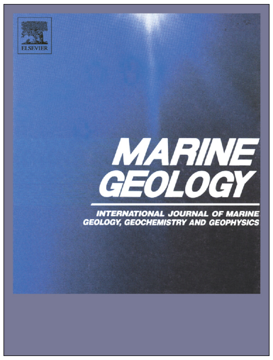

Integrating observational targets and instrumental data on rock coasts through snorkel surveys: A methodological approach

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Integrating observational targets and instrumental data on rock coasts through snorkel surveys: a methodological approach

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Abstract

This work deals with recent advances in scientific snorkel surveying, starting from the results of several case studies in the Mediterranean between 2012 and 2018, for a total survey length of 531.4 km, with the aim of illustrating the pros and cons.

The snorkel survey method, described here, also called ‘Geoswim’, allows rough-and-ready surveys of long sectors of rocky coasts. In particular, it is able to collect time-lapse images perpendicularly to the coastline and observe long sectors of rocky coastline, with particular reference to the tidal zone. In addition to the photographic survey along the coast, rough measures, lateral variations in geomorphological, geological, biological, and ecological parameters and the collection of hydrological data are usually performed during the work. The expeditions also provide the opportunity to produce large databases of coastal landforms such as coastal sea caves and tidal notches. The data collected can be improved by additional on-the-spot observations.

The evaluation of the methodology here proposed was based on the results of SWOT analysis starting from the results and the experience of previous expeditions. Geoswim is the first snorkel approach that allows the collection of large amount of multidisciplinary data along wide sectors of rocky coastline. At the moment, this approach is the best and probably the only technique for characterizing the tidal and nearshore zone, but also to collect observational data of prominent objects along rocky coasts. However, snorkel observations are affected by limitations similar to those of terrestrial field surveys. The ability to observe specific forms or phenomena increases through the practice of field observation and are strongly observer-influenced. Sheltered sea basins are better suited than ocean basins, where tides and wave energy are generally higher. Data collection is also affected by weather and sea conditions. The quality of time-lapse images and videos may be reduced as a result of breakers at the cliffs, producing images that cannot be used for subsequent analysis. As for external factors, some sectors of the coast may be closed due to local restrictions on field activities.

Keywords

Coastal geomorphology; swim and snorkel surveys; tidal notches; sea caves; Geoswim; Mediterranean Sea.

Highlights

- The Geoswim approach permits the collection of large amounts of data through snorkel surveys along wide sectors of rocky coastline.
- The surveys are carried out following a precise protocol and using a specially-built raft that hosts sensors and cameras.
- The surveys aim to collect geological, geomorphological, hydrogeological and biological data.
- Details of the method, pro- and contra-, and correlations are discussed.

1 Introduction

Swim-surveys represent an intriguing challenge for geologists and geomorphologists that are commonly involved in field surveys of rocky coasts. A swim-survey can be classified as an expedition, or a long journey undertaken with specific aims, in this case for scientific, exploratory and geographical purposes. The expedition involves a single rough survey implying a loss in resolution, while fieldwork involves returning to the same place, to examine the same and related scientific issues, possibly with other scientists, and recovering the richness forfeited in the successive losses in resolution of the expedition (Richards, 2011).

Initially, the swims along rocky coasts were carried out mainly for recreational purposes or within guided excursions (Epstein, 2006). Snorkel surveys were carried out along short routes, mainly for ecological studies, such as fish populations (e.g. Thurow, 1994) or turtle populations (Sterrett et al., 2010), etc. On the other hand, until 2012, swim and snorkel surveys for long routes were never used for scientific purposes along the coasts (Furlani, 2012). In 2012, an extensive programme, called ‘Geoswim’, began collecting geomorphological, hydrogeological and biological data together with field visual observations along wide sectors of rocky coasts in the Mediterranean basin (Furlani, 2012; Furlani et al., 2014a, 2017a, b; Antonioli et al., 2015, 2018) using wide-ranging swims around the Mediterranean rocky coasts, that cover about half the basin (Furlani et al., 2014b). Despite their importance, extensive swimming or underwater surveys had never been carried out before the Geoswim experience.

Rocky coasts are the tangled consequence of the interplay between marine and subaerial processes (Kennedy et al., 2017) that produce wide spatial-scale landforms. Historically, Trenhaile (1987) and Sunamura (1992) represent the two fundamental books of the research on rocky coasts. However, studies on rocky coasts focussed on specific sites or problems, and studied with punctiform observations, are mostly carried out walking (e.g. Kennedy, 2013; Kennedy et al., 2014 and references therein) or through remote sensing-based data. Around the Mediterranean, research on rocky coasts have mainly been devoted to sea level change (Furlani et al., 2014b, Mourtzas et al., 2016), and secondarily to processes and rates, such as erosion or bioweathering (e.g. Torunski, 1979; Furlani and Cucchi, 2013; Gomez-Pujol et al., 2006), shore platform processes (e.g. Gomez-Pujol et al., 2006), tsunami or storm wave hazards (e,g, Mastronuzzi and

Sansò, 2000; Scicchitano et al., 2007, Biolchi et al., 2019), phenomena of coastal instability (e.g. Devoto et al., 2013;) or models on the evolution of particular landforms, such as tidal notches (Trenhaile, 2017). Only occasionally have review studies crisscrossed wide sectors of coastline (Antonioli et al., 2015, 2017), but even these involved just the collection of punctiform data. The common feature of the works examined here is the fact they are very localized, because of the complex logistics of swim and underwater surveys (Furlani et al., 2014a). The greater efforts related to the physical commitment of swimming has certainly discouraged many researchers from swimming along rocky coasts, especially along plunging cliffs.

The availability of very detailed remote data, both in the subaerial and underwater environment, such as, respectively, LiDAR and Multibeam data, cannot satisfactorily contribute to describing the tidal zone, its peculiar landforms, such as tidal notches, or the horizontal variations in these parameters. Recently, LiDAR-based methods (Terefenko et al., 2018) and TLS (Schneiderwind et al., 2017) were used to study tidal notches, but the high slope of sea cliffs and the presence of an air-water interface prevent the acquisition of remote data, making swimming a potentially useful approach for photographic and photogrammetric surveys.

In the paper, the potential and the limits of snorkel surveys of long sectors of rocky coastline have been. The analysis follows the experience gained in 12 expeditions along a total route covering 531.4 km in the central and Eastern Mediterranean Sea (Fig. 1, Tab. 1), carried out within the Geoswim programme. Morevoer, the instrumentation adopted and the procedures followed to do the research are fully described. The paper analyses an unusual approach to survey coastal landforms and hydrogeology, but it could also be useful in other fields, such as biology and ecology.

2 Description of the Geoswim approach

The snorkel surveys within the Geoswim method follow the approach reported below and using specific instrumentation. In particular, the raft used during swimming activities (par. 3.1), the instruments housed on the raft (par. 3.2), navigation issues (par. 3.3), types of data collected (par. 3.4), data storing and coordination between instruments and data saving (par.3.5), surveyor training and expertise (par. 3.6), expedition design and limitations (par. 3.7) have been described.

2.1 Raft description

The snorkel surveys are carried out using a specially-built raft (Fig. 2 and 3) to support the swimming activities and to house all the surveying equipment, such as cameras, CTD divers, GPS, tablet, echosounder, etc. Several tests were made to find the best support for snorkel surveys (Fig. 3). In the end, a base constituted by the spearfishing Sporasub platform EVA (Fig. 2a) was adopted. Its total length is 1.15 m, the width is 0.57 m and the total height with the plastic bag is 0.27 m, 0.13 m without the plastic glove for fish storage, while the weight of 3 kg. The raft is constructed with Ethylene-vinyl acetate (EVA), a light polymer, about 0.98 g/cm^3 with very good resistance to permanent deformation after compression and quite good resistance to abrasion, excellent resistance to UV and very resistant to seawater. It is considered virtually unsinkable by producers. In the bow, a reel with 25 m of rope can be used to drag the raft. The raft was modified by adding L-section aluminium bars fixed from bow to stern above and below the boat in order to facilitate the housing of the instruments (Fig. 2b, c, d and 3). In particular, the nylon/PVC glove on the top of the raft was removed in order to obtain an almost flat deck upon which to set the instruments. The deck was equipped with aluminium bars with an L section. A removable home-made plastic dome was added to the aluminium structure in the bow of the raft (Fig. 2c and 3). The dome is 0.40 m in diameter and can host two action cameras, also mounted on a gimbal (Fig. 3d, e), or one mirrorless one to collect videos, images or to document the surveying activities (Fig. 2c, d). On the aluminium structure, a roll-bar built with the same material is set on the stern of the raft. A set of cable holders are used to fix removable instruments on the raft.

The raft is equipped with 14 bindings that can be used to fix the instruments and avoid their loss in choppy conditions (Fig. 2d). Removable shoulder straps were added using 4 bindings to reach some starting or ending locations that can be reached by car, when snorkel operations are made without boat support. Moreover, in the bow there is also a scuba gear dive flag for the safety of surveyors (Fig. 2a, d).

