messina, Italy

* Correspondence: a.muzirafuti@edu.umi.ac.ma or muzansel@gmail.com; Tel.: +39-3312976306

S3.1. Municipality of Taormina

The classified LULC map of the Taormina PBs obtained from Sentinel-2B image (Figure S1a) represents three classes, in addition to one primary street, identified near the coastline (Figure S1b). We achieved an overall classification accuracy of 96.98% and Kappa coefficient of 0.93. A summary of the classification is presented in Table S1. We noticed that in the 500 m buffer zone of the PBs, the large area is occupied by vegetation, and surrounded by built-up areas. The buildings are distributed on the plateau where the city of Taormina is almost completely contained by the walls and narrow strip of hotels and villas along the seaside. Most parts of the PBs are artificially limited by rail. The vegetation intersects the slope between the two areas and covers the largest part of the territory. Missing data (shadow) can be connected with the vegetation itself or to the degree of the slope.

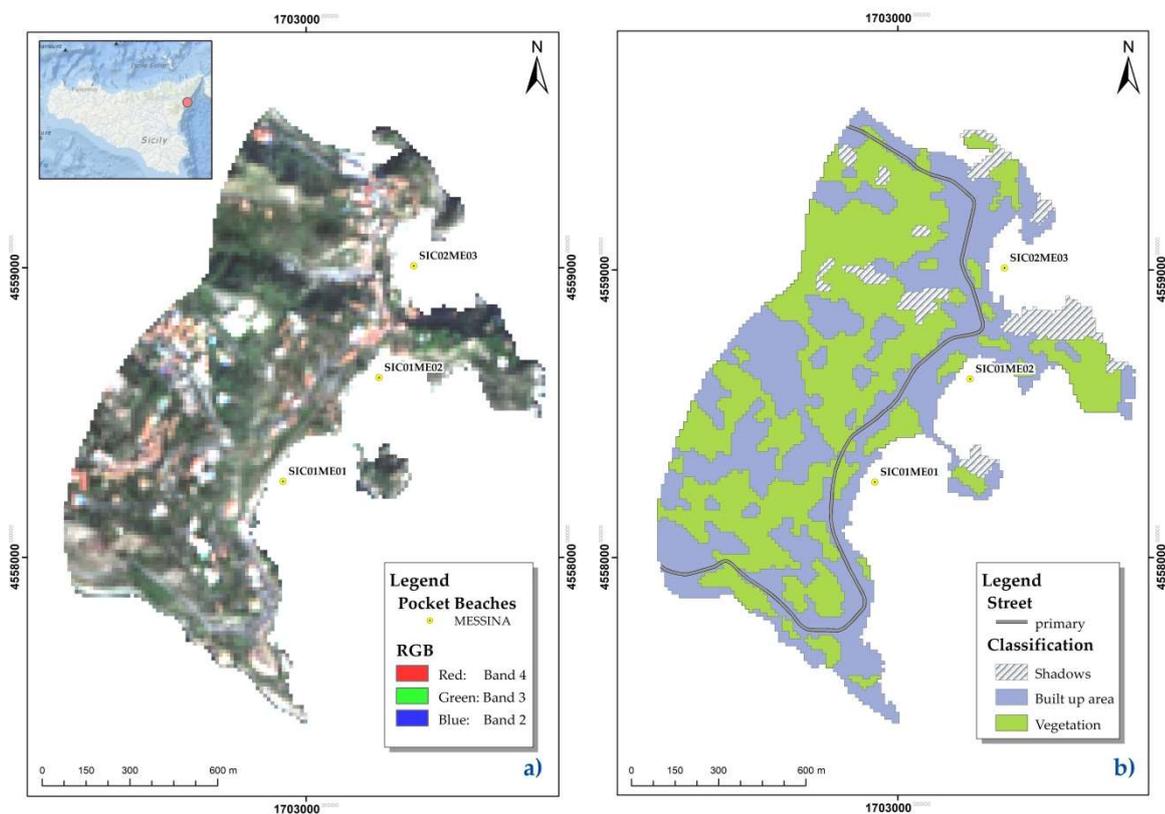


Figure S1. Sentinel-2 natural color composite image of Taormina: (a) showing two PBs of Isola Bella (SIC01ME01 and SIC01ME02) and one in Mazzarò Bay (SIC02ME03) and (b) the land use/land cover classification result.

Table S1. Land Use/Land Cover classification results of South Isola Bella (SIC01ME01), North Isola Bella (SIC01ME02), and Mazzarò (SIC02ME03) PBs and accuracy assessment (Taormina).

Classes	Area		Producer's Accuracy (%)		User's Accuracy (%)	
	m ²	(%)				
Shadows	53,700	6.05	100		27.78	
Built-up	426,100	48	100		98.62	
Vegetation	407,800	45.94	95.70		100	

S3.2. Municipality of Milazzo

The classified LULC map of Milazzo PBs obtained from Sentinel-2B image (Figure S2a) represents three classes identified near the coastline (Figure S2b). An overall classification accuracy of 89.07% and Kappa coefficient of 0.85 was achieved. A summary of the four classes is presented in Table S2. This peninsula is completely intersected by natural terrain and the marine protection area is widely covered by traditional agricultural activities, represented by a classification accuracy of 40.8% in the 500 m buffer zone. Identification of farmland close to the North-east PBs (SIC03ME04 and SIC04ME05) suggest that agricultural activities may be the origins of the slight anthropogenic activities affecting these PBs and existing before the protection institution.

