Evelpidou, N., Pirazzoli, P.A., 2015. Sea-level indicators. In: Finkl, C.W., Makowski (Eds.), Environmental Management and Governance: Advances in Coastal and Marine Resources, Coastal Research Library 8. Springer, Switzerland, pp. 291–311. http://dx.doi.org/10.1007/978-3-319-06305-8_12.

Evelpidou, N., Melini, D., Pirazzoli, P.A., Vassilopoulos, A., 2014a. Evidence of repeated late Holocene rapid subsidence in the SE Cyclades (Greece) deduced from submerged notches. Int. J. Earth Sci. Geol. Rund. 103 (1), 381–395. http://dx.doi.org/10.1007/s00531-013-0942-0.

Evelpidou, N., Karkani, A., Pirazzoli, P.A., 2014b. Fossil shorelines at Corfu and surrounding islands deduced from erosional notches. Holocene 24 (11), 1565–1572.

Evelpidou, N., Koutsomichou, I., Pirazzoli, P.A., 2013. Evidence of Late Holocene subsidence events in Sporades Islands: Skopelos and Alonnisos. Cont. Shelf Res. 69, 31–37.

Evelpidou, N., Kampolis, I., Pirazzoli, P.A., Vassilopoulos, A., 2012. Global sea-level rise and the disapperane of tidal notches. Glob. Planet. Change 92–93, 248–256.

Evelpidou, N., Pirazzoli, P.A., Saliège, J.-F., Vassilopoulos, A., 2011. Submerged notches and doline sediments as evidence for Holocene subsidence. Cont. Shelf Res. 31, 1273–1281.

Focke, J.W., 1978a. Limestone cliff morphology and organism distribution on Curaçao (Netherlands Antilles). Leidse Geol. Meded. 51 (1), S31–S150.

Focke, J.W., 1978b. Limestone cliff morphology on Curaçao (Netherlands Antilles), with special attention to the origin of notches and vermetid/coralline algal surf benches. Z. Geomorphol. 22, 329–349.

Jevrejeva, S., Moore, J.C., Grinsted, A., Woodworth, P.L., 2008. Recent global sea level acceleration started over 200 years ago? Geophys. Res. Lett. 35, L08715 doi: 1029/2008GL33611.

Kemp, A.C., Horton, B.P., Donnelly, J.P., Mann, M.E., Vermeer, M., Rahmsorf, S., 2011. Climate related sea-level variations over the past two millennia. Proc. Natl. Acad. Sci. 108, 11017–11022.

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Reply to comment by Evelpidu N., and Pirazzoli P. on "Tidal notches in the Mediterranean sea: A comprehensive analysis"

We take the chance offered by the comment of Evelpidou and Pirazzoli (2015a) to our paper (Antonioli et al., 2015) to clarify some aspects of our work. We reinforce our statement that a present-day tidal notch is almost continuously developed along much of the central Mediterranean coast.

First of all, we clarify that Antonioli et al. (2015) describe tidal notches, not "erosion notches" as stated in Evelpidou and Pirazzoli (2015a). To our understanding, erosion (or abrasion) notches are typically intended the submerged notches carved by sediments rolling at the base of the cliff by the wave energy; generally they are connected to a beach or to a wave cut platform and unrelated to the local tide. We do not deal with this type of notches.

Antonioli et al. (2015) report observations on tidal notches shaped along tectonically stable carbonate coasts from 73 sites not only from Italy, as incorrectly stated by Evelpidou and Pirazzoli (2015a), but also, albeit in a more limited number, from France, Croatia, Montenegro, Greece, Malta and Spain, plus additional observations carried outside the Mediterranean (5 sites in 3 different oceans). In all these places, notches are prominently developed in correspondence of the present-day mean sea level. At each site, we measured notch width and depth and described the characteristics of the algal rim that characterizes the base of the notch. We correlated these parameters with wave energy, tide gauge datasets and rock lithology.

We regard our study as the most updated and comprehensive analysis of central Mediterranean notches, supported by abundant observational data, and not the result of elaborations performed by "*confused researchers*" as stated in the comment.