The raft is pushed or dragged during the snorkelling activities by swimming, but no engine has been added because the high-capacity battery required would be very heavy to support surveys of up to 8 hours.

2.2 Instruments

All the surveying instruments are housed on the raft, so as to be accurately fixed to the bindings and the bars, in order to optimize the collection of data in relation to swimming navigation. Depending on the goals of the expedition, all the instruments, or part them, can be used.

One or more cameras can be set in waterproof housings, and allow the collection of ongoing videos and time-lapse images of the coastline being surveyed, both above and below the waterline. Different settings of cameras were adopted during the expeditions (Tab. 1) for the collection of videos or images as needed. The minimum number of cameras, usually various GoPRO versions, one above and one below the waterline. The cameras should be set laterally with respect to the raft in order to collect time-lapse images every second in the direction of navigation (Fig. 4). The cameras set below the waterline include a Telesin plastic dome 6 inches in diameter in order to perform with superior optical performance in the seawater (Fig. 4). In the home-made dome fixed in the bow (Fig. 2c, d and 3), the cameras can collect videos above and below the waterline simultaneously thanks to the geometry of the lens itself (Fig. 3). They are used to constantly document the field surveys. The plastic domes must be protected with a neoprene case during the transportation because they are very sensitive to abrasion.

The raft hosts two CTD divers datalogger produced by Eijkelkamp Soil & Waters. These are fixed to the raft at -0.05 m and -0.25 m below the waterline and collect temperature (°C) and

Electrical Conductivity (EC, mS/cm). In addition, a set of 4 thermometers are set at -0.05 m, -0.15 m and -0.5 m below the waterline (Fig. 4) and are automatically coupled to GPS data. The purpose-built unit is controlled via an Arduino shield (Fig. 4).

The raft supports two ORSDA 1800 lm waterproof led lamps, in particular for the surveys within sea caves together with several portable underwater lamps.

On the raft, a Navionics echo sounder, Velixar T-Box Sonar Phone SP200, a WiFi fishfinder dual-BEAM, min depth 0.6 m and max depth 73 m, can be added to collect depths values along the path (Fig. 2d). The instrument is Wi-fi controlled via smartphone with the Sonar phone app. Depth values are automatically corrected by the app for astronomical tide variations at local level, but then these data must be corrected with the atmospheric pressure, temperature and salinity of the water using sensors housed on the raft. Depth data are georeferenced and can be automatically uploaded to the Navionics website at the end of the survey. Data can subsequently be provided, on request, in csv format. These data are used to collect more data at prominent sites with calm sea rather than precise submerged profiles, since waves alter the reference level of the sensor across space and time during the surveys. An additional portable echosounder, Digital Sonar H22PX, min depth 0.6 m and max depth 61 m, is housed on the boat to collect any additional depth data at prominent sites.

A 9.7 inch tablet is housed within a waterproof case on the roll-bar in the stern (Fig. 2d). A specific app to store observational data together with some additional information is under construction within a parallel project called ‘Teleswim’. The roll-bar also holds the radio and an additional GPS (Fig. 2d and 3).

2.3 Navigation issues

The Geoswim approach is based on field surveys of long sectors of rocky coasts carried out following a planned route and using snorkeling. Usually the campaigns are carried out during the spring or summer seasons, because of the generally favourable sea conditions that allow easy navigation. The survey follows a route at roughly 1 m to 5 m from the coastline in order to identify the lateral variations in coastal geo-targets, and at the same time collect time-lapse images above, below and at sea level (Fig. 4). Small changes in the route can occur with respect to the planned one due to the local topography or due to worsening in weather and sea conditions. The latter forces the swimmer to move out from the coast for safety reasons. The navigation usually proceeds at a constant speed, ranging between 1 to 2 km/h, unless they encounter significant changes in the coastline, prominent geomorphological features, or topographic obstacles (Fig. 4).

2.4 Data

2.4.1 Observational targets

Snorkel surveying activities are carried out by observing and mapping prominent coastal landforms, the lateral variations of coastal landforms of different size, from metres to tens of metres, such as tidal notches or sea caves, the occurrence of significant changes in temperature along the surveying route, mainly related to submarine springs, and other geological objects of note. Geomorphological targets are located using GPS and mapped. In particular, tidal and roof notches (Fig. 5c), potholes (Fig. 5d), submarine springs, sea caves (Fig. 5a, b), biological trottoirs (Fig. 5e), etc. are measured, geolocated and mapped.

Observations are communicated via radio to the support boat and reported on the log book. The latter also records other navigational information, such as the start point, end point, changes in swimming direction, etc. In the case of single observer surveys, observations are reported on a tablet housed on the raft. Waypoints, or geotags, are also documented by single point images (Fig.5). The types of targets can be chosen based on the local characteristics of the study area. For example, tidal notches can often develop on carbonate coasts, while they are completely missing on volcanic ones. Here, other coastal landforms are present, such as volcanic landforms re-shaped by marine processes, abrasional landforms, etc.

Morphometric parameters of observed landforms are measured using common field instruments, such as invar rods, compasses, stainless steel metric folding rules, and tape measures for submerged environments, with a laser distometer being used only for emerged environments. Depths are measured using the aforementioned echosounders.

2.4.2 Instrumental data

Instrumental data include time-lapse images and videos collected with several types of cameras, in particular GoPros, housed above, below or at the waterline (Fig. 5c, d), and measures of variations in electrical conductivity (EC) and temperature (T) using data-loggers along the survey route (Tab. 2).

Time-lapse images and videos

Time-lapse images are collected both above, below and at the waterline (Fig. 6). The overall configuration of the cameras was modified during the campaigns due (1) to the improvement of technologies and (2) the experience gained in the previous campaigns.

In the first and second campaign (Tab. 1), videos both above the waterline, with a CANON G12 camera, and below the waterline, with two GoPRO Hero cameras set in a double box for 3D video were collected. In the third campaign in 2014, videos at the waterline were collected by two GoPRO cameras, the first horizontal and the last inclined. After 2015, time-lapse images at the waterline were collected using GoPRO cameras. From 2016, time-lapse images were collected both above and below the waterline; the videos being collected by the camera housed in the front dome. Cameras are normally set to collect images every 0.5 s to 2 s. Images collected above or below the waterline can be post-processed to produce 3D models of short sectors of rocky coasts (Fig. 6). Data processing of the time-lapse images is carried out using software for photogrammetric processing, such as Agisoft (Fig. 6) and photo editing, such as Adobe Photoshop.

Moreover, images can constitute the background for a survey 0, useful for future geological/geomorphological, but also for environmental comparisons. Images are, in fact, geotagged with Exif Image Metadata.

CTD data

CTD data were collected along the entire swimming route (Tab. 2). Lower temperature and electrical conductivity peaks highlight the possible occurrence of freshwater outflows along the surveyed coasts (Fig. 7).

The data-logger (CTD Diver) was set up to measure electrical conductivity (EC) and temperature (T) along the coastline (every 2 seconds). The accuracy, provided by the producer, was ±0.1 °C (T) and ±1% (EC).

Hydrological data were collected with the sole purpose of identifying and locating any submarine springs along the surveyed sectors. However, swimming at about 2-3 km/h, temperature data can be affected by a strong thermal inertia, preventing the rapid equilibrium of the thermal CTD Diver sensor. The determination of the true value of EC can be also be affected by a film of saltwater on the instrument, which may provide false values in correspondence to the submarine spring. CTD data and GPS data were synchronised and processed to correlate EC and T, since data were collected following the favourable wind driven currents.

Depth data

Depth data are collected both along the route and at prominent sites (Tab. 2). The first do not allow us to reconstruct the sea-bed, but they provide a rough description of it during snorkel surveys. Usually, at prominent sites, a profile perpendicular to the coast is acquired by considering 50 fins from the site. Within the sea caves, the depths of sea bottom together with the width of the submerged part of the caves are collected with the portable echosounder.

2.5 Data storing, time register and coordination between instruments and data saving and storage

The issues of this paragraph are related both to the storing of visual observations and (2) to the logging of time-lapse images, videos and physical/chemical parameters *en route*.

During solitary expeditions (Tab. 1), observations are reported on a waterproof log book. The general characteristics of the geo-targets were reported on the log book together with the time of surveying and the geographic position as a GPS tag. These operations are all made by the operator in the water. During team expeditions with boat support, geo-targets are communicated via radio and reported on the notebook by assistants on the boats. From 2017, 3 tests were carried out using a specially created app.

Instrumental data are stored in different ways, with images and videos being stored in SD or microSD cards, while physical/chemical data are stored both in the internal memory of the instruments, and subsequently downloaded to the server, or stored in an SD card.