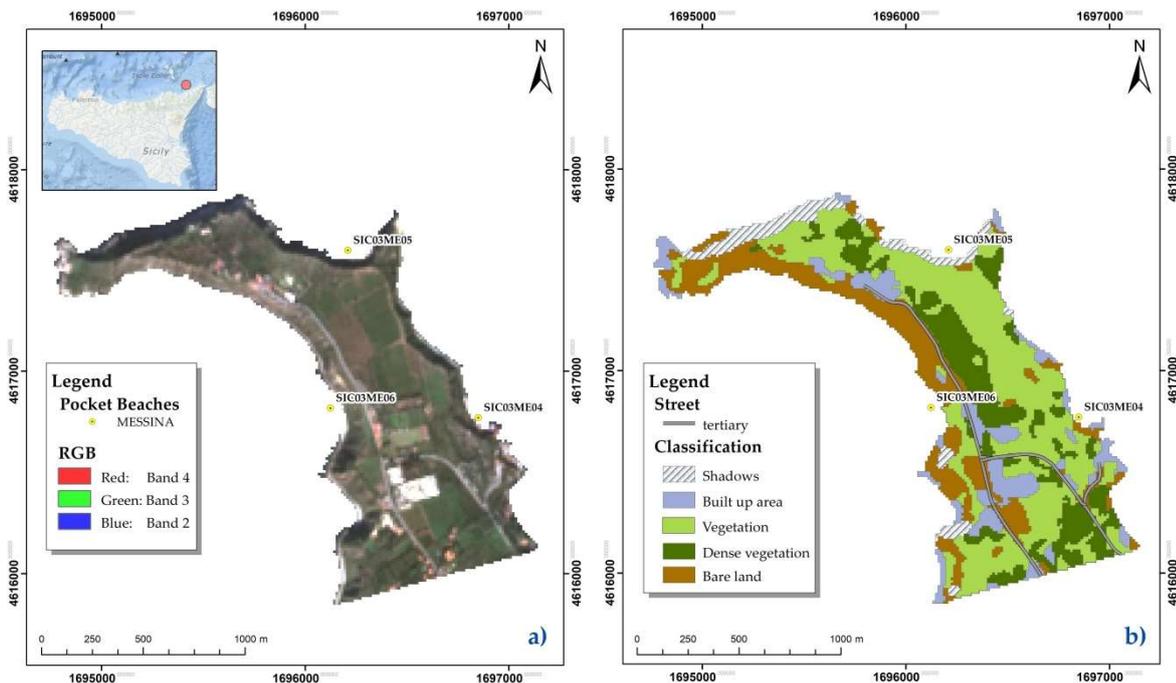


Figure S2. Sentinel-2 natural color composite image of Milazzo: (a) showing three PBs of East (SIC03ME04), North (SIC03ME05), and West (SIC03ME06) located along the coast of the Marine Protected Area and (b) the land use/land cover classification result.

Table S2. Land Use/Land Cover classification results of Milazzo’s PBs East (SIC03ME04), North (SIC03ME05), and West (SIC03ME06) and accuracy assessment.

Classes	Area		Producer’s accuracy (%)	User’s accuracy (%)
	m ²	(%)		
Shadows	61,500	6.27	100	76.47
Built-up	119,600	12.21	86.36	96.94
Vegetation	399,700	40.8	96.35	84.62
Dense vegetation	189,400	19.33	81.48	97.06
Bare land	209,300	21.36	95.12	75.00

S3.3. Municipality of Patti

For three PBs in the municipality of Patti, the results of the LULC classification obtained from Sentinel-2B image (Figure S3a) represent five classes and three types of streets (Figure S3b). LULC statistical analysis and accuracy assessment are reported in Table 7. During image processing, we reached an overall classification accuracy and Kappa coefficient of about 87.06% and 0.79, respectively. The most dominant classes in this area are dense vegetation and scattered vegetation forestry with different degrees of coverture (23.49%, 45.42%) due to a significant slope of the promontory. The shadow (5.45%) is due to this slope, which limits the acquisition data from the satellite images. The “Construction” located near the easternmost PB is represented by a Sanctuary devoted to the Black Virgin and the ruins of the ancient (Greek to Roman) town.

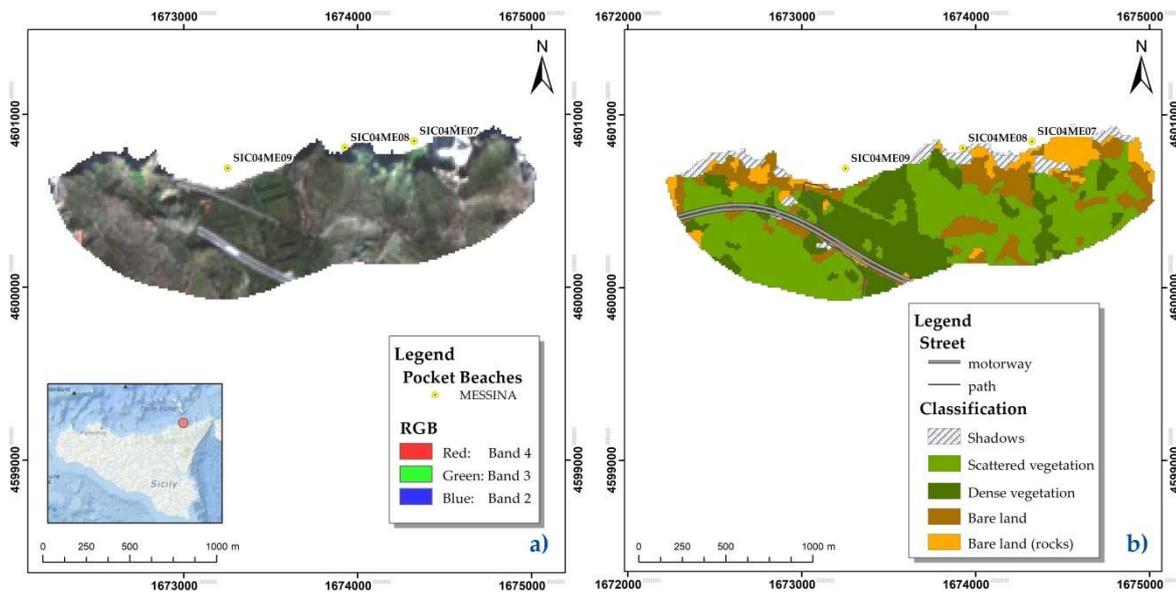


Figure S3. Sentinel-2 natural color composite image of Patti: (a) showing three of Tindari's PBs from East (SIC04ME07), Center (SIC04ME08), and West (SIC04ME09) located along the rocky promontory of the homonymous cape and (b) the land use/land cover classification result.

