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Geomorphological features of Favignana Island (SW Italy)

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ABSTRACT

We present a large scale (1:10,000) geomorphological map of Favignana Island, in which landforms were recognized and genetically categorized based on analysis of stereoscopic aerial photographs and freely available satellite images, complimented by a few validation tests performed in the field. The map was created following the guidelines of the Italian Geomorphological Working Group for landforms symbolic representation. This includes an immediate visual differentiation of the genetic character and the state of activity of landforms. Favignana, belonging to the Egadi Archipelago in the Tyrrhenian Sea (SW Italy), is a mid-sized (ca. 20 km²) mostly carbonatic island. The marine protected area surrounding the island represents the main attraction for tourists. Through this map, it was possible to highlight the richness and diversity, in terms of abundance and peculiarity of landforms, that characterizes the Island. This peculiarity makes of Favignana an excellent candidate for the exploitation of its geoheritage for touristic purposes.

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1. Introduction

Small islands in the Mediterranean Basin represent a cue of its environmental and ecological richness (Furlani et al., 2014; Woodward, 2009).

Geomorphological mapping of small islands is a valuable tool for the management of their territories, like case-studies from Italy and Malta show (Biolchi et al., 2014; Devoto et al., 2012; Graciotti et al., 2008; Miccadei et al., 2012). In fact, these fragile territories are occupied by small communities of permanent dwellers frequently facing economic and environmental issues. These communities need to be supported, in that they preside a land that would otherwise represent a management issue for the country. Geomorphological mapping on one side is a basic tool to understand critical environmental issues that need to be addressed in order to avoid geological hazards, on the other is a tool to understand which are the territory natural features that deserve to be exploited in terms of geoheritage (2016).

The Italian Geomorphological community has a long lasting tradition of Geomorphological mapping, based on specific criteria worked out in the 1980s and established in the 1990s (Brancaccio et al., 1994) and recently revised (Campobasso et al., 2018) specifically for the coastal morphological agent (Mastronuzzi et al., 2017). These criteria are based on the use of different colours to differentiate forms, deposits and processes due to different morphological agents and different tonalities within the same colour to highlight their state of activity. Although these criteria are not

adopted outside Italy, they represent an exceptional tool to produce scientifically significant thematic cartography that is also easily understandable by end-users such as urban planners and landscape engineers. Another type of application of geomorphological maps is in the exploitation of geological heritage (2016).

In this work a large scale geomorphological map (Main Map) of the Island of Favignana (SW Italy, Figure 1) is presented. The economy of the Island has traditionally been based on its marine resources, such as fishing and touristic activities oriented towards the sea (e.g. sailing, diving, etc.). Favignana is, in fact, included within a marine protected area (<http://www.ampisoleegadi.it>), the aim of which is the protection of marine biodiversity and the sustainable management of coastal areas of the Egadi Archipelago, of which Favignana is part. The richness and diversity of landforms that shape the Island's coastal profile but also its inland territory, suggest that also local economic activities based on the touristic exploitation of its geoheritage can be developed.

2. Study area

Favignana is an island within the Egadi Archipelago (Figure 1(B)). This is formed by three major islands, Levanzo and Marettimo apart from Favignana itself, and two minor islands (Formica and Maraone). The Egadi Archipelago is located in the Southern