2.6 Users training and expertise

The first expedition was carried out by myself alone for its marine objectives. I'm an expert swimmer and a senior researcher in coastal geomorphology, with certified experience in field research. The training pre-expedition, in particular the first expedition, involved, in particular, my physical training for 6 months. From the second expedition, the team was composed by myself, two experts in coastal surveys and a number of students as assistants. All the participants were requested to have a medical certificate for non-competitive sports activities and personal insurance for diving activities.

The surveyors are usually requested to have a prior lesson regarding coastal geomorphology, swim surveys and safety on site. Moreover, two field expeditions, usually from 1 to 2 km in length are requested to gain the minimum expertise needed by the project.

2.7 Expedition design and limitations

Field expeditions are designed starting from some basic needs. First of all, the choice of a study area starts from safety in maritime activities. The surveys must be carried out within a maximum safety framework, both for one-man surveys and teams. Then, logistical considerations play a fundamental role. If distances of the potential surveying sites are up to some tens of kilometres from local ports, it can be very difficult to reach them, when they cannot be reached with other means of transport. In this case, the choice fell on other sites. Another key consideration is the presence Marine Protected Areas, or Maritime Police or Coastal Guard that can guarantee experts for swim surveys. In many cases, expeditions began through specific invitations from local researchers, Public Agencies, such as those in Malta, the Egadi islands and Ustica experiences, etc. (Tab. 1). In some cases, expeditions started from the presence of significant percentage of plunging cliffs in the study sector, exceeding 50%, since they allow the collection of very reliable data. In the planning of the campaign, the overall complexity of the coastal topography is also considered. The presence of too many semi-submerged rocks and boulders can limit or prevent the acquisition of reliable images, because it may prove very difficult to swim along the planned routes. In the end, also the need for specific goals to be achieved, such as coastal mapping, or the acquisition of data to study local relative sea level changes can be crucial when choosing the survey area.

3 Field tests

Field expeditions were carried out from 2012 to 2018 without interruptions, as summarized in table 1, in several coastal sectors of the Mediterranean basin. A description of this area is provided in paragraph 3.1. In 2019 the Geoswim programme was halted to test new camera configurations to produce 3D models of the coastline. The post-processing of the tests is now in progress. Following, a description of the most important field tests, with the total number of kilometres covered, the presence of a team or one-man survey, the type of support, such as land-based or boat-based, the type of data collected, any publication of the data and, eventually, any notes are reported in paragraph 3.2.

3.1 Study area: Mediterranean Sea

Woodward (2009) described the physical geographical features of the Mediterranean (Fig. 1), a marine basin almost completely enclosed by land. The Mediterranean coastline (Mc) extends for approximately 46,000 km and approximately half of this is rocky coasts (Furlani et al., 2014b). Biolchi et al. (2016) described five types of rocky coasts in the Mediterranean area: plunging cliffs, sloping coasts, screes, shore platforms and pocket beaches.

The Mediterranean is connected to the Atlantic Ocean through the Straits of Gibraltar to the west, and to the Sea of Marmara and the Black Sea through the Dardanelles and the Bosporus Straits to the east. In 1869, the Suez Canal was opened, creating a connection between the Mediterranean and the Red Sea. On its northern shores it is flanked by the coasts of Europe and the Middle East, and, to the south, by North Africa. It can be divided into the Western and Eastern Mediterranean along an imaginary axis in correspondence to the Straits of Sicily and Tunisia (International Hydrographic Organization, 1953), but many papers also identify an undefined "central Mediterranean area" (e.g. Benjamin et al., 2017, Mastronuzzi et al., 2017). The Mediterranean also includes many large islands and covers an area of about 2.5 million km².

The Mc has a long and complex geological history that began about 250 Mya ago, following the break-up of the continent of Pangea and the formation of the Tethys Ocean, the forerunner of the Mediterranean (Mather, 2009). From a geological point of view, the Mediterranean borders the westernmost sector of the Alpine-Himalayan orogenic belt. Its geodynamic evolution was driven by the differential seafloor spreading along the Mid-Atlantic Ridge, which led to the Alpine orogenesis (Mather, 2009). It hosts wide extensional basins and migrating tectonic arcs.

Vertical and horizontal crustal movements control the geological and geomorphological history of the area. The Mediterranean Sea includes zones of active subduction associated with volcanic activity and older zones of quiescent subduction (Mather, 2009). The coastal reliefs, coupled with seismic activity generated by geodynamics, drive most erosional processes within the area. The resultant geomorphic features on rocky coasts include sea cliffs and shore platforms, plunging cliffs, etc., which may be at different altitudes (Furlani et al., 2014b). The combination of raised and drowned shorelines define the active nature of tectonics in the Mediterranean. The spatial variation in uplift can be highlighted e.g. by geomorphological markers, such as tidal notches, marine terraces or other tidal landforms together with other well-defined markers, such as archaeological and sedimentological ones (e.g. Anzidei et al. 2014; Benjamin et al., 2017).

For the aforementioned reasons, rocky coastal landforms along the Mc are closely connected with sea level history (Benjamin et al. 2017). These coastal landforms are spread in elevation from few metres up to more than 100 m asl, due to the relevant tectonic uplift that patchily affects the basin coastline (Anzidei et al., 2014). Pleistocene highstands have mainly been responsible for the formation of stepped flights of terraces along the rocky sections of the Mc.

The typical Mediterranean climate is hot, dry summers and mild and rainy winters (Rohling et al. 2009). Water circulation and environmental evolution in the Mediterranean Sea are tightly controlled by the Straits of Gibraltar. Water circulation is driven by interactive factors, such as climate and bathymetry, which can lead to precipitation of evaporites. In the Mediterranean, evaporation greatly exceeds precipitation and river runoff, and this also affects the water circulation within the basin (McElderry 1963). Evaporation is especially high in the eastern Mediterranean and causes the water level to decrease and salinity to increase (Pinet, 1996). This pressure gradient pushes relatively cool, low-salinity water from the Straits of Gibraltar across the basin. Here, it warms and becomes saltier as it moves eastwards, before sinking in the eastern Mediterranean, moving back westward, to spill out through the Strait of Gibraltar at depth. Thus, following Rohling et al. (2009) the flow is eastward on the Strait's surface waters, and westward at depth. A current of 2 knots and flows southwards in summer and northwards in winter (McElderry, 1963).

The mean vertical variation of tides is about 0.4 m, as a result of the narrow connection with the Atlantic Ocean (Pinet, 1996). At the Straits of Gibraltar, tides are affected by the ocean, thus the mean amplitude increases to 1.5 m, and it quickly decreases eastwards. Weather conditions can cancel out or amplify tides, up to a maximum range of nearly two metres in the Gulf of Gabes, Tunisia, and the Northern Adriatic Sea.

3.2 Description of the field tests

In 2012, the first and longest campaign along the northeastern Adriatic rock coast was planned, for a total length of 253.2 km (Tab. 2). The snorkel surveys were carried out by me alone in 27 steps, covering an average of 10 km/day. The support was entirely land-based, apart for the final step that was supported by boat. Data were published in Furlani et al. (2014a). Videos were collected both above and below the waterline along the entire route. Above the waterline, a Canon G12 camera was used, while below the waterline two GoPRO cameras set for 3D acquisition were used. Additional photos were collected at prominent sites, where swimming stopped for visual surveys and measurments. Observational data were reported on a waterproof log-book. Limitations to the survey were mainly caused by sea conditions that in some sectors forced me to swim away from the coastline, and battery life, that limited the complete coverage of the route with images or videos. A detailed map of submerged tidal notches, previously partially known in the area, and coastal submarine springs, was produced at the end of the expedition (Furlani et al., 2014a).

In 2013, the Gozo and Comino campaign was carried out in 7 days along a total route of 57 km. The support was boat-based. Data were published in Furlani et al. (2017a). Videos were collected both above and below the waterline with the same setting of the previous expedition. Observational data were communicated to the assistant in the boat. The presence of the boat permitted the transport of backup batteries. In 2013, a 2 km one-man campaign was carried out to evaluate the use of an electric motor on the boat. I decided not to use it due to the bad relationship between battery weight and battery life. Videos and CTD data were collected together with observations of local coastal landforms. Videos were collected with the same setting as previous campaigns. Observational data were reported on a waterproof log-book. A detailed map of the present-day notch together with the absence of MIS5.5 notches was surveyed by the team (Furlani et al., 2017a).

In 2014, the expedition was carried out along the coastlines of the Aegadian archipelago (Italy) in 7 days along a route covering another 67km (Tab. 2). Videos were collected at the waterline with two cameras within the dome at the bow. Cameras were hosted on gimbals in order to reduce roll and pitch. Observational data were communicated to the assistant in the boat via radio. A semi-submerged sea cave was discovered during this expedition at about 500 m from the main harbour on the islands. It was completely unknown by locals (Busetti et al., 2015).

