Short Communication

Can recreational scuba divers alter natural gross sedimentation rate? A case study from a Mediterranean deep cave

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Di Franco, A., Ferruzza, G., Baiata, P., Chemello, R., and Milazzo, M. 2010. Can recreational scuba divers alter natural gross sedimentation rate? A case study from a Mediterranean deep cave. – ICES Journal of Marine Science, 67: 871–874.

Submarine caves are environments with features distinguishing them from other littoral habitats but, despite their ecological importance, their response to anthropogenic disturbance has been seldom verified. One potential threat affecting natural communities within caves is represented by recreational scuba diving. Divers' disturbance within marine caves is mainly related to physical contacts and increased sediment resuspension potentially affecting sessile organisms. The aim was to assess the potential effect of recreational divers' frequentation on the natural gross sedimentation rate (GSR) in a Mediterranean deep-water cave. To achieve this, sediment traps were deployed along a scuba trail before, during, and after the peak season for tourist-related diving. No effects of divers' frequentation were evident in terms of alteration of natural GSR, but findings will need to be validated for other caves to asses whether potential disturbance depends on frequentation levels and/or cave characteristics, i.e. sediment grain size or cave depth.

Keywords: asymmetrical experimental design, resuspension, scuba diving, sediment traps, sediments, submarine caves.

Received 27 July 2009; accepted 11 January 2010; advance access publication 4 March 2010.

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Introduction

Submarine caves are common along the coast of the Mediterranean Sea and can be considered a typical feature of the basin (Riedl, 1966). The presence of slow-growing sessile species with fragile skeletons (Bussotti *et al.*, 2006), of cave-restricted endemic species under extinction threat (Chevaldonne and Lejeusne, 2003), and under specific circumstances (e.g. deep caves), the infrequency of natural disturbance to which they can be exposed have led researchers to highlight the vulnerability of such habitat (Di Franco *et al.*, 2009a). For these reasons, submarine caves constitute one of the listed habitats (code 8330) in the Habitats Directive (European Union, Council Directive 92/43/EEC), but despite their ecological importance, their response to anthropogenic disturbance has been seldom verified. One of the possible threats affecting the natural communities of submerged caves is that of human access and frequentation for recreational scuba diving.

Anthropogenic disturbance from diving activity within marine caves is mainly attributable to physical contacts, i.e. by divers' fins, body, and scuba gears, and increased sediment resuspension potentially affecting sessile organisms (see Milazzo *et al.*, 2002, for a review). Although much is known about the disturbance deriving from direct contact of divers on sessile and fragile organisms (e.g. Uyarra and Côtè, 2007; Di Franco *et al.*, 2009b; Luna *et al.*, 2009), as far as we know, quantitative data have never been collected to assess the potential effects of scuba diving on sediment dynamics. Therefore, the aim of the present work was to assess the effect of recreational divers' frequentation on the "natural" gross sedimentation rate (GSR) in a Mediterranean deep-water cave, defining as natural the rate not attributable to human presence inside the cave. To quantify sedimenting particles, we adopted a multifactorial sampling design using sediment traps.

Material and methods

The study was carried out at the Grotta dei Gamberi marine cave in the Ustica Island Marine Protected Area (southwest Italy). Grotta dei Gamberi is a diving location of great importance, commonly visited by diving centre customers, especially in summer, when more than 200 declared dives can be performed. The cave has two openings: a very large one (17.3 m wide, 6 m high, at a depth of 42 m) usually used by divers as the entrance, and a narrower one (1 m wide, 1.5 m high, at a depth of 26 m) usually used as the exit (Figure 1). Owing to these characteristics, natural disturbance within Grotta dei Gamberi can be considered infrequent. The bottom of the cave is covered by a floor of bioclastic sediment showing a non-homogeneous grain size distribution ranging from 1 μm to 1.5 cm (Di Franco *et al.*, 2009c).

Gross sedimentation rate (defined as the total quantity of material sampled in a sediment trap, with a known cross-sectional area and over a known length of time, *sensu* Charles *et al.*, 2005) inside the cave was measured by 28 sediment traps positioned along the cave. Traps consisted of a PVC cylinder 10 cm long with a mouth inner diameter of 9.1 cm. The aspect ratio