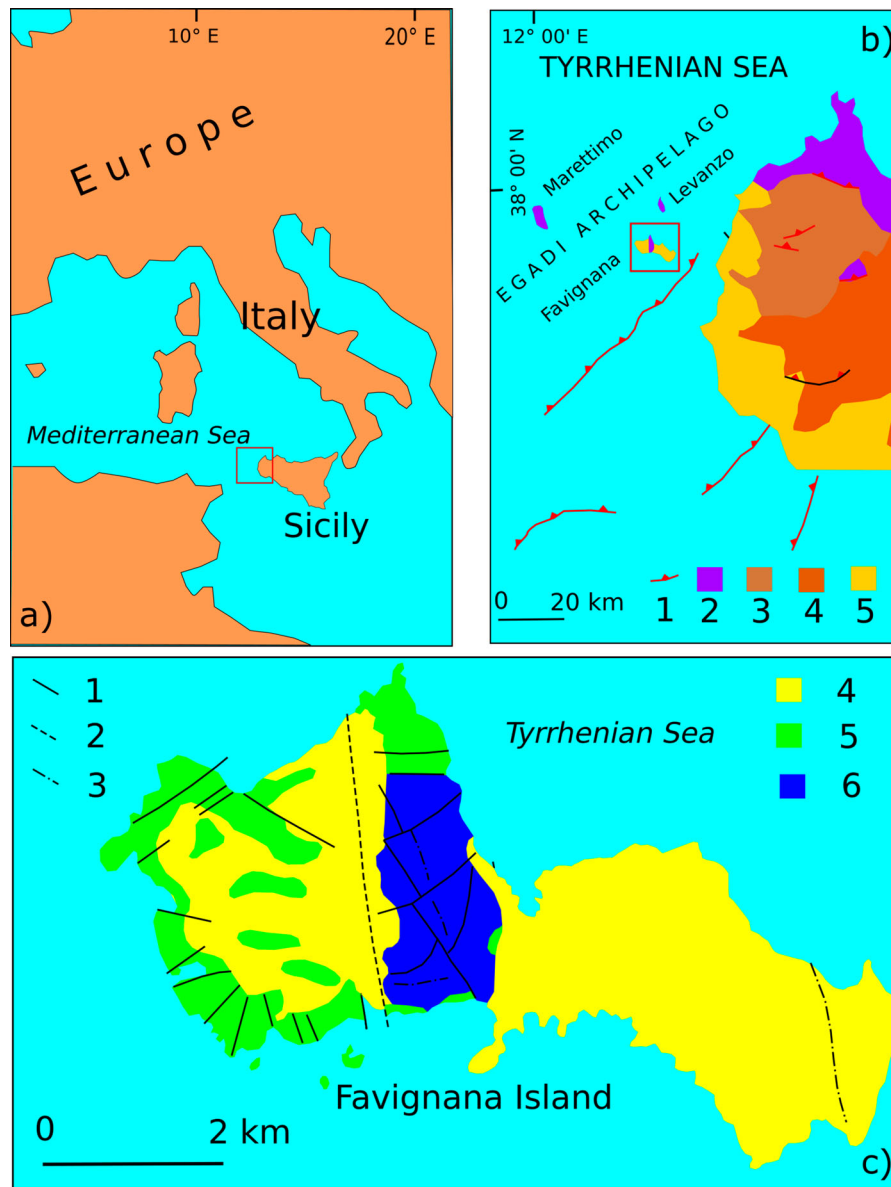


Figure 1. A: Location map of the study area within the Mediterranean basin. B: Structural setting of Western Sicily; (1) Thrust line; (2) Carbonate platform units; (3) Numidian Flysch units; (4) Synorogenic Deposits; (5) Pleistocene deposits (after: Di Stefano et al., 2015); the location of the Egadi Archipelago, W of the western coast of Sicily, is shown. C: Structural map of Favignana Island; (1) fault line; (2) inferred fault line; (3) anticline axis; (4) Plio-Quaternary deposits; (5) Punta Fraraglione unit; (6) Mt. Santa Caterina unit (after: Ventura Bordenca, 2014).

Tyrrhenian Sea at a short distance from the coast of Western Sicily, the largest Mediterranean Island. Favignana is the biggest (19.8 km²) of the Egadi Islands and the closest to the coast (4.45 nautical miles). It displays a coastal perimeter of 33 km, with an E-W elongated shape. The Island lies on the continental shelf that borders Western Sicily (D'Angelo et al., 2004). The sea bottom is shallow (within 20 m) between the mainland and the eastern coast of Favignana, has an intermediate depth (within 50 m) offshore the Island northern and southern coast and degrades deeply (up to 350 m ca.) into the so-called Marettimo Trench to the west (Nautical Chart n° 260 *Litorale tra Trapani e Marsala e Isole Egadi*, Istituto Idrografico della Marina, www.marina.difesa.it).