In 2015, 3 expeditions were carried out, all of them with different teams. The first was along the coastline of the volcanic island of Ustica along a route of 14 km in 2 days. Data were published in Furlani et al. (2017b). A new semi-submerged sea cave was discovered during the surveys. Moreover, tidal notches were identified for the first time on the island, in correspondence of small outcrops of carbonate rocks. Time-lapse images were collected above and below the waterline along the entire route. The second expedition in 2015 was carried out along the coastlines of the islands of Santa Maria, Budelli and Razzoli, the promontory of Capo Caccia, and the island of Tavolara (Sardinia, Italy), for a total length of 22.5 km. At Tavolara, modern notch and MIS5.5 notch were identified and described to be compared with submerged notches that produced mushroom-like landforms (Antonioli et al., 2017). Time-lapse images were collected by two cameras set within the dome at the bow. The third expedition in 2015 was carried out along 19.2 km of the Maltese coasts. Time-lapse images were collected both above and below the waterline along the entire route. In all three cases, the support was from a boat.

In 2016, a 2 km route along the Monte Conero coastal area (W Adriatic Sea) was surveyed by a team. The campaign aimed to collect data to evaluate sea cliff stability during the late Holocene, starting from the occurrence of tidal notches. Data were published in Furlani et al. (2018). Time-lapse images were collected both above and below the waterline. The second expedition in 2016 was carried out by a team along the SE Istrian coasts. Time-lapse mages were collected with GoPRO cameras. In both cases, observational data were communicated via radio to the assistant in the boat.

In 2017, 24 km of rocky coasts were surveyed around the island of Paros (Greece), on metamorphic rocks. Part of the island was not surveyed because of archaeological restrictions. Time-lapse images were collected both above the waterline and videos by a camera set in the dome at the bow. Videos were collected along 25% of the coastline because the dome holders broke during field surveys. Many archaeological remains were reported along the route, and a roofless cave was studied using photogrammetry and visual observations (Furlani et al., 2019). Observational data were reported both to assistants via radio and in the app on the waterproof tablet.

In 2018, a total of 10 km was covered close to Ansedonia and part of the Argentario promontory in Tuscany, Italy. Time-lapse images above and below the waterline were collected along the entire route. The first identification of MIS5.5 tidal notch was reported along this sector of coast (Vaccher et al., 2019). Data collected in the afternoon were strongly affected by waves that reduced the reliability of images. Observational data were reported both to assistants via radio.

4 Discussion

Snorkel surveys are a form of field survey. The role and methods of terrestrial field surveying in geomorphology has been comprehensively investigated by Goudie (1990) and Dackombe and Gardiner (1983). They suggested that field survey is the collection and gathering of data at the local level that represents a procedure carried out mainly through observation, measurement, sketching, etc. The approach proposed here is that of a research expedition from local to intercontinental in extent. Field surveys of rocky coasts had never been extensively carried out before the Geoswim approach (e.g. Furlani, 2012, 2014a). Nowadays, field-based studies often focus on hostile sites, such as ecological and biological studies on vertical cliffs (Krajick, 1999). Surveying sea cliffs can also be very dangerous when waves are striking the cliff faces. Swim-surveys obviously require a solid athletic training, similar to that obtained in the course of many field surveys carried out in hostile or dangerous environments, such as underwater speleological research (Dutton et al., 2009), or studies on high and exposed cliffs (Krajick, 1999). This kind of research requires the use of specific knowledge, such as in this case swimming skills, etc. Richards (2011) recognised that field locations are sometimes selected more for convenience, aesthetics, or political reasons than for explicitly epistemological purposes. In many cases the possibility exploring certain sectors may be rather critical to the study, since the aim of defining the fieldwork location is that it should exclude variables extraneous to the phenomenon being researched. Some sectors of the southern Mediterranean, such as the Libyian coasts, may be off-limits, at least temporarily. Place-based methodology (Pitty, 1979), is the choice of a field area, because its distinctive characteristics enable particular phenomena to be better understood. Swimming and snorkeling activities are better performed in favourable environments and thus sea basins with low wave energy and low tide amplitude represent a better choice. The latter is preferable because the mid-tide zone remains roughly stable with respect to the surveying time. The maximum tide amplitude in the Mediterranean basin is about two metres at most, but is usually between 0.10 m and 0.30 m. As far as the wave energy is concerned, the Mediterranean is generally sheltered when compared to ocean basins, apart for some selected areas or events (Liberti, 2013). Moreover, plunging cliffs, or vertical sea cliffs without a shore platform at sea level, can be considered the best environment for snorkel surveys as visual observations and photo acquisition at the waterline are enhanced (Fig. 3). On the contrary, sloping coasts or, even worse, shore platforms, visual observations may be reduced due to topography and the photo survey may fail to frame significant stretches of coastline that are barely visible to the lens (Fig. 3).

Below, the two main aspects involved in the Geoswim approach are discussed: 1) visual observations and collection of geo-tags, 2) the collection of instrumental data, such as time-lapse images and physical/chemical parameters, and 3) analysis of the SWOT matrix to summarize the internal and external pros and contra of the Geoswim approach.

4.1 Visual observations and geo-tags

Visual observation represents a basic procedure to survey the geological and geomorphological structure of the rocky coasts. This kind of survey is simplified by the almost complete lack of vegetation along the shoreline, so geo-tags are easily detectable unlike, in many cases, in terrestrial environments in the northern part of the Mediterranean basin. Observation is one performance in the field frequently emphasized as a critical part of the geographical interpretation of landscape (Powell, 2002). Snorkel surveying allows the collection of puntiform tags along wide sectors of rocky coasts, covering up to 16 km per day, through visual observation of the coastline. Different set of observations can be achived, such as presence/absence of selected landforms, such as stacks, sea caves, etc., or visual description of geological, biological or geomorphological objects, such as marine notches, potholes, etc. Frondeman (2003) suggested that long periods spent in the field have taught the scientists how to sift through the superabundance of information and identify the significant anomaly. The comparison of successive lateral variations of selected tags, such as tidal, submerged or uplifted tidal notches, the occurrence of potholes or other abrasional landforms, etc., allows the production of detailed maps and accurate modelling of a wide sector of coast. Establishing a reasonable ratio between the need to cover a given sector of coast and the precision of measurements required, rough field measures can be achieved, such as rapid measurements of sea caves (e.g. Furlani et al., 2017a), or the morphometric parameters of tidal notches (Antonioli et al., 2015; Furlani et al., 2017a, b). Observations are usually brief, or confined to a moment of surveying, as they can be considered a survey 0 for selected processes or forms, but with the survey being widely extended across space, up to a magnitude of tens of kilometres. The Geoswim approach mainly focusses on forms and their changes around the waterline.

Another important question regards “getting one’s eye in”, the training required to recognize landforms, geological structures, and their variations along the planned route. An observational approach requires a trained knowledge and a distinctive mentality of alert receptivity (Frondeman, 2003). Following Baker (2000), the nature of the objects in the field is interwoven with the prior interpretations of similar phenomena, e.g. tidal notches, so that the objects become signifiers of meaning. All this may have involved an initial expedition with repeated visits to the same location to answer specific questions, with more fieldwork, however much of an expedition it may have continued to be, in logistical terms.

Moreover, the patterns of landforms or structures may be evident only at a certain distance from the coast, that may change slightly during the survey because of topographical or environmental factors, preventing a detailed survey. You may have an initial question, but the serendipity factor leads to changes to the original goals of the expedition after the reconsideration of the importance of new, casual discoveries. For example, the discovery of a new sea cave at Favignana (Busetti et al., 2015), not reported in local cave cadaster, entailed stopping the survey in order to collect detailed measures. Moreover, differences in landforms may be more clearly recognizable after the training following many kilometres of snorkel survey.

4.2 Instrumental data collection

Instrumental data, time-lapse images and T and EC, are collected along the entire route of the survey. Instrumental acquisition could also be carried out using unmanned vehicles, such as small radio-controlled boats. The combination of traditional survey with the simultaneous acquisition of instrumental data allows an instant data check and makes slight changes to the surveying parameters possible, such as the survey direction, the distance from the coast, etc. Moreover, it is possible to directly check landforms that might not be easily detectable without the presence of the surveyor, such as sea caves with small entrances, etc. Moreover, the surveyor may perceive strong differences in temperature during the survey and stop the survey to search, for example, for any fractures or joints from which water is emerging.

Images collected along the route implement a database that can be used as survey 0 dataset. Time-lapse images allow monitoring over time of geomorphological, biological, environmental changes, simply by repeating the route. Moreover, the time-lapse survey allows the collection of large numbers of images, both above and below the waterline, that can be used for building 3D models of the coast (Fig. 6), following, for example, the SfM method (Micheletti et al. 2015) below the waterline as well (e.g. Gaglianone et al., 2018). Post-processing of images can help refine the mapping of forms, but also to better define the morphometric parameters of coastal landforms through 3D models.