Table S3. Land Use/Land Cover classification results of the Patt–Tindari's PBs East (SIC04ME07), Center (SIC04ME08), and West (SIC04ME09) and accuracy assessment.

Classes	Area		Producer's accuracy(%)	User's accuracy(%)
	m ²	(%)		
Shadows	59600	5.45	56.1	96.72
Scattered vegetation	496200	45.42	91.01	93.08
Dense vegetation	256600	23.49	99.32	82.21
Bare land	184500	16.89	68.25	89.84
Bare land (rocks)	95400	8.73	83.56	46.56

S3.4. Municipality of Gioiosa Marea

On the coast of Gioiosa Marea two PBs, East Capo Calavà (SIC05ME10) and West Capo Calavà (SIC06ME11), were studied. The results of the LULC classification obtained from the Sentinel-2B image (Figure S4a) represent seven classes and two types of streets (Figure S4b). We reported the LULC statistical analysis and accuracy assessment in Table S4. Overall classification accuracy and Kappa coefficient of about 89.63% and 0.86, respectively, were achieved. These values are relatively low compared to the accuracy reached for the other PBs. This is due to the highly heterogeneous LULC as well as the number of hills surrounding the PBs. The most dominant anthropogenic activities in this area are agriculture and forestry, respectively representing 16.79%, 8.83%, and 25.24 % in the 500 m buffer zone for these PBs. The location of the built-up (urban) areas, especially near the West Capo Calavà (SIC06ME11) PB, suggests that activities such as construction, transport, and recreation may be the origin of the anthropogenic activities affecting this PB.

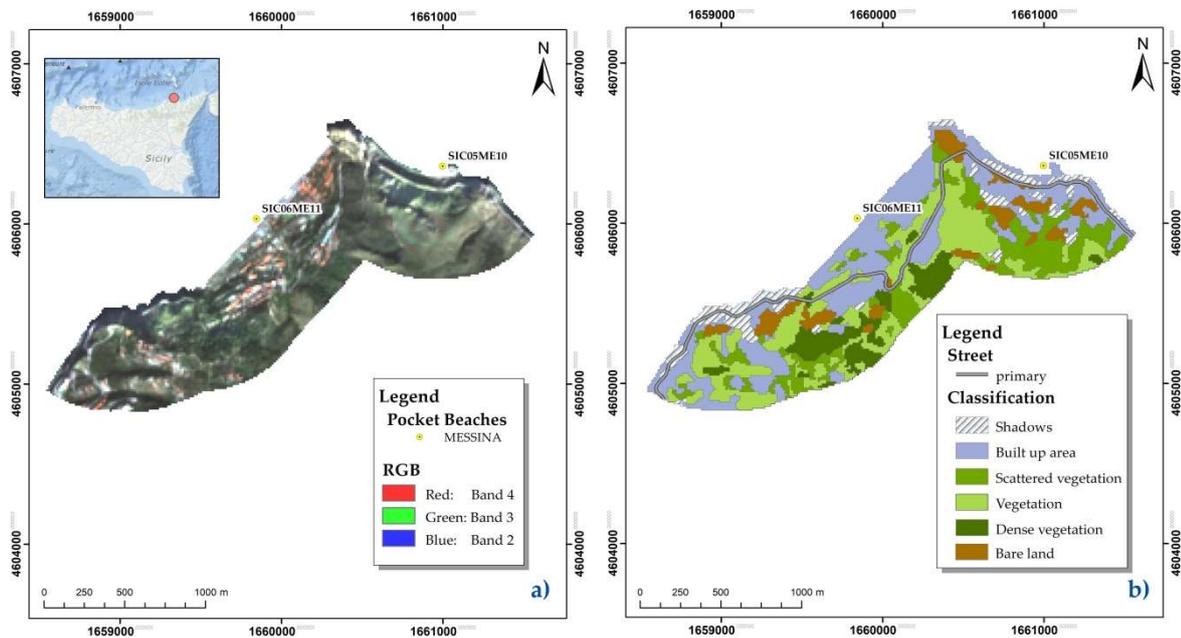


Figure S4. Sentinel-2 natural color composite image of Gioiosa Marea: (a) showing the two PBs of East Capo Calavà (SIC05ME10) and West Capo Calavà (SIC06ME11) and (b) the land use/land cover classification result.

Table S4. Land Use/Land Cover classification results of East Capo Calavà (SIC05ME10) and West Capo Calavà (SIC06ME11) PBs and accuracy assessment (Gioiosa Marea).

Classes	Area		Producer's accuracy(%)	User's accuracy(%)
	m ²	(%)		
Shadows	94,100	7.37	98.08	100
Built-up	428,800	33.62	92.24	99.55
Scattered vegetation	214,200	16.79	74.71	65.33
Vegetation	322,000	25.24	88.10	81.70
Dense vegetation	112,700	8.83	89.39	100
Bare land	103,500	8.11	100	98.54

S3.5. Municipality of Lipari

11 PBs were located on the coasts of four islands (Vulcano, Lipari, Panarea, and Filicudi) administratively belonging to the municipality of Lipari.

S3.5.1. Lipari Island

Along the coast of Lipari Island, we studied four PBs: La Forbice, Pignataro di Fuori, Sabbie Bianche, and Lido Blu referred to by the SIC09ME14, SIC10ME15, SIC11ME16, and SIC12ME17 codes, respectively.