The only mountain ridge of the Island (Monte Santa Caterina, 314 m a.s.l.) separates the Island in two parts of almost equal area with a N-S elongated water divide (Figure 2). The remaining part of Favignana is shaped into the form of a tableland, with an average elevation around 10 m a.s.l. on the east and of 20 m a.s.l. on the west. Geologically (Fig. 1B and C) Favignana represents an emerged part of the Egadi Thrust Belt (Abate et al., 1995; Abate et al., 1997) a sector of the Apenninic-Maghrebian Fold and Thrust Belt (Catalano et al., 1993). In the Island central ridge and western plain the Upper Triassic Sciacca Fm. outcrops (D'angelo, 2005; Malatesta, 1957). This is represented by dolomites and dolomitic limestones with mollusks, algae and foraminifera. They are layered and partly intercalated,

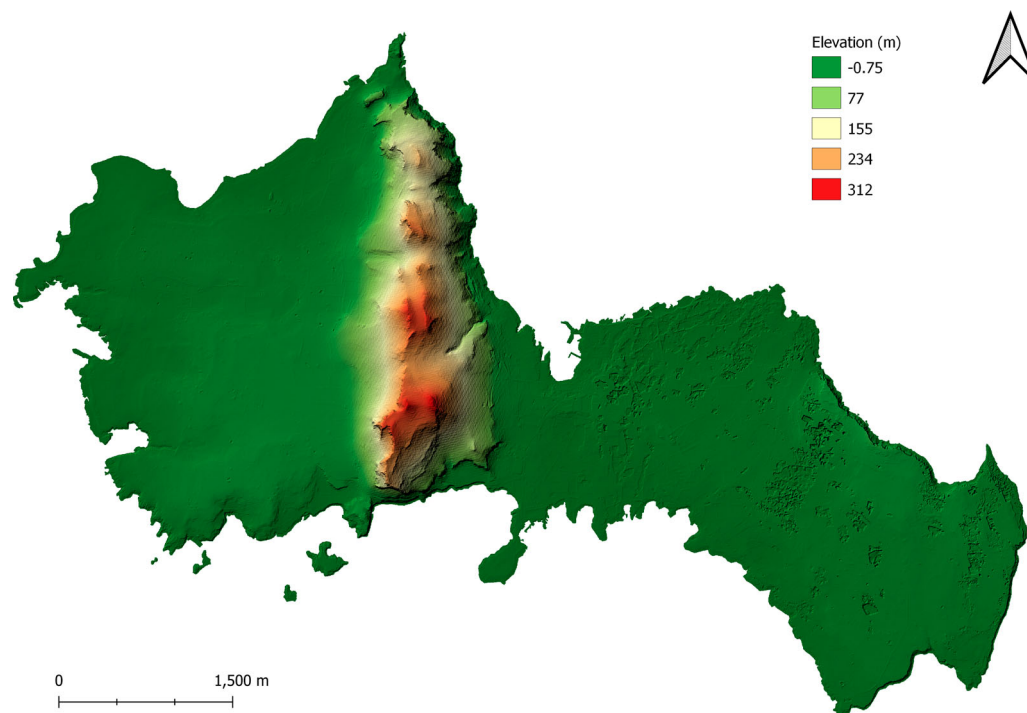


Figure 2. Orography of Favignana Island (after LiDAR data, see Table 1).

including layers of dolomitic (loferitic) breccias and dolomitized marls. In the southern edge of the central ridge the Lower Jurassic Inici Fm. outcrops, represented by limestones and dolomitic limestones with calcareous breccias intercalations. Minor outcrops of Mesozoic–Upper Neogene carbonatic rocks are accounted for. In the eastern plain and the northern edge of the western plain the Lower Pleistocene Sintema di Marsala outcrops (D’angelo, 2005). This rests on an unconformity of the bedrock, shaped in Middle–Upper Pliocene marls and shales, and is represented by Lower Pleistocene calcareous sandstones (Tondi et al., 2012; Uchman et al., 2012) with mollusks, echinoids, sponges and calcareous algae. The western tableland, carved in the Triassic dolomites and dolomitic limestones, is partly overlapped by conglomerates, bioclastic sandstones and scattered aeolianites (Sintema Paceco, Sintema Barcarello in D’angelo, 2005; Ventura Bordenca, 2014) dated to the Upper Pleistocene and Holocene, due to the presence of diagnostic faunas (Agnesi et al., 1993). The two tablelands have been morphologically interpreted as the product of marine shaping occurred during Upper Pleistocene sea-level highstands (Agnesi et al., 1993).