4.3 SWOT analysis

The SWOT matrix for the snorkel surveys along rock coasts is shown in Table 3. The SWOT analysis of the results of the tests discussed above can be can be summarized as follow:

- The Strengths show that Geoswim is the first swim, or snorkel, method that allows the collection of large amount of multidisciplinary data, both puntiform and continuous, along wide stretches of rocky coastline.
- The Weaknesses are related to the fact that observational data are strongly observer-influenced and the overall resolution depend on the topographical characteristics of the study areas.
- The Opportunities are mainly related to the implementation of swim survey capabilities and the technological improvement of instruments specifically built for the project.
- The Threats include any local restrictions to field activities and changes in environmental conditions, such as the weather.

5 Conclusions

The applicability of this snorkel survey approach has many pros: 1) it represents the first and, at the moment, unique approach to characterize the tidal and nearshore zone of large sectors of rock coast; 2) the method is particularly effective on plunging cliffs, where it is easy to swim at the same distance from the coast and the data are well-distributed above and below the waterline; 3) time-lapse images are very useful in producing 3D models of the coastline and recognizing coastal landforms or lateral variations of the latter if these were not identified during field surveys; 4) CTD sensors successfully locate submarine springs with high precision; 5) it is possible to survey large sectors of rocky coastline in a continuous fashion, recognizing the lateral variations in coastal landforms, such as tidal notches in high detail, or the occurrence of sea caves; 6) snorkel surveys represent a survey 0 for future field comparisons; 7) horizontal observations from the waterline allow coastal landforms that cannot be recognized using other remote-based methods, such as lidars or multibeams, to be identified.

Snorkel surveys are 1) difficult to carry out along low-lying rocky coasts, because it is difficult to swim at the same distance from the coast and cameras cannot collect data to produce effective 3D models; 2) the last section of the daily routes is usually less precise than the starting sectors, because of fatigue; 3) post-processing of images is very complex and time-consuming; 4) it is fundamental to swim at a steady velocity along the route, otherwise the comparison of data becomes difficult.

Future research will be devoted to the improvement of training for young snorkel surveyors, the improvement of procedures to collect and process photogrammetric data to obtain 3D models of the coast both above and below the waterline and a quality control plan to produce more reliable data. Moreover, the programme will aim to continue the survey of the rocky coasts of the Mediterranean as well as to test the approach outside the Mediterranean basin in exposed microtidal sites.

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Figures and tables

Fig. 1. *Map of the rocky coasts of the Mediterranean (top, modified from Furlani* et al*., 2014b)*

and a satellite overview of the basin (bottom, from Google Maps). The sectors surveyed during the snorkel expeditions are shown as red boxes in the maps.

Fig. 2. Images of the original raft and the one modified for the Geoswim campaigns; a) the original raft produced by Sporasub. In some expeditions (see fig. 3), other home-made raft were used; b) the lower part of the raft with to measure temperature and electrical conductivity; c) the raft with two GoPROs and as many domes below the waterline. This configuration is used to collect images to build 3D models of the coast; d) top view of the raft with some instruments used during the expeditions.

Fig. 3. *The raft has been slightly modified over the years. Several prototypes were tested during the campaigns, in order to solve scientific and logistic problems. a) 2015 campaign at Ustica island (Sicily, Italy); b) 2016 campaign at Stokovacisland (Croatia); c) 2016 campaign at Monte Conero (western Adriatic Sea, Italy); d) tests in Muggia (Northeastern Adriatic Sea, Italy); Marettimo island (Egadi, Sicily, Italy).*

Fig. 4. *Setting of the surveys and navigation mode. Sketch of data acquisition method tested in this paper. A) The surveying activities are carried out snorkeling at a short distance from the coastline, from 1 to 5 metres, according the slope and landscape setting. The route followed during the surveys is roughly represented by the black dashed line. Along the route, time-lapse images allow the morphological features of the coastal landscape and the horizontal variations of the biological zonation, in particular in the tidal zone to be reconstructed in detail. At the same time, hydrological parameters, such as temperature and electrical conductivity, are also measured, mainly to identify the occurrence of submarine springs or freshwater flows. B) The sketch shows the limitations posed by the cliff slope. Higher cliff slope allows to produce better 3D models of the coast. On the contrary, lower cliff slopes renders the creation of point clouds for morphometric analysis very difficult, because cameras are set horizontally on the raft*.

Fig. 5. *Collection of photos of relevant geotags, such as (a) sea arches, (b) coastal sinkholes, (c) tidal notches, (d) potholes, (e) biogenic trottoirs.*

Fig. 6*. Example of time-lapse images collected above the sea level. At the top, a 3D model of a*

short sector of coast produced using the time-lapse images of the subaerial part. The 3D model was created using Agisoft Photoscan.

Fig. 7. *Graph of the variations of Electrical Conductivity (EC) and Temperature (T) collected along the Sistiana-Duino sector (NE Gulf of Trieste, Italy). The map show the location of the main freshwater submarine outflow along the coast detected using the CTD sensor. The location of the springs were obtained coupling the CTD data and GPS track. Coordinates reported in the graph refer to the centre of the anomaly.*

Tables

Tab. 1. *The expeditions within the Geoswim programme from 2012. The total number of kilometres geo-swum over these years is much greater considering the long sectors of rocky coasts, mainly in the Gulf of Trieste, used to test the instrumentation. The table reports A) the year in which the expedition took place; B) the location; C) the number of snorkel surveyors involved; D) the type of support provided to the surveys and surveyors, either on a boat or on land; E) the type of rocks outcropping along the studied sector; F) the total length of the route snorkeled during the expedition in kilometres; G) the duration of the expedition (survey days).*

A **Year**	**B** **Location**	**C** **Number of surveyor**	**D** **Support (land/boat)**	**E** **Type of rocks**	**F** **Total lenght of the route (km)**	**G** **Days of survey**	**H** **Type of data collected**	**H** **Literature**
2012	W Istrian Peninsula (Croatia, Slovenia, Italy)	One-man survey	Land	Limestone, sandstone and marlstones	253,2	27	Geomorphology, hydrogeology	Furlani, 2012; Furlani et al. 2014a
2013	Gozo and Comino (Malta)	10	Boat	Limestones, clays	57	7	Geomorphology, hydrogeology	Furlani et al., 2017a
2013	Stara Baska (Krk,	One-man survey	no support	Limestones	2,2	1		/

	Croatia)							
2014	Egadi Islands (Italy)	7	Boat	Limestones, dolostones, siltite, breccias	67	7	Geomorphology, hydrogeology, biology	Busetti et al., 2015 Antonioli et al., 2015
2015	Gaeta Promontory (Latium, Italy)	4	Boat	Limestones	2,5	1	Geomorphology, hydrogeology	Work in progress
2015	Ustica (Sicily, Italy)	5	Boat	Volcanic rocks	14	2	Geomorphology, lithology, hydrogeology, biology	Furlani et al., 2017b
2015	Razzoli, Budelli, Santa Maria (Sardinia, Italy)	7	Boat	Granites	22,5	3	Geomorphology, lithology, hydrogeology, biology	Work in progress
2015	Capo Caccia (Sardinia, Italy)	6	Boat	Limestones	26	2	Geomorphology, hydrogeology, biology	Work in progress
2015	Tavolara (Sardinia, Italy)	7	Boat	Limestones, granites	14,9	2	Geomorphology, hydrogeology, biology	Work in progress
2015	Malta (Malta)	7	Boat	Limestones	19,2	3	Geomorphology, hydrogeology, biology	Work in progress
2015	SE Istria (Croatia)	5	Boat	Limestones	7	1	Geomorphology, hydrogeology	/
2016	Monte Conero (W Adriatic Sea, Italy)	3	Boat	Limestones, marlstones, calcarenites	2,9	1	Geomorphology, hydrogeology, biology	Furlani et al., 2018
2016	Addaura (Palermo, Sicily, Italy)	5	Boat	Limestones, breccias	7	1	Geomorphology, lithology hydrogeology, biology	Caldareri et al., 2018

2017	Paros (Greece)	10	Land, boat	Marbles, volcanic rocks	24	8	Geomorphology, hydrogeology, biology	Work in progress
2017	Sistiana-Duino (Gulf of Trieste, Italy)	One-man survey	Land	Limestone	2	1	Geomorphology, hydrogeology,	Furlani and Biolchi, 2018
2018	Ansedonia and Argentario (Tuscany, Italy)	7	Boat	Limestones, breccias, dolostones	10	2	Geomorphology, hydrogeology, biology	Work in progress
TOTAL					**531,4**	**69**		

Tab. 2. *Description of type of data collected during Geoswim expeditions, The table includes A) the category of data collected; B) type of data collected; C) unit of measure; D) the nature of data collected; E) the type of survey; F) the type of coverage; G) the type of instrument; and H) notes.*