The results of the LULC classification obtained for La Forbice PB (Figure S5a) reveal four classes and two types of streets (Figure S5b). The LULC statistical analysis and accuracy assessment show an overall classification accuracy and Kappa coefficient of about 92.63% and 0.89, respectively. The most dominant classes are built up with 36.64% followed by vegetation area representing 24.47% of the studied area (Table S5). This suggests that activities such as diffused farming and small villages are the origin of anthropogenic activities affecting this PB.

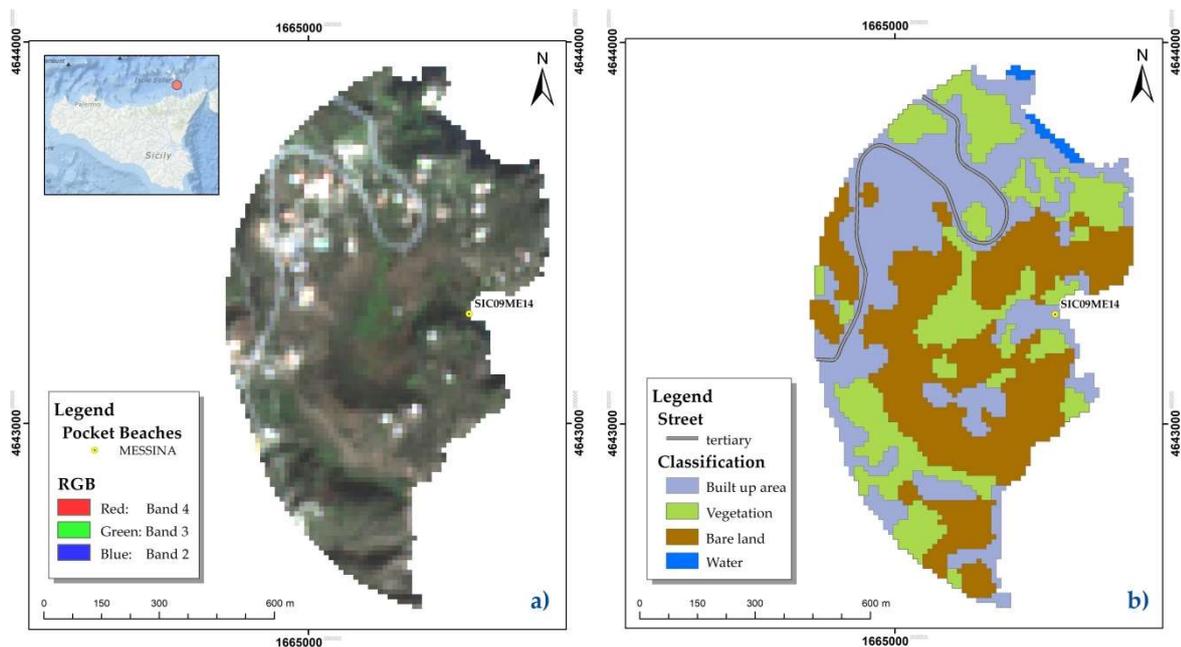


Figure S5. Sentinel-2 natural color composite image (a) showing the PB of Lipari-La Forbice (SIC09ME14) located on the East coast of the island and (b) the land use/land cover classification result.

Table S5. Land Use/Land Cover classification results of Lipari-La Forbice (SIC09ME14) PB and accuracy assessment.

Classes	Area		Producer's accuracy (%)	User's accuracy(%)
	m ²	(%)		
Built-up	167100	36.64	92.83	89.80
Vegetaton	111600	24.47	95.73	94.58
Bare land	173500	38.04	94.32	93.79
Water	3800	0.83	67.65	100

For the PB of Pignataro di Fuori, the results of the Sentinel-2B image (Figure S6a) analysis reveal only two LULC classes and two types of streets (Figure S6b). The statistical analysis and accuracy assessment show an overall classification accuracy and Kappa coefficient of about 94.81% and 0.87, respectively. The PB is surrounded by hills covered by vegetation representing 71.93% of the studied area (Table S6). This suggests that activities such as forestry are the only land use types surrounding this PB.