Based on the Köppen–Geiger scheme the Egadi Archipelago climate can be classified as of Csa type, which represents a variety of the Mediterranean climate (Fratianni & Acquafredda, 2017). Although no meteorological record is available for Favignana itself, the closest meteorological station on the mainland (Trapani, SIAS dataset: http://www.sias.regione.sicilia.it/frameset_dati.htm) records a mean Summer

temperature of 26°C and mean Winter temperature of 12°C with a total yearly rainfall of 450 mm, clustered during the Autumn season. The prevailing winds blow from NW, NNW and ESE and accordingly wave’s direction is from the NW, with significant wave height values around 3–4 m. The tidal regime is of semidiurnal microtidal type with maximum tide amplitude of ca. 0.5 m (Polizzi, 2011).

3. Methods

Landforms were recognized and genetically categorized based essentially on remote sensing, i.e. on the analysis of stereoscopic aerial photographs and freely available satellite images (Table 1). These include aerial photographs and optical satellite imagery. Moreover, morphometric elaborations on a digital elevation model based on LiDAR data were undertaken to detect morphological evidence of landforms (Jaboyedoff et al., 2012). The ALS (airborne laser scanning) survey was performed in 2008 using an ALTM Gemini. The points clouds acquired were geo-coded in WGS 84 lat long, with horizontal and vertical accuracies of ± 15 cm and ± 30 cm, respectively. Remote sensing outputs were validated by means of field visits performed on February 2019.

The geomorphological map was created following, except for minor amendments and additions, the guidelines of the Italian Geomorphological Working Group (Campobasso et al., 2018; Mastronuzzi et al., 2017) for landforms symbolic representation. These include an immediate visual differentiation, achieved through the use of different colours, of the

Table 1. Data and images used for the work.

Type	Properties	Name	Year	Source
Cartographic Map	Scale 1:10,000	ATA0708_604080 ATA0708_605050	2007–2008	Sicily Region
LiDAR	Resolution: 2 × 2 m	/	2006	Ministero dell'Ambiente
Airbornes b/w	Scale 1:20,000	1263, 1264, 1265, 1271, 1272, 1273, 1274 e 1275	2003–2004	Assessorato Territorio e Ambiente
Landsat 7 ETM imagery	Resolution: 30 m	/	2015	Nasa
Google Earth imagery	Resolution up to 0.6 m	/	2013–2015–2017–2019	Digital Globe

geomorphological agent responsible for the genesis of landforms and of different tonalities of the same colour to highlight the state of activity of landforms. The Identified geomorphological features were digitally drawn in a geographical information system (GIS) environment (QGIS 2.18, open source software). The geomorphological map was originally drafted on the 1:10,000 topographic base-map of Sicily Region. For the final layout contour lines extracted from a digital elevation model based on LiDAR data were used as a base-map. The layout was adapted in order to fit also into an A3 format for printing, to enable a friendly handling by end-users (e.g. tourists).

4. Results

The landforms recognized in the study area, categorized in terms of erosional and depositional forms, can be related to the bedrock structure (structural landforms) and to six morphological agents. In the map they have been overlapped to the bedrock, which has been differentiated through the standard colours of the lithological categories (Campobasso et al., 2018; Brancaccio et al., 1994), in which the formal geological formations were grouped. The most outstanding landforms detected within each geomorphological category are illustrated below.

4.1. Structural landforms

Along the central mountain ridge rock structure controls the development of minor landforms. Particularly saddles are the expression of a W-E fault system along the main watershed. Some of the scarps affecting the ridge slopes are also structural in origin, although they are subjected to secondary weathering and gravity-driven processes.

4.2. Gravity-induced slope landforms

The central mountain ridge is the only part of the island where slope gradient (relief energy) is strong enough to create gravity-induced landforms. Its western flank is almost entirely covered by a scree slope of variable thickness. The eastern flank, instead, displays a belt of loose, coarse and angular debris at the foothill. Locally the scree is displaced in the form of

a fan. Gravity is actively dislodging the weathered parts of the bedrock. The uppermost edge of the scree slope is overwhelmed by a degradation escarpment. The concave shape of part of the escarpment, suggests that in the past landslides, the body of which is currently submerged, may have been triggered along it. Some small sized active rockfalls were identified along the flanks of Mt. Santa Caterina.