We appreciated that the main important outcome of Evelpidou and Pirazzoli (2015a) comment is their first recognition, following our study, that tidal notches are still found, in Mediterranean sea, at sea level. In fact, in 2012, Evelpidou et al. (2012) wrote:

- *The most recent continuous sea level rise has resulted to the absence of a present-day notch.*
- *The recent rise in global sea level is causing the disappearance of an important geomorphological sea-level indicator, the tidal notch.*
- *The fact that during the last two centuries the rate of global sea-level rise has become greater than the natural possibilities of marine bioerosion, causing the disappearance of tidal notches, is producing a lacuna in geologic marks, which should be taken into account in the interpretation of geologic and oceanographic events during the last few centuries.*
- *No marks of present-day tidal notch appear in 2009 in the Atalandi Mines coastal area (Gulf of Euboea, central Greece). (SE Cyclades, Greece), no marks of present-day tidal notch appear here in 2010. At Ios Island (southern Cyclades) tidal notches are absent in the present-day mid-littoral zone (caption of Fig. 4 of* Evelpidu et al. *2012).*
- *The recent sea-level rise at the rate of 2 mm/a exceeds the possibilities of bioerosion in the intertidal zone. This means that, especially on carbonate rocks, the deepening of tidal notches is interrupted. As a consequence, in microtidal areas, no new tidal notches could have formed during the last two centuries, leading to the disappearance of this type of feature, as shown by* Evelpidou et al. *2012. In contrast, tidal notches developed before the nineteenth century will be submerged and preserved in fossil form (they are called 'modern' tidal notches) at a depth of the order of about 20 cm. The reality of such a recent disappearance has been verified in most areas of the Mediterranean, where submerged 'modern' tidal notches testify of the local MSL position preceding the recent period of sea–level rise, e.g. in Greece, in the Cyclades and the Sporades Islands (*Evelpidou and Pirazzoli 2015b*)*

Considering the above assertions, the hypothesis put forth by Evelpidou et al. (2012), based only on the observation of few coastal site in Greece without any tectonic control (stable vs. unstable coastlines, with potentially coseismic effects) is that notches have disappeared and are not forming anymore around modern sea level, because bioerosion rates cannot cope with sea level rise. In Antonioli et al., 2015 we showed that tidal notches are found both in a large number of sites at sea level, where a number of processes is shaping them. In all our sites, no notch was found at around 20 cm below sea level.

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Fig. 1. A tidal notch with 20 cm thick on coralline reef in a very high wave energy area (see also Fig. 5a and Fig. 6 sketch number 5, Capo Caccia, of Antonioli et al., 2015; with 11kW/m energy and wave up to 7m).

A partly different view from what summarized above is expressed by Evelpidou and Pirazzoli (2015a), in commenting our paper: " *a recent gradual depletion of tidal notches in relation to recent rate of sea-level rise (19 cm in the 20th century) can be expected in areas where the tidal range is less than the sea-level rise*": 20 cm of amplitude in Greece, and 45 in the Mediterranean sea.

On the contrary, we show that tidal notches are currently forming, challenging the hypothesis that sea level rise has drowned them. It is not a problem of tide amplitude, but even if it was so, our conclusion is that tidal notch development since 7.8 ka BP (with a rate of sea level rise of 6–7 mm\year) matches the rise of the sea. On the other hand, considering the mean erosion rates in the tidal zone in the Mediterranean sea, ranging from 0.3 to 1 mm/yr (Furlani and Cucchi, 2013; Furlani et al., 2014a), we exclude the possibility that fossil tidal notches younger than 7.8 ka BP can be found in stable coastal areas. Tidal notches are shaped in few hundreds of years, therefore they are not a stable morphology (as Evelpidou and Pirazzoli, 2015b tend to believe) but are continuously shaped following the sea-level rise as shown in Fig. 10c of Antonioli et al., 2015.