A Category of data	**B Data**	**C Unit of measurement**	**D Nature of data**	**E Type of survey**	**F Coverage**	**G Type of instrument**	**H Notes**
Instrumental data	Temperature	°C	Physical data	instrumental	Continuous survey of lateral variability	CTD sensor	/
	Electrical conductivity	mmS/cm	Physical data	instrumental	Continuous survey of lateral variability	CTD sensor	/
	Depth	m	Physical data	instrumental	Continuous survey of lateral variability	Echosounder	/
	Depth	M	Physical data	instrumental	Puntiform survey	Portable echosounder	Punctual measures at prominent sites
	Time-lapse images	number/sec	Visual	instrumental	Continuous acquisition of images	GoPRO action camera set in time-lapse mode	These data can be used both as survey zero and for creating

							3D models
	Images	number	Visual data	instrumental	Puntiform survey	Reflex or other action cameras	/
Visual data	Sea-caves	number/total lenght	Geomorphological data	visual census of presence / absence	Puntiform observation	/	/
	Submarine springs, freshwater	number/total lenght	Hydrogeological data	presence / absence	Puntiform observation	/	Survey based on body perception of differences in temperature and visual detection of increasing in water turbidity and local turbolence
	Stacks	number/total lenght	Geomorphological data	visual census of presence / absence	Puntiform observation	/	/
	Sea arches	number/total lenght	Geomorphological data	visual census of presence / absence	Puntiform observation	/	/
	Marine notches	/	Geomorphological data	Morphometric survey and coupled with visual description	Puntiform observation	Invar rod, ruler	/
	Potholes	Number/total lenght	Geomorphological data	Morphometric survey and coupled with visual description	Puntiform observation	Invar rod, ruler	Large number of potholes are considered as clusters
	Lithology	descriptive	Geological data	visual description of specific ecological transects	Puntiform observation	hammer	Visual observation, possibly description of samples obtained by hammering

	Structural description	descriptive	Geological data	visual description of specific landforms associated with the local structural setting	Punctiform observation	/	Joints, fractures, faults, etc.
	Biological objects	descriptive	Biological data	visual observation of presence/absence of specific organisms	Punctiform observation	ruler	Possibly measures of size and elevation above or below the mean sea level with ruler
	Ecological description	descriptive	Biological data	visual description of specific ecological transects	Punctiform observation	ruler	Visual observation, possibly description of samples collected during the survey
	Prominent objects	descriptive	All the types	visual description and possibly measures	Punctiform observation	All the type of available tools	Visual observation, possibly description of samples collected during the survey

Tab. 3. The SWOT matrix. This analysis allows the identification of the strengths allows to define the characteristics of the method that give an advantage to other approaches of coastal survey; the weaknesses allow to define the characteristics of the approach that need improvements; the opportunities define the goals, or the elements that the project could exploit to its advantage, while the threats analyze the obstacles for using at maximum the method.

SWOT analysis	**HELPFUL**	**HARMFUL**

INTERNAL	**Strenghts** • Potential detailed surveys of many kilometers of rock coasts; • Only one surveyor can collect a large amount of data, in particular instrumental ones; • The method represents a useful approach to model the topography of the tidal and nearshore zone of rocky coasts in microtidal environments; • It is a relatively cheap approach; • Gathering more than one field of research on rock coasts, such as geology, geomorphology, hydrogeology, biology, etc. • It is the only approach tested to study large sectors of rock coasts.	**Weaknesses** • Many kilometers of rock coasts to be surveyed with a time-consuming method; • Low-lying rocky coasts are difficult to survey using this approach; • The distance of navigation is often different from plans because of local topography; • Observations are strongly observer-influenced; • The accuracy of observations of the final sectors of long routes can be affected by fatigue that reduce the capability to observe and collect data.
EXTERNAL	**Opportunities** • Emerging need of data on rock coasts for applied sciences, such as researches about sea level changes, ecological changes along rock coasts, etc. • The resulting database represent a survey zero for future comparisons; • Opportunity to test the capability of snorkel surveys to provide useful field data; • Opportunity to improve technologies for coastal surveys; • Training for safety field activities.	**Threats** • Weather and sea conditions can limit or prevent the acquisition of field data; • the patterns of landforms or structures may be evident only at a certain distance from the coast, that may change slightly during the survey because of topographical or environmental factors, preventing a detailed survey • Weather and sea conditions can cause safety issues to snorkel surveyors; • The battery life of the cameras can affect the possibility to collect images in the final sectors of long routes. Local laws limitations, such as environmental or archaeological ones, can limit or prevent the surveys.

Graphical abstract

Highlights:

- The Geoswim approach allows to collect large amount of data through snorkel surveys along wide sectors of rocky coasts.
- The surveys are carried out following a precise protocol and using a specially-built raft that hosts sensors and cameras.
- The surveys aim to collect geological, geomorphological, hydrogeological and biological data.
- Details of the method, pro- and contra-, and correlations are discussed.


Legend
Beaches
Rocky coasts
EUROPE
Istria
M.Conero
Adriatic Sea
Ansedonia
Corsica
Maddalena
Tavolara
Gaeta
Capo Caccia
Tyrrenian Sea
Sardinia
Balearic Islands
Ustica
Addaura
Egadi
Sicily
Ionian Sea
Black Sea
Anatolia
Paros
Aegean Sea
Crete
Cyprus
ASIA
Gibraltairstraits
Malta and Gozo
N
AFRICA
0
250
500 km
France
Austria
Hungary
Romania
Croatia
Serbia
Black Sea
tugal
Italy
Bulgaria
Spain
Tyrrhenian Sea
Turkey
Greece
Syria
Lebanon
cco
Tunisia
Mediterranean Sea
Israel
Jordan
G

Figure 1

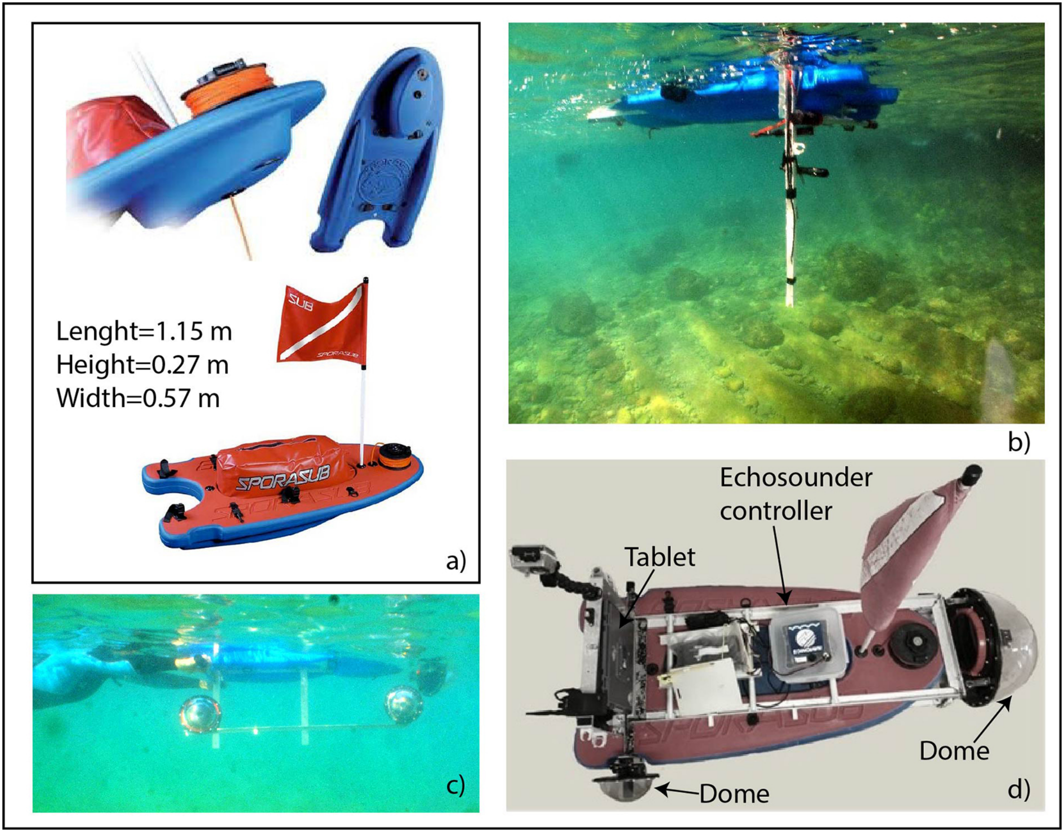
Lenght=1.15 m
Height=0.27 m
Width=0.57 m
SUB
SPORASUB
a)
b)
c)
Echosounder controller
Tablet
Dome
Dome
d)