4.3. Fluvial and slope landforms due to runoff

The overall flat morphology and the small extension of the island prevent the development of a drainage network. Only a few single-branched gullies cut the flanks of Mt. Santa Caterina. They are occupied by ephemeral streams that form only in connection with the main precipitation events. Some of them end with small alluvial fans. On top of the tablelands the weathered part of the bedrock is represented by a layer of fine-grained loose deposit, rich in iron oxides (*terra rossa*), representing the residual product of karst dissolution (Durn, 2003). Rainwaters mobilize this material through sheet erosion, without developing a channel network. The product of this process, thus, was indicated in the geomorphological map as a colluvial talus.

4.4. Karst landforms

Karst processes dominate the bedrock of the tablelands in Favignana. Only a few flat-bottomed dolines, 40–200 m in diameter, were identified in the aerial/satellite views (Figure 3(a)). More dolines were naturally developed on the tablelands, but they were artificially filled in with *terra rossa* to produce humid ploughing soils. In fact, being a drainage network not developed on the island, the ponors within the dolines are responsible for rainwaters penetration down to the groundwater table. As a result, dolines appear in aerial/satellite views as more humid and vegetated areas. They represent, thus, valuable areas for agriculture, so that their contour was in some cases rectified by human action. Owing to this rehandling, dolines could not be categorized simply by means of a field survey. Interestingly, many of the Island bays result from marine erosion breaching a doline wall in a framework of sea-level rise. Inland the doline wall has



Figure 3. Outstanding karst and anthropogenic landforms: (a) wide, seaward-open doline (Pirreca); (b) griza scree (Cala Rotonda); (c) coastal karst pinnacles (*spitzkarren*) along the south-western coast; (d) cave entrance (Grotta delle Uccerie); (e) coastal abandoned quarries of the eastern tableland (Punta San Nicola); (f) recent quarries locally named ‘the skyscrapers’ (west of Punta San Nicola).

been preserved in the form of a steep rocky scarp and its bottom, currently occupied by the sea, creates a shallow and sandy pool along the coast. Griza scree and karren fields (Ginés et al., 2009) occupy the most exposed edges of the western tableland (Figure 3(b)). At the seaward edge of the ramps, especially within the zone where biofilm spreads, the bare rock has an overall spongy appearance being shaped in the form of cm-scale sharp-edged pinnacles (Figure 3(c)). These karstic microforms, not reported in the geomorphological map due to scale issues, are generally termed *spitzkarren* (De Waele and Furlani, 2013), and related to biokarstic processes (Taboroši & Kázmér, 2013). The entrances of five caves are reported in the map, located at different altitudes along the slopes of the central mountain ridge (Figure 3(d)). Many of these hypogeal karst landforms contain speleothems. Traces of human occupation (Martini et al., 2007; Colonese et al., 2011) are accounted for from some of them and especially from Grotta d’Oriente, a cave on the eastern flank of the mountain ridge, that contains discontinuous traces of human

occupation from the late Upper Palaeolithic to the Bronze Age.

4.5. Coastal and submarine landforms

According to Agnesi et al. (1993) both the eastern and the western tableland in Favignana were shaped by marine processes not later than the Lower Pleistocene and thus they can be considered inherited landforms. Due to scale issues, they were not reported in the map. Otherwise, all geomorphological features directly or indirectly shaped by sea were included in the category of coastal landforms. Actively sculptured cliffs and ramps (Figure 4(a)) are widespread all around the perimeter of the Island. Along the north-eastern slope of the central mountain ridge the cliff is directly plunging into the sea. Its upper edge is around 10 m a.s.l. and its toe can be inferred from bathymetric data at ca. 25 m depth. The cliff is plunging also along most of the eastern tableland perimeter, where its upper edge is at a lower elevation. Marine terraces are not a well-developed feature in Favignana. A flat surface at an



Figure 4. Outstanding coastal landforms and deposits. (a) marine cliff in Pirreca Locality; (b) the southernmost tip of the Mid-Pleistocene marine terrace (Case Canino); (c) MIS 5.5 marine deposit with *Persististrombus latus* individuals (Scindo Passo); (d) tidal notch (Cala San Nicola) (e) waves breaking highlighting vermetid reefs along the south-western coast; (f) storm waves-generated boulder accumulation (Cala Pozzo).