On the other hand, Evelpidou and Pirazzoli (2015b) seem to ignore tidal ranges in their specific study areas. They state that in all their coastal areas in Greece, the tidal range is 20 cm, without quoting references or tidal stations. Unfortunately, this is not true because at Agria, near the gulf of Eubea, tidal range is 35 cm, at Aegio (gulf of Corinth) is 55 cm, at Calks, near Eubea is 33 cm (as reported in http://www.tide-forecast.com.

To elaborate more on this point, we have provided a new tidal analysis to estimate the tide amplitude for the Aegean sea, similarly as we have done in chapter 3.2 of our paper. Specifically, we have used tidal data from Kasteli station, located in western Crete, which can considered a good analogue for tidal amplitudes in the Aegean sea. Data have been retrieved from IOC (http://www.ioc-sealevelmonitoring.org/station.php?code=kast) and an histogram representing the number of hours per year for which a given sea level occurs, has been computed. The mean tidal range at Kasteli is 30 cm, with max values up to about 60 cm, which are well above the tidal ranges indicated by Evelpidou et al., 2012, (Fig. 1).

Hereafter we try to give some replies to specific comments:

Regarding the rate of sea level rise in the Mediterranean, the most updated estimates for the last century are at 1.7 mm/yr (Wöppelman and Marcos, 2012) or 1.8 mm/yr (Anzidei et al., 2014) and not at 2 mm/yr as reported by Pirazzoli and Evelpidou.

Regarding the nomenclature of notches, despite some attempts to summarise and simplify the question, it is very difficult to find a real convergence in the existing literature (e.g.: Focke, 1978; Higgins, 1980; Pirazzoli, 1986). Trenhaile (2015) suggested that several parameters can be used to define notches. Some Authors, such as Kaye (1959) or Higgins (1980), called visor the rock ledge which develops above the high tide. We and other Authors, such as Furlani et al. (2011), Benac et al. (2004, 2008), called "roof notch" the notches lacking the base. Anyway, a widely accepted terminology does not exist. We are confident that, through schemes and

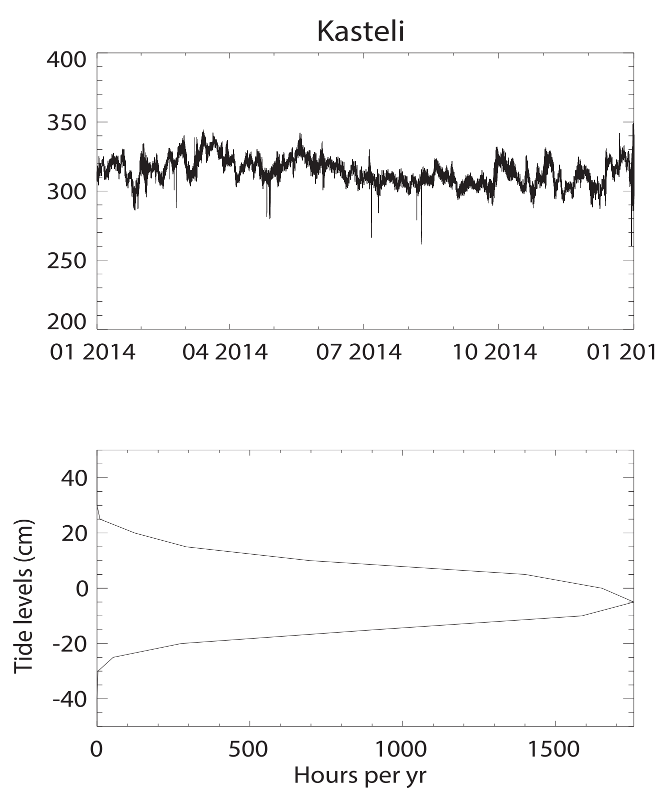

Fig. 2. Analysis of the tide gauges data for the Kasteli station: above:tidal recordings for 2014; below height of tide trend(hours/year) for 2014.

Fig. 3. Measuring a tidal notch at Punta Giglio (Sardinia, Italy) during Geoswim 2015 (https://www.facebook.com/Geoswim).

description in the paper, we made clear what we mean when we address one specific morphology, or one specific part of the notch.