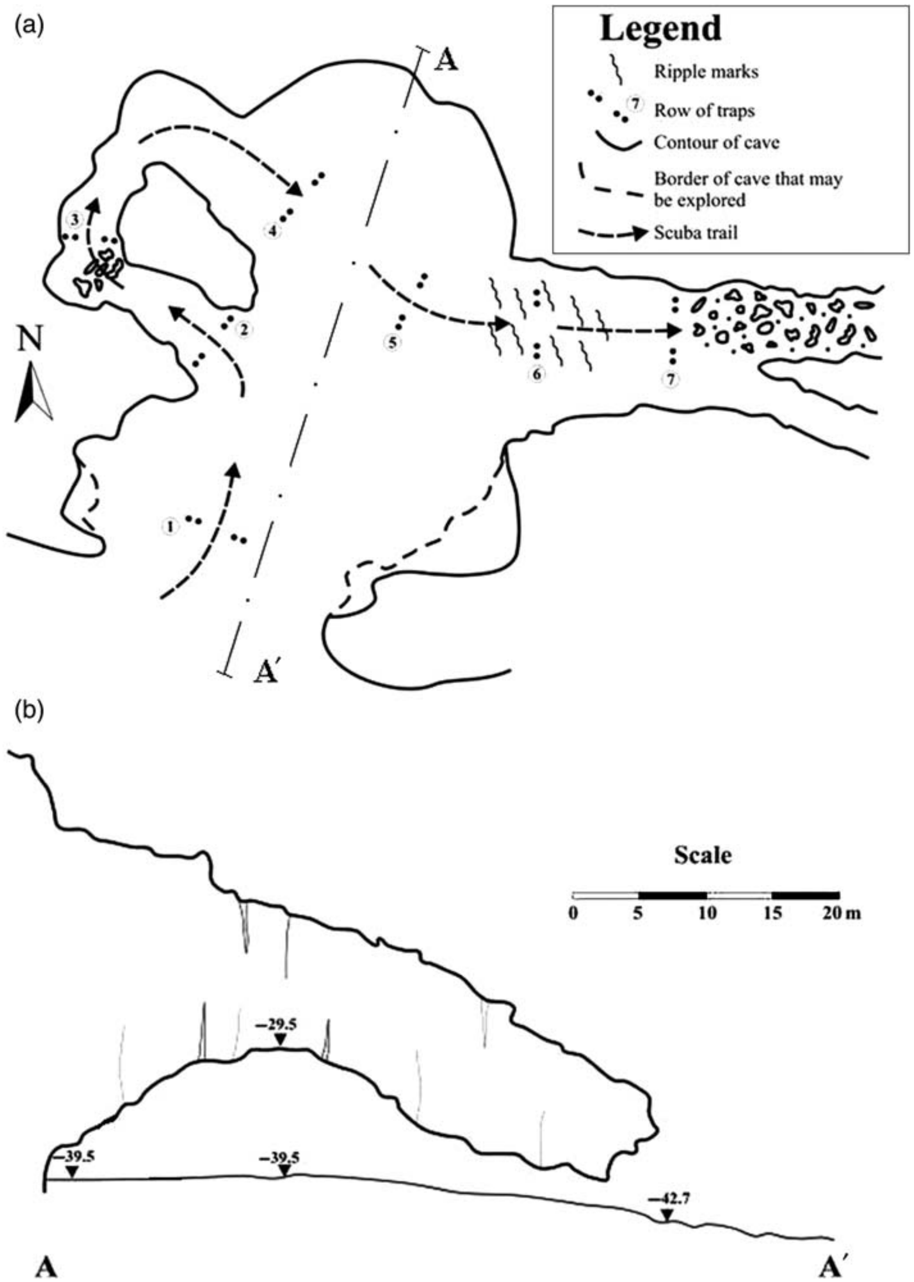

Figure 1. (a) Schematic representation of the Grotta dei Gamberi (modified from Colantoni *et al.*, 1991). (b) Longitudinal section of the Grotta dei Gamberi, with indications of depth (modified from Colantoni *et al.*, 1991). Drawings by GF.

Table 1. Recreational diver frequentation per sampling occasion of 4 d during three periods at Grotta dei Gamberi, Italy.

Frequentation rate		
Before	**During**	**After**
0	20	5
0	15	5
5	18	0
Mean 1.66 ± 1.66	Mean 17.66 ± 1.45	Mean 3.33 ± 1.66

Means are average ± s.e.

(height/diameter) of the trap was ~1.1, a value considered appropriate for preventing sediment resuspension and measuring gross sediment input in a non-turbulent environment (White, 1990; Wielgus *et al.*, 2004), such as a deep cave. We laid traps along the trail used by recreational divers, a trail previously identified following guides during dives. Such scuba trails are generally conservative at a diving location such as a cave (Di Franco *et al.*, 2009a). We placed seven rows of traps along the trail (Figure 1), each row consisting of four traps: two at ~1.5 m and two at ~3 m from the outer margin of the scuba trail (Figure 1).

Sampling was carried out from May to December 2007, covering three periods: before the tourist season (B: May/June), during

Table 2. Results of a PERMANOVA on log($x + 1$)-transformed data (see text for factor label definitions).