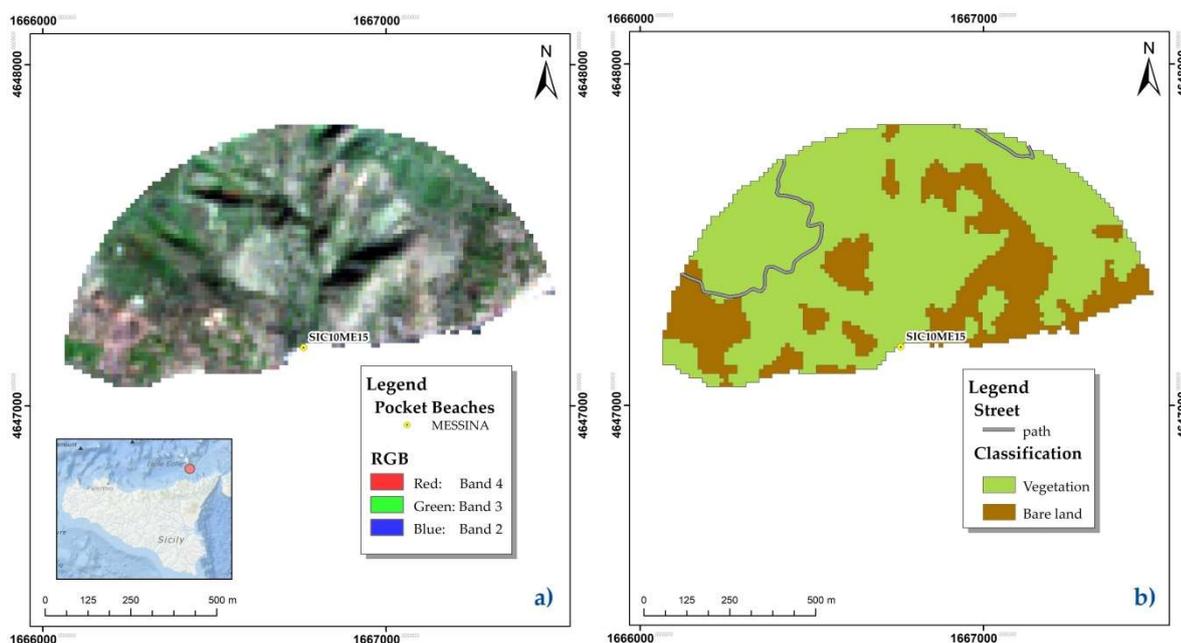


Figure S6. Sentinel-2 natural color composite image (a) showing the PB of Lipari- Pignataro di Fuori (SIC10ME15) located on the South coast of the island and (b) the land use/land cover classification result.

Table S6. Land Use/Land Cover classification results of Lipari- Pignataro di Fuori (SIC10ME15) pocket beach and accuracy assessment.

Classes	Area		Producer's accuracy (%)	User's accuracy (%)
	m ²	(%)		
Vegetation	333800	71.93	100	83.55
Bare land	130200	28.06	92.96	100

For the remaining two PBs, Sabbie Bianche and Lido Blu (Figure S7a), the results of the LULC classification reveal four classes (Figure S7b). We obtained overall classification accuracy of about 98.76% and a Kappa coefficient of about 0.97. The most dominant class is the vegetation scattered on rocky slopes. This class represents 53.44 % in the 500 m buffer zone for these PBs. Built-up areas accounted for 26.77% of the studied area, representing the second-largest class for these PBs (Table S7).

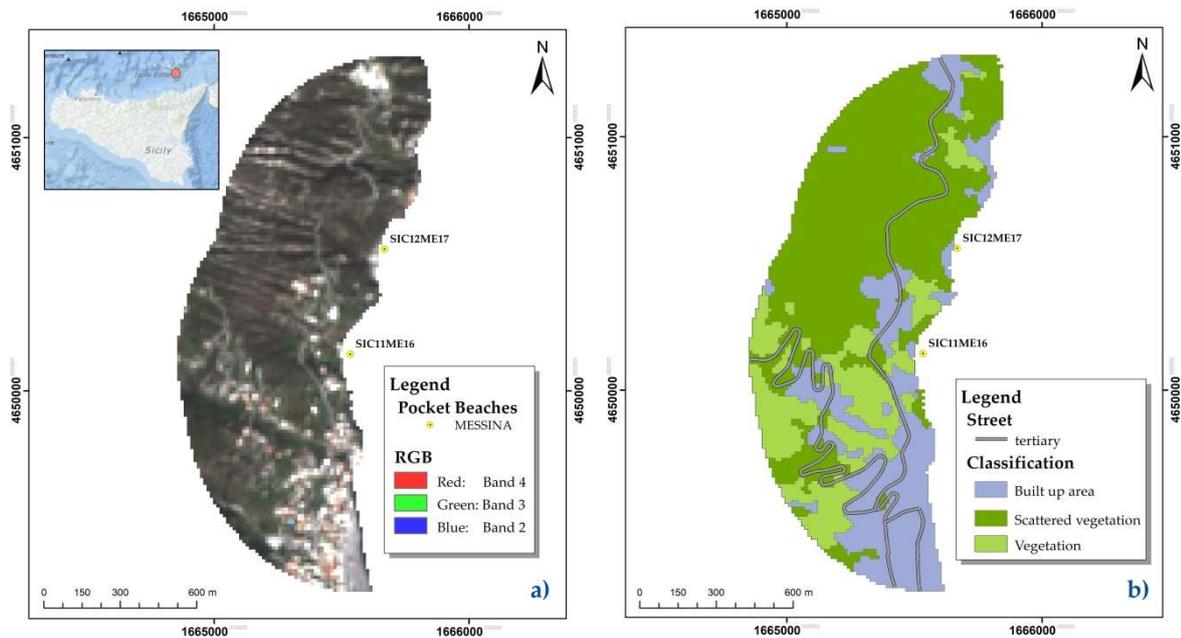


Figure S7. Sentinel-2 natural color composite image (a) showing the two PBs of Lipari - Sabbie Bianche (SIC11ME16) and Lipari - Lido Blu (SIC12ME17) located on the East coast of Lipari and (b) the land use/land cover classification result.

Table S7. Land Use/Land Cover classification results of Lipari - Sabbie Bianche (SIC11ME16) and Lipari - Lido Blu (SIC12ME17) pocket beaches and accuracy assessment (next).

Classes	Area		Producer's accuracy (%)	User's accuracy (%)
	m ²	(%)		
Built-up	7088	26.77	97.74	98.30
Scattered vegetation	424400	53.44	99.15	99.09
Vegetation	157100	19.78	100	97.17

S3.5.2. Volcano Island

The two PBs located on the coast of the Volcano Island are Punta dell'Asino and Punta Bandiera, referred to by the SIC07ME12 and SIC08ME13 codes, respectively. The results of the LULC classification obtained from the Sentinel-2B image (Figure S8a) represent four classes and two types of streets (Figure S8b). The LULC statistical analysis and accuracy assessment achieved an overall classification accuracy of about 96.08% and a Kappa coefficient of about 0.93. The accuracy assessment results achieved high values, indicating a high level of confidence of the LULC results obtained for these PBs. The most dominant anthropogenic activity in this area is agriculture, which represents 43.93% in the 500 m buffer zone for these PBs. The area holds a small built-up area representing only 8.58% (Table S8).