Figure 2

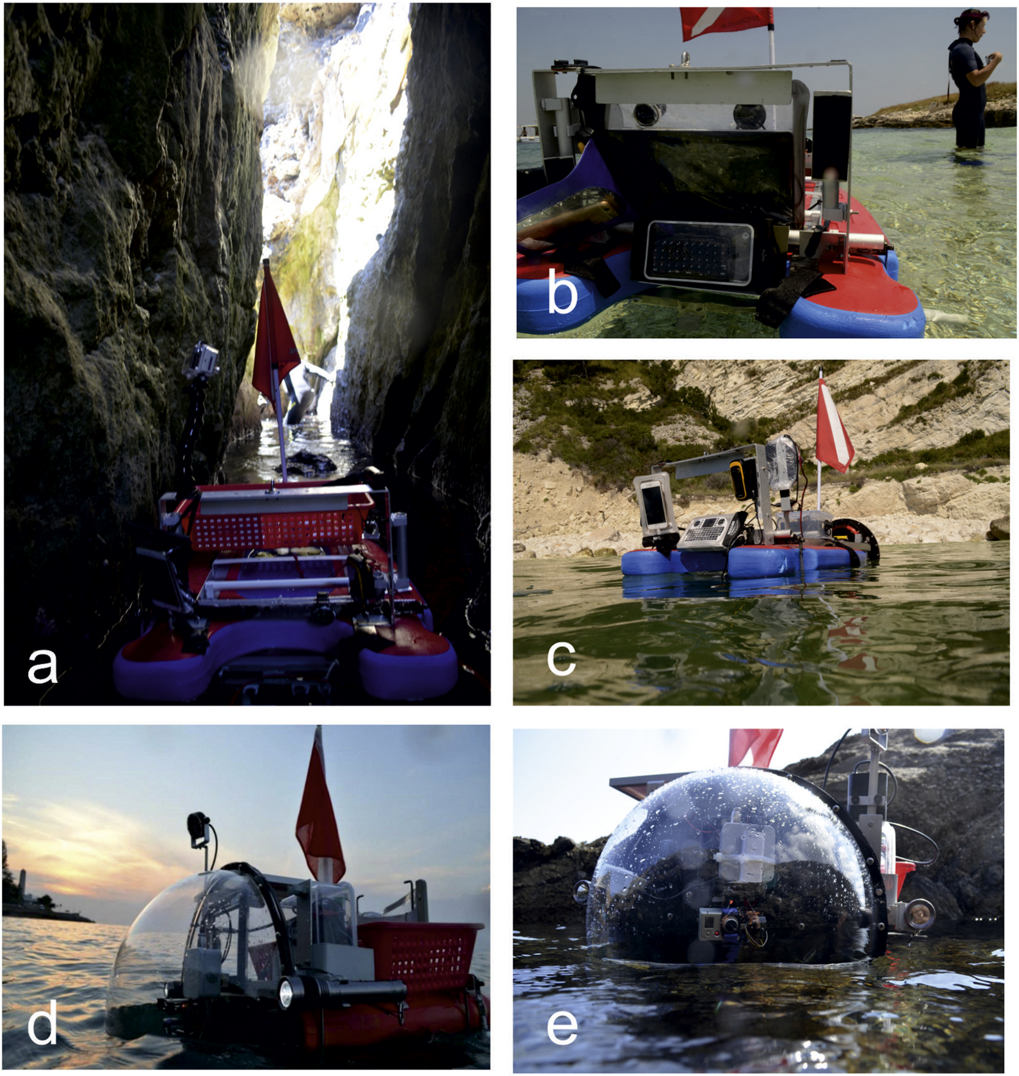

Figure 3

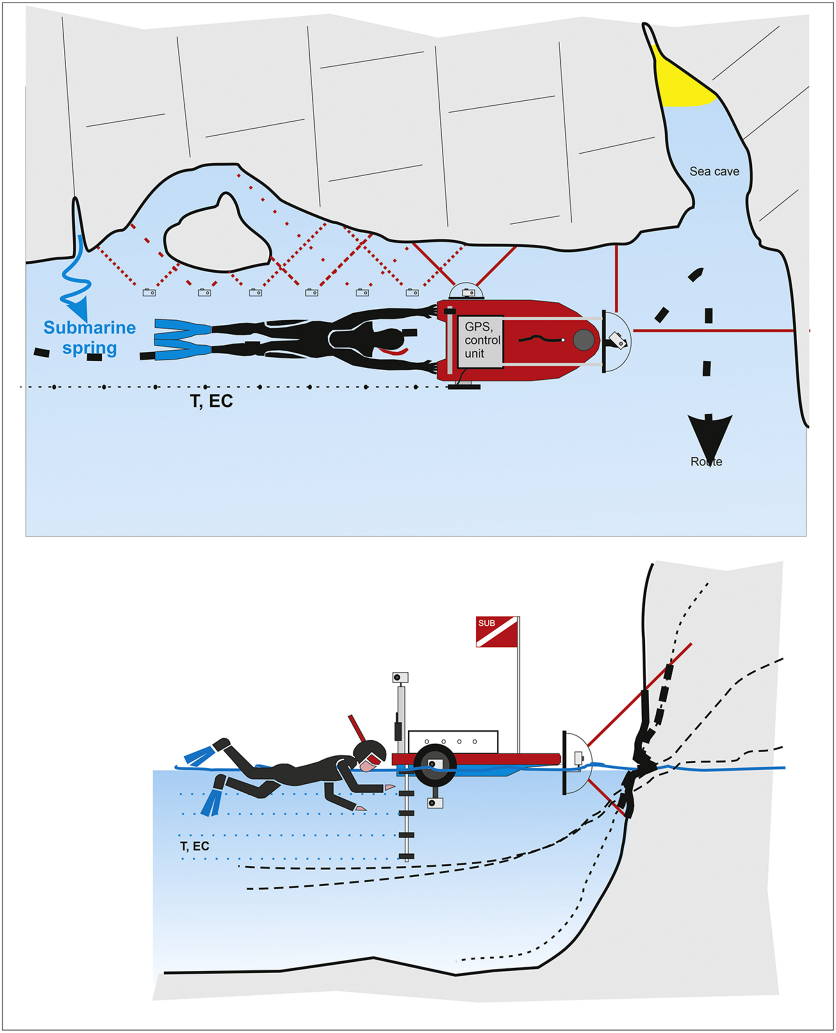
Sea cave
Submarine spring
GPS, control unit
T, EC
Route
SUB
T, EC