Source	d.f.	Sum of squares	Mean square	Pseudo-*F*	*p* (Permutation)	Permutations
IvsC	1	0.0009	0.0009	0.0164	0.9212	835
Ro	6	0.7322	0.1220	1.3611	0.2575	9 955
Di	1	0.0218	0.0218	0.4193	0.5397	9 828
Pe(Iv)	1	0.0082	0.0082	0.1413	0.7261	829
IvC × Ro	6	0.0918	0.0153	0.1707	0.9817	9 940
IvC × Di	1	0.0343	0.0343	0.6602	0.4446	9 835
Ro × Di	6	0.1235	0.0205	0.3146	0.9249	9 940
Da(Pe(Iv))	6	0.3495	0.0582	1.1143	0.3635	9 951
Pe(Iv) × Ro	6	0.2434	0.0405	0.4525	0.8406	9 944
Pe(Iv) × Di	1	0.0795	0.0795	1.5294	0.2628	9 844
IvC × Ro × Di	6	0.6402	0.1067	1.6299	0.1672	9 948
Da(Pe(Iv)) × Ro	36	3.2277	0.0896	1.7151	0.016	9 885
Da(Pe(Iv)) × Di	6	0.3121	0.0520	0.9951	0.4367	9 949
Pe(IvC) × Ro × Di	6	0.2606	0.0434	0.6635	0.6813	9 949
Da(Pe(Iv)) × Ro × Di	36	2.3569	0.0654	1.2524	0.1685	9 881
Res	126	6.5868	0.0522			
Total	251	15.188				

the tourist season (D: July/August), and after the tourist season (A: October–December). In each period, we performed three sampling experiments at random times. On each occasion, we also recorded leisure diver frequentation by interviews with diving centre owners and direct observation. Traps were deployed for 4 d on each occasion. After traps were collected by divers, sediment weight was measured in the laboratory following standard procedures (White, 1990; Wielgus *et al*., 2004).

Because of the uniqueness of each cave (Bussotti *et al*., 2006), it was impossible to find any similar cave unfrequented by recreational divers to use as a control location, so an asymmetrical experimental design was selected based on different periods (one impact and two controls), logically analogous to asymmetrical designs to detect environmental impacts (see Terlizzi *et al*., 2005, and references therein). Based on diver frequentation data [D > B = A; one-way ANOVA ($p < 0.01$) and a Student–Newman–Keuls (SNK) test], we considered five factors for the analyses: impact vs. controls [IvsC; fixed, two levels: impact (during) and controls (before and after)], period (Pe; fixed nested in IvsC, three levels: before, during, and after), date (Da; random, nested in IvsC with three levels: first, second, and third), row (Ro; fixed, seven levels: from 1 to 7), and distance (Di; fixed, two levels: near and far). For each of these five, there were two replicates per combination of factor levels. Permutational analysis of variance (PERMANOVA; Anderson, 2001) based on Euclidean distance was used on log($x + 1$)-transformed data to test for differences in sedimentation rate.

Results and discussion

Despite the difference in divers' frequentation among sampling periods [Table 1; D > B = A; one-way ANOVA ($p < 0.01$) and SNK test], no significant differences were recorded in the quantity of sediment collected by the traps nor among impact and control periods and among all periods considered (Table 2). Moreover, there was no variability between different occasions. The analysis failed to provide any evidence of a difference between the two distances from the scuba trail considered (Di: not significant) nor any space-localized effect (IvsC × Di: not significant).

In the present study, therefore, we conclude that there were no effects of diver frequentation in terms of alteration of the natural GSR, despite the body of literature indicating resuspension as a potential way that scuba divers may induce disturbance (see Milazzo *et al*., 2002, for a review). No differences in the quantity of sediment trapped were recorded between unfrequented or less frequented and highly frequented occasions of sampling, suggesting to us that limited diver frequentation (as recorded in the present study) cannot alter natural sedimentation and resedimentation processes. This is particularly true if we specifically consider the granulometric patterns of the Grotta dei Gamberi (Di Franco *et al*., 2009c).

The evidence emerging from our work needs to be validated for caves with different exposure to water flow (e.g. at shallower depths), with different sediment types, and/or for caves with greater frequentation rates of scuba divers. We anticipate that our results will be simply the starting point for more detailed assays on sediment dynamics and benthic communities within marine caves.

Acknowledgements

This paper is dedicated to the memory of Gaetano Ferruzza, who tragically passed away on 6 October 2009 along with Dario Romano in a scuba-diving accident while working in a marine cave off Siracusa, Sicily. Gaetano lost his life doing what he loved best: advancing knowledge on sediment dynamics in the marine environment. We thank M. Di Lorenzo, G. Milisenda, G. Aglieri, A. Barcellona, C. Scianna (Cooperativa CoRIS, Palermo), and M. Maniscalco (Alta Marea Diving Center, Ustica) for their help during field sampling, and J. Claudet (University of Salento, Lecce) for suggestions on data analyses. The study was partially funded by the Ustica Island MPA management authority. GF and ADiF contributed equally to the drafting of this manuscript.

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doi:10.1093/icesjms/fsq007