Evelpidou and Pirazzoli (2015a) comment " *… exposure seems predominant at most sites and biological rims are also frequent, implying a possible confusion between tidal notches and surf notches (Focke, 1978), as was already done by some of the same authors in the Orosei Gulf (Evelpidou and Pirazzoli, 2015a,b).*"

Focke (1978) studied an island with tidal range over 3 m, where development of surf notches is predictable. On the opposite we studied the Mediterranean sea (about 35–45 cm of mean tide, with only 2 sites over 1 m: Trieste and Gabes gulfs). We have never found "surf notches" in the whole Mediterranean sea. In addition, our data show no correlation between energy and notch dimension, but only between reef thickness and wave energy (Fig. 2). Biological reefs are carefully described in Antonioli et al. (2015).

Evelpidou and Pirazzoli (2015a) comment *"The late 19th century the global rise in sea level has been estimated at an average rate of 2.1 mm/yr (Jevrejeva* et al.*, 2008; Kemp* et al.*, 2011), i.e. at a rate greater than the expected rates of bioerosion in carbonate rocks in the Mediterranean".*

We believe that part of the misunderstanding by Evelpidou and Pirazzoli (2015b) derives from the fact that they think that the only and main process responsible for the formation of tidal notches is bioerosion. Indeed, bioerosion is an important factor, but we also assign an important role to other processes, such as chemical and mechanical erosion, intending with the last process the effect of waves on the micro-pores in the rock. We disagree with Evelpidou et al. (2012) contention that notches in one particular area in Greece were only formed by bioerosion, and maintain that it is not possible to disentangle all these processes.

Evelpidou and Pirazzoli (2015a) comment: even the tentative demonstration attempted by Antonioli et al. (2015) is based on the number of notches investigated rather than on their genetic quality, and fails to be fully convincing, because it probably includes also some non-tidal notches.

We studied 78 sites, in 3 sites we show roof notches, all the others represent tidal notches.

In conclusion, we stand to the points made in our paper, Antonioli et al. (2015). We attempted, probably for the first time in literature, to analyse the morphology of notches against tide gauge, wave and lithological datasets. The reply by Evelpidou and Pirazzoli (2015a) to our paper shows what we already knew, that there is ground for a lot of work to be done in the field of the study of tidal notches, and that scientific discussion is always welcome, when fair and supported by data. Disentangling rates and processes of tidal notch formation must be done in the field, combining physical measurements with conceptual models. Tidal data should be evaluated against tide gauges, as the intensity of waves hitting a shoreline should be evaluated against wave buoys, or satellite data. Measurement of carbonate consummation rates must be attempted with micro erosion metres, keeping in mind the spatial variability of marine processes. If Pirazzoli, Evelpidou and colleagues want to stand by their point that sea level rise is drowning those notches where bioerosion is the one and only agent of formation, in order to strengthen their science they need much more fieldwork in much more diverse areas and rigorous data on bioerosion rates and tides to sustain their conclusions. The data we collected across the Mediterranean sea (Furlani et al., 2014b), Geoswim 2012 (Istria, Croatia), 2013 (Malta), 2014 (Egadi islands, Gaeta and Circeo, Italy) 2015 (Ustica, N Sardinia, Italy, Fig. 3) (https://www.facebook.com/Geoswim), support the hypothesis that tidal notches are not disappearing due to sea level rise. The hypothesis contrasts the one put forth by Evelpidou et al. (2012), and their reply to our paper fails to bring any further convincing data or arguments to falsify our hypothesis.

References

Antonioli, F., Lo Presti, V., Rovere, A., Ferranti, L., Anzidei, M., Furlani, S., Mastronuzzi, G., Orrù, P., E., Scicchitano, G., Sannino, G., Spampinato, C., Pagliarulo, R., Deiana, G., de Sabata, E., Sansò, P., Vacchi, M., Vecchio, A., 2015. Tidal notches in Mediterranean sea: a comprehensive analysis. Quat. Sci. Rev. 119, 66–84.