Figure 4

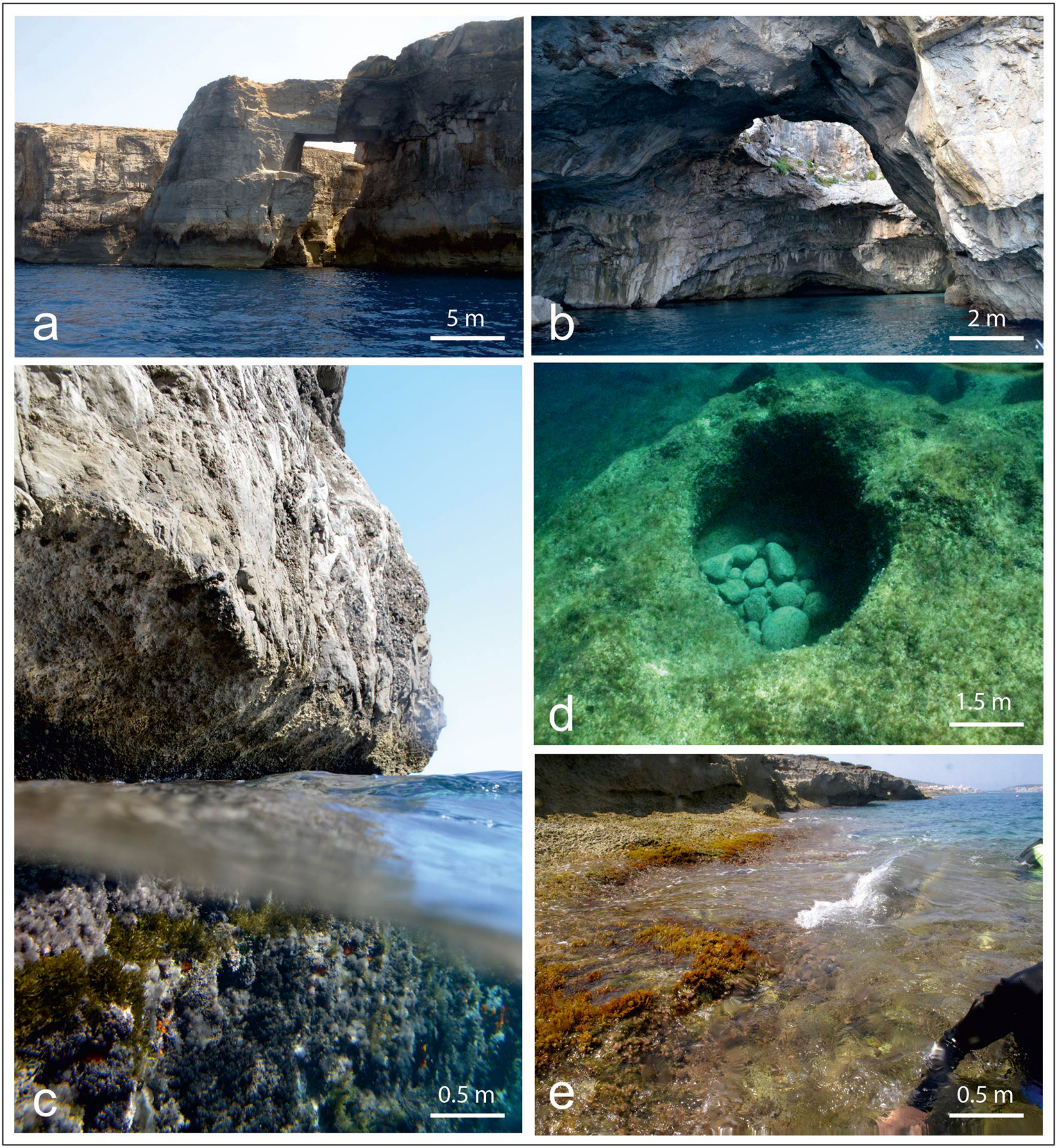

Figure 5

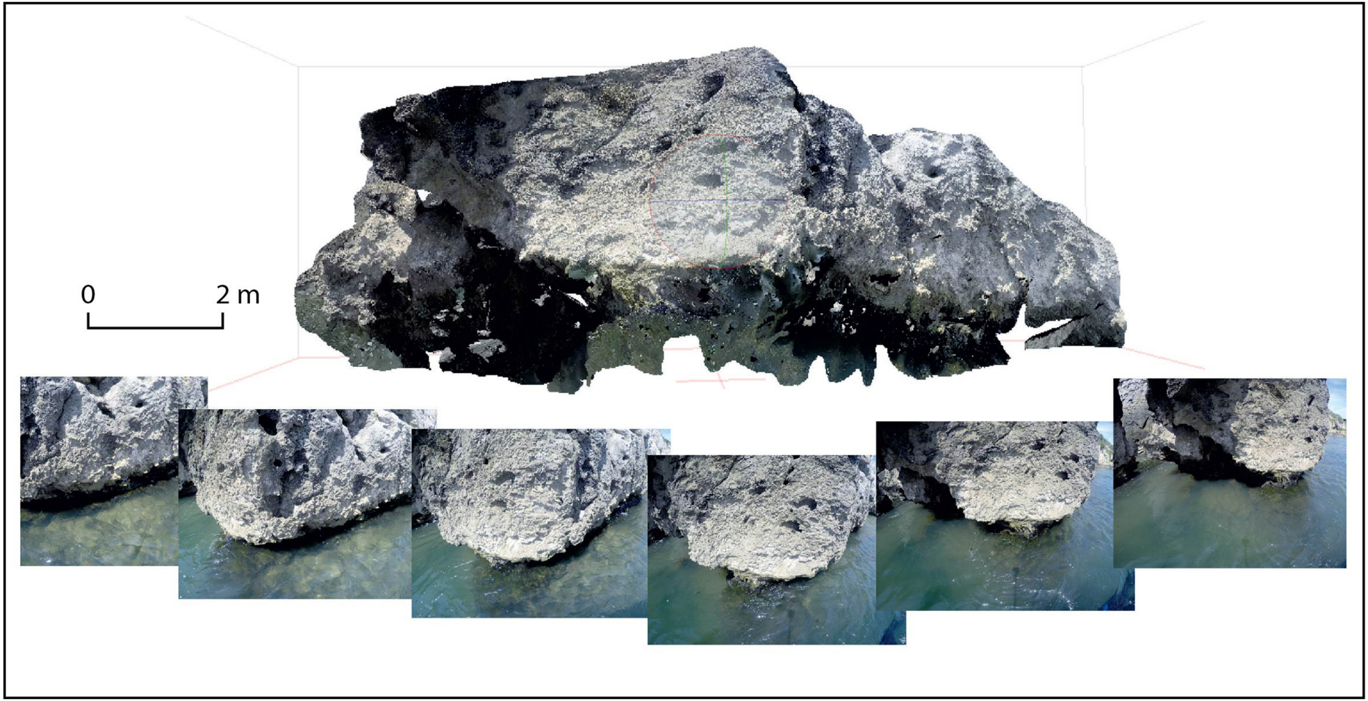

Figure 6

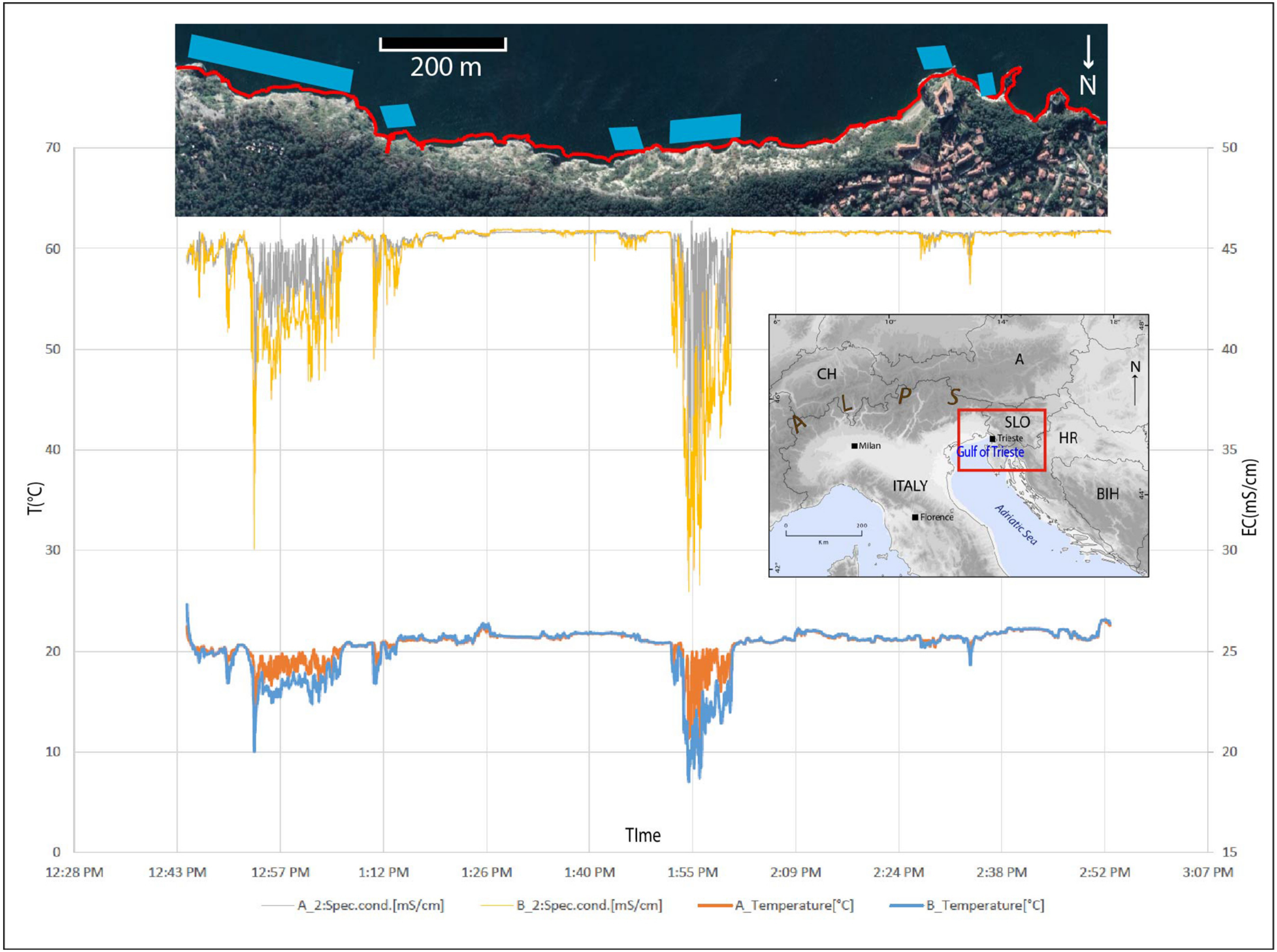
200 m
N
CH
A
A L P S
SLO
Trieste
Gulf of Trieste
HR
Milan
ITALY
Florence
Adriatic Sea
BIH
0
200
Km
70
60
50
40
30
20
10
0
T(°C)
50
45
40
35
30
25
20
15
EC(mS/cm)
TIme
12:28 PM
12:43 PM
12:57 PM
1:12 PM
1:26 PM
1:40 PM
1:55 PM
2:09 PM
2:24 PM
2:38 PM
2:52 PM
3:07 PM
A_2:Spec.cond.[mS/cm]
B_2:Spec.cond.[mS/cm]
A_Temperature[°C]
B_Temperature[°C]

Figure 7