elevation of ca. 30 m borders the western slope of the main mountain ridge (Figure 4(b)). A steep scarp separates it from the underlying western tableland. This feature was interpreted by Malatesta, 1957 as a product of marine abrasion and referred to a Mid-Pleistocene interglacial phase. Moreover, patches of a marine terrace at the elevation around 2 m a.s.l were mapped in different tracts of the Island coastline, overlapped by marine deposits (Ventura Bordenca, 2014) containing *Persististrombus latus* shells (Figure 4(c)), that in the Mediterranean are generally considered exclusive of the MIS 5.5 highstand (Antonioli et al., 2006; Repetto et al., 2020). In the cross profile (see Main Map inset) its best morphological expression is shown.

Where the cliff is absent, the coastline is frequently shaped as a gently seaward dipping ramp. This morphology is particularly developed at the western edge of the Island. Both the cliff face and the ramp outer edge frequently display, undercuttings at mean sea-level elevation interpreted as tidal notches (Figure 4 (d)). Locally the ramp is bordered seaward by a narrow platform morphology (Figure 4(e)), covered by

gastropod mollusk *Dendropoma petraeum* (Balistreri et al., 2015), that forms a vermetid reef in the intertidal. Active marine deposits are poorly represented along the coast of Favignana. Sandy or pebbly beaches are rare as active features and very small. An inactive beach ridge was recognized along the western coast. A boulder accumulation (Figure 4(f)) interpreted by Pepe et al. (2018) as derived from high magnitude storm waves was mapped along the shore in Cala Pozzo.

4.6. Weathering landforms

The ramps surfaces are mostly carved by rounded and shallow rockpools, from a few dm up to ca. 2 m long/wide. Being located in the lower supratidal zone, they were interpreted as erosional features shaped by elementary processes promoted by aerosol spray. Salt weathering and wetting and drying are normally considered the main processes causing the formation of rockpools (2007). Sea water may temporarily fill them, especially those that are closer to the shore. In

this case the role of some biota, such as green algae, may play a role in shaping them (Maggi et al., 2012).

4.7. Anthropogenic landforms

The morphology of the eastern tableland of Favignana Island is deeply modified by quarrying activities. The Lower Pleistocene calcareous sandstones outcropping there have been extensively carved (Figure 3(e)). Different quarrying techniques have been used through time. Along the coast blocks were dislodged directly from the cliff face, promoting enhanced cliff retreat up to 80 m from its original position. This can be reconstructed based on relic rock outcrops. Inland the most common quarrying technique has been in the underground, although a few open-air quarries are still active (Figure 3(f)).

5. Discussion and conclusion

The combination of remote sensing techniques applied to detect the landforms of Favignana validated by a geomorphological field survey revealed that the Island morphology is dominated by different morphological agents in the central ridge and in the eastern and western plains. The morphological evolution of the central ridge is constrained by the geological structure, being represented by a monocline relief, the slopes of which are affected mostly by active gravitational processes. Conversely the western plain is dominated by karst action. Limestone dissolution produces different landforms. In the view of previous Authors (e.g. Agnesi et al., 1993) the overall flat morphology is the result of marine abrasion during an undetermined ancient interglacial with a relatively higher sea-level. Karst action, in this view, should have acted on a previously flattened surface. Our geomorphological survey, though, highlights a dominance of karst landforms on the western tableland over the marine ones.

Geomorphology of the eastern part of the Island is dominated by anthropogenic landforms. Quarrying affected a geological unit formed in a shallow sea bottom and then raised above sea-level, in the form of a NW dipping tableland. On the surface of the eastern tableland, no traces of marine abrasion were found.

Interestingly, thus, the geomorphological map of Favignana Island demonstrates that landforms directly related to sea as a shaping agent are mostly constrained to a very narrow land stripe backing the shoreline. Through this map, instead, it was possible to highlight the richness and diversity, in terms of morphological agents, of the landforms that characterizes the relatively small territory of the Island. This peculiarity makes of Favignana an excellent candidate for the exploitation of its geoheritage for touristic purposes.

Software

Vector data management and final layout were performed using QGIS 2.18. The topographic profile was carried out from LiDAR data (Ministero dell'Ambiente, <http://www.pcn.minambiente.it/mattm/tag/dati-lidar/>) using Profile tool plugin and it was verified on the field using DGPS Leica GS09.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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