Anzidei, M., Lambeck, K., Antonioli, F., Furlani, S., Mastronuzzi, G., Serpelloni, E., Vannucci, G., 2014. Coastal Structure, Sea-level Changes and Vertical Motion

of the Land in the Mediterranean, vol. 388. Geological Society, London. http://dx.doi.org/10.1144/SP388.20. Special Publications.
Benac, Č., Juračić, M., Bacran-Petricioli, T., 2004. Submerged tidal notches in the Rijeka Bay NE Adriatic sea: indicators of relative sea-level change and of recent tectonic movements. Mar. Geol. 212 (1–4), 21–33.
Benac, Č., Juračić, M., Blašković, I., 2008. Tidal notches in Vinodol channel and Bakar Bay, NE Adriatic sea: indicators of recent tectonics. Mar. Geol. 248 (3–4), 151–160.
Evelpidou, N., Kampolis, I., Pirazzoli, P., Vassilopoulos, A., 2012. Global sea level rise and disappearance of tidal notches. Glob. Planet Chang. 92–93, 248–256.
Evelpidou, N., Pirazzoli, P., 2015a. Tidal notches in Mediterranean sea: a comprehensive analysis. In: Antonioli, F., Lo Presti, V., Rovere, A., Ferranti, L., Anzidei, M., Furlani, S., Mastronuzzi, G., Orrù, P., E., Scicchitano, G., Sannino, G., Spampinato, C., Pagliarulo, R., Deiana, G., de Sabata, E., Sansò, P., Vacchi, M., Vecchio, A. (Eds.), Quaternary Science Reviews 119 (2015) 66–84. JQSR-D-15-00379.
Evelpidou, N., Pirazzoli, P.A., 2015b. Sea-level indicators. In: Finkl, C.W., Makowski (Eds.), Environmental Management and Governance: Advances in Coastal and Marine Resources, Coastal Research Library 8. Springer, Switzerland, pp. 291–311. http://dx.doi.org/10.1007/978-3-319-06305-812.
Focke, J.W., 1978. Limestone cliff morphology on Curacao (Netherlands Antilles) with special attention to the origin of notches and vermetid/coralline algal surf benches ("corniches", "trottoirs"). Z. Geomorphol. 22, 329–349.
Furlani, S., Biolchi, S., Cucchi, F., Odorico, R., 2011. Notches in the northern Adriatic sea: genesis and development. Quat. Int. 232, 158–168.
Furlani, S., Cucchi, F., 2013. Downwearing rates of vertical limestone surfaces in the intertidal zone (Gulf of Trieste, Italy). Mar. Geol. 343, 92–98.
Furlani, S., Pappalardo, M., Gomez-Pujol, L., Chelli, A., 2014a. Mediterranean and Black sea. In: Kennedy, D.M., Stephenson, W.J., Naylor, L.A. (Eds.), Rock Coast Geomorphology: a Global Synthesis, 40. Geological Society, London Memoirs, pp. 89–123.
Furlani, S., Ninfo, A., Zavagno, E., Paganini, P., Zini, L., Biolchi, S., Antonioli, F., Coren, F., Cucchi, F., 2014b. Submerged notches in Istria and the Gulf of Trieste: results from the Geoswim project. Quat. Int. 332, 37–47.
Higgins, C.G., 1980. Nips, notches, and the solution of coastal limestone: an overview of the problem with examples from Greece. Estuar. Coast. Sci. 10, 15–30.
Kaye, C.A., 1959. Shoreline features and quaternary shoreline changes Puerto Rico. U. S. Geol. Surv. Prof. Pap. 49–140, 317-B.
Pirazzoli, P.A., 1986. Marine notches. In: van de Plassche, O. (Ed.), Sea-level Research: a Manual for the Collection and Evaluation of Data. Geo Books, Norwich, pp. 361–400.
Trenhaile, A.S., 2015. Coastal notches: their morphology, formation, and function. Earth Sci. Rev. 150, 285–304.
Wöppelman, G., Marcos, M., 2012. Coastal sea level rise in southern Europe and the nonclimate contribution of vertical land motion. J. Geophys. Res. 117 http://dx.doi.org/10.1029/2011JC007469. C01007.

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