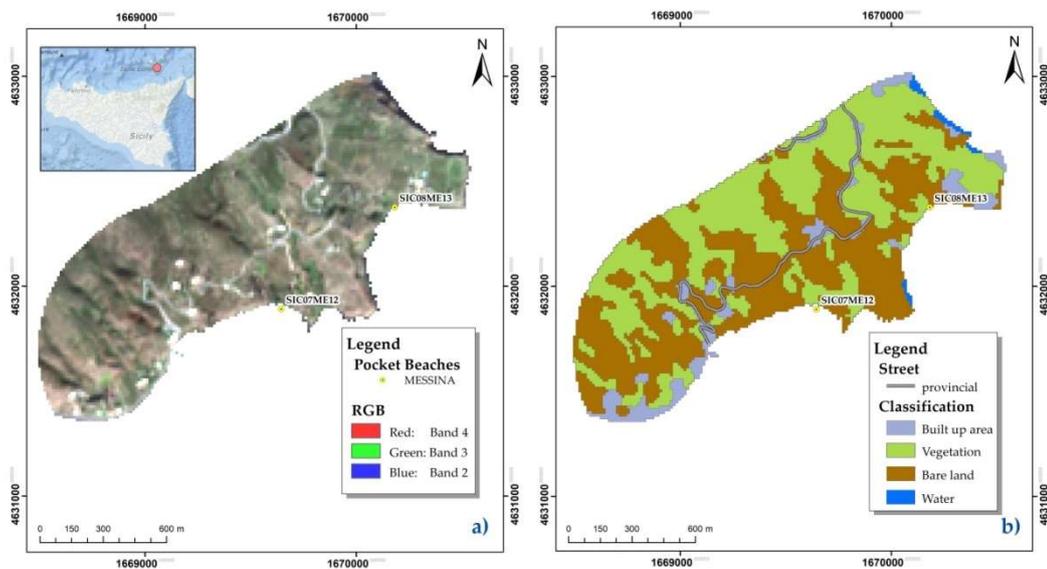


Figure S8. Sentinel-2 natural color composite image of Volcano Island (Lipari): (a) showing the two PBs of Volcano Island: Punta dell'Asino (SIC07ME12) and Punta Bandiera (SIC08ME13) and (b) the land use/land cover classification result.

Table S8. Land Use/Land Cover classification results of Volcano Island - Punta dell'Asino (SIC07ME12) and Volcano Island - Punta Bandiera (SIC08ME13) PBs and accuracy assessment.

Classes	Area		Producer's accuracy (%)	User's accuracy (%)
	m ²	(%)		
Built-up	82400	8.58	82.83	93.18
Vegetation	421900	43.93	97.51	99.49
Bare land	448400	46.69	100	94.67
Water	7600	0.79	66.67	100

S3.5.3. Panarea Island

On the Coast of Panarea Island, we identified four PBs: Zimmaro, West Preistorico, Center Preistorico, and East Preistorico represented by the SIC15ME20, SIC16ME21, SIC16ME22, SIC16ME23 codes, respectively (Figure S9a). The results of the LULC classification obtained for these PBs reveal three classes and one type of street (Figure S9b). The LULC statistical analysis and accuracy assessment show an overall classification accuracy and Kappa coefficient of about 92.807% and 0.88, respectively. The area is dominated by vegetation, which covers 52.21%. A built-up area was identified in the Eastern part of the studied area and represents 12.44% of the total area (Table S9).

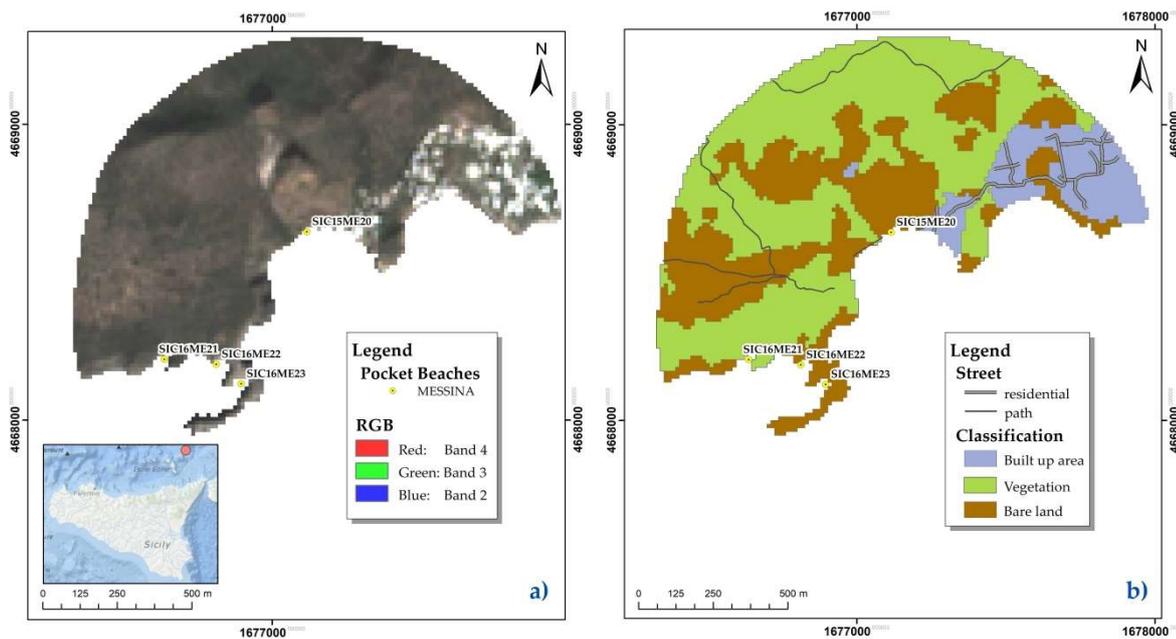


Figure S9. Sentinel-2 natural color composite image of Panarea Island (Lipari): (a) showing four PBs of Zimmaro (SIC15ME20), West Preistorico (SIC16ME21), Center Preistorico (SIC16ME22), and East Preistorico (SIC16ME23) and (b) the land use/land cover classification results.

Table S9. Land Use/Land Cover classification results of Zimmaro(SIC15ME20), West Preistorico (SIC16ME21), Center Preistorico(SIC16ME22), and East Preistorico (SIC16ME23) pocket beaches and accuracy assessment (Panarea Island - Lipari).

Classes	Area m ²	(%)	Producer's accuracy (%)	User's Accuracy (%)
Built-up	835,00	12.44	98.42	95.04
Vegetation	350,200	52.21	98.31	84.30
Bare land	237,000	35.33	86.44	99.14

S3.5.4. Filicudi Island

The PB studied on the coast of Filicudi Island is Le Punte. It is located on the Southeast side of the island and was designated the SIC17ME24 code. The results of the Sentinel-2B image (Figure S10a) analysis reveal three LULC classes and two types of streets (Figure S10b). In this area, the presence of hills decreases the ability of satellite sensors to capture all LULC features due to the presence of shadows. These missing data pixels were identified and classified as shadows. The statistical analysis and accuracy assessment show an overall classification accuracy and Kappa coefficient of about 90.45% and 0.82, respectively. The area is dominated by scattered vegetation covering 59.35% and dense vegetation covering 19.82% (Table S10). A built-up area was identified in the Northwest section of the PB representing 17.35% of the area. The location of vegetation identified in this area suggests that the area is wild, without any presence of human activity.

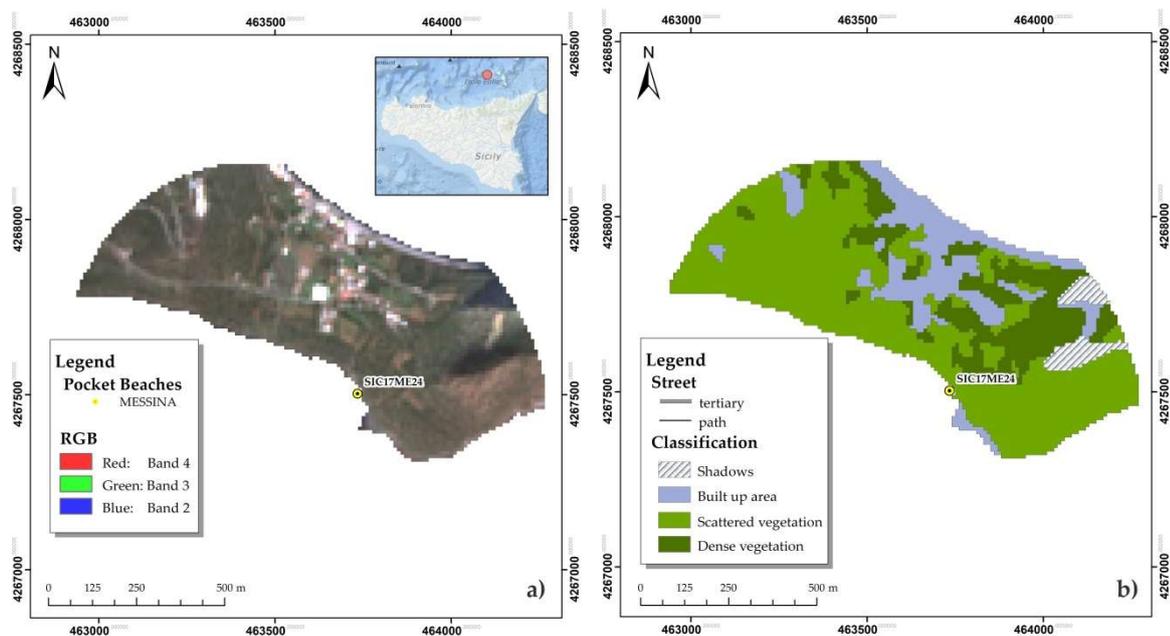


Figure S10. Sentinel-2 natural color composite image of Filicudi Island (Lipari): (a) showing one PB of Filicudi - Le Punte (SIC17ME24) and (b) the land use/land cover classification results.

Table S10. Land Use/Land Cover classification results of Filicudi - Le Punte (SIC17ME24) pocket beach and accuracy assessment.

Classes	Area		Producer's accuracy (%)	User's accuracy (%)
	m ²	(%)		
Shadows	19,800	3.47	98.63	100
Built-up	99,000	17.35	94.59	100
Scattered vegetation	338,600	59.35	87.84	98.26
Dense vegetation	113,100	19.82	95.06	70

S3.6. Municipality of Malfa

For Salina Island, Punta Scario, and Pollara, referenced by the codes SIC13ME18 and SIC14ME19, respectively, were studied. These two PBs are located on the coast of Malfa municipality.

For the PB of Punta Scario (Figure S11a), the results of Sentinel-2B image analysis reveal three LULC classes and one type of street (Figure S11b). The LULC statistical analysis and accuracy assessment show an overall classification accuracy and Kappa coefficient of about 97.76% and 0.95, respectively (Table S11). Built-up area, covering an area of about 51.53%, was identified as the most dominant class; while vegetation was found to cover 40.19% of the area.

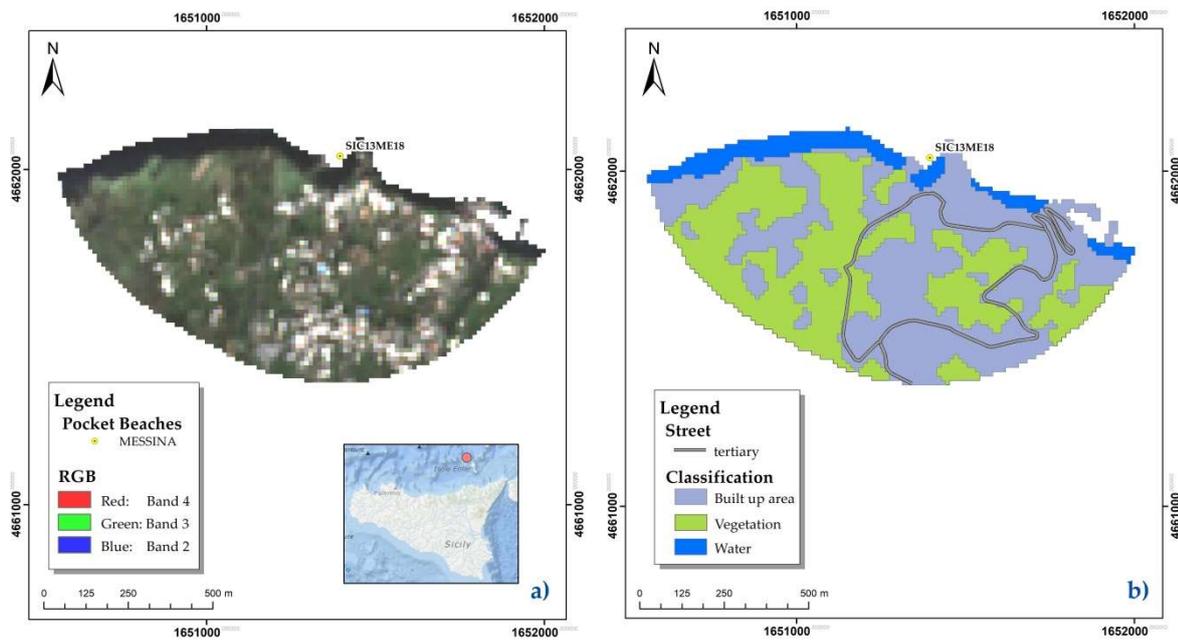


Figure S11. Sentinel-2 natural color composite image of Municipality of Malfa in Salina Island: (a) showing one PB of Punta Scario (SIC13ME18) and (b) the land use/land cover classification result.

Table S11. Land Use/Land Cover classification results of Salina - Punta Scario (SIC13ME18) pocket beach and accuracy assessment.

Classes	Area		Producer's accuracy (%)	User's accuracy (%)
	m ²	(%)		
Built-up	226800	51.53	96.99	99.56
Vegetation	176900	40.19	100	92
Water	36400	8.27	97.97	99.32

For the PB of Pollara (Figure S12a), five LULC classes and two types of streets were obtained from the analysis of Sentinel-2B images (Figure S12b). The LULC statistical analysis and accuracy assessment show an overall classification accuracy and Kappa coefficient of about 94.89% and 0.92, respectively (Table S13). Vegetation covers an area of about 34.84%, was identified as the most dominant class. Due to the mountainous landscape surrounding this PB, there is a large number of missing data pixels that were classified as shadows.

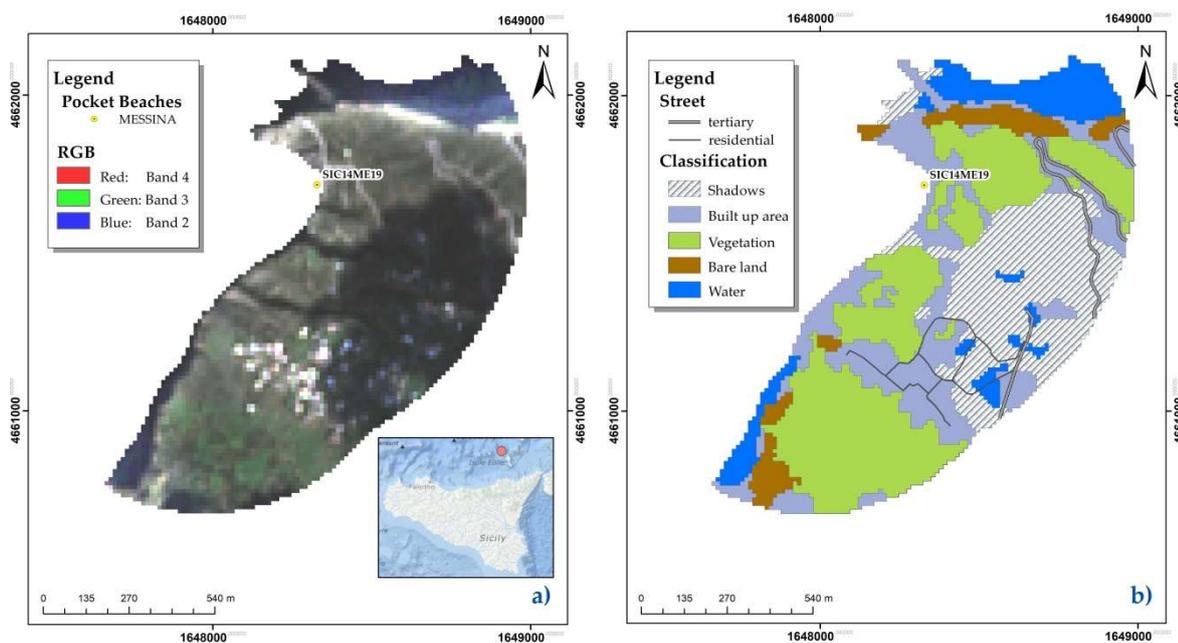


Figure S12. Sentinel-2 natural color composite image (a) showing one PB of Pollara (SIC14ME19) located on the coast of Malfa and (b) the land use/land cover classification result.

Table S12. Land Use/Land Cover classification results of Salina – Pollara (SIC14ME19) pocket beach and accuracy assessment.

Classes	Area		Producer's accuracy (%)	User's accuracy (%)
	m ²	(%)		
Shadows	153400	23.92	97.40	100
Built-up	158500	24.71	92.48	72.32
Vegetation	223400	34.84	99.08	98.19
Bare land	38700	6.03	63.43	96.52
Water	67200	10.48	100	95.63