Researches Reviews of the Department of Geography, Tourism and Hotel Management
50–2/2021

Original scientific article

COULD YOU SEE THE SEA? UPPER PLEISTOCENE SEA LEVEL FLUCTUATION OVER THE BALKAN PENINSULA: A REVIEW

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Received: August 27, 2021 | Accepted: February 14, 2022
DOI: 10.5937/ZbDght2102078R

ABSTRACT: *Tectonic movements affected the southern part of the coast the most, while some parts such as Danube delta remained almost untouched through the Upper Pleistocene, covering the last 124.000 years. This is why the reconstruction of the Balkan coast requires multiple proxy data. The chronostratigraphy used in this paper is marine isotope stages, as it allows comparing different records used for paleo environmental reconstruction. The paper is divided into five parts, one for each basin surrounding the Balkan Peninsula: Adriatic, Ionian, Aegean, Marmara and Black Sea basin. All of the basins experienced sudden shrinking in the Last Glacial Maximum, when the sea level fell for ~120 m when the aquatic mollusks entered a population bottleneck, but the terrestrial ones flourished, as their habitat grew. As the Mediterranean territory got submerged again, the migration corridors for the humans disappeared, leaving their traces preserved under the sea level.*

Keywords: *Mediterranean Sea, sea level fluctuation, last glacial maximum, Upper Pleistocene, Balkan Peninsula.*

INTRODUCTION

The sea level fluctuation over the last ice age is found to be the consequence of the build up and decay of ice caps (Lambeck, Chappell, 2001).The eustatic, isostatic, and tectonic movements are the major factors for the locations of paleo coasts (Lambeck, 1995). The new international global stratigraphic chart places the Pleistocene (which covers the last 2.58 Ma) in the Quaternary period, Cenozoik era and Phanerozoik eon. Pleistocene is divided on Low/Early including the Gelasian and Calabrian stage (starting at 2.58 Ma, and 1.80 Ma, respectively), Middle called Chibanian stage (starting at 0.774 Ma) and Upper/Late Pleistocene (starting at 0.124 Ma) (Cohen, et al., 2013). This study focuses on the paleo coasts of the Upper Pleistocene Balkan Peninsula, which is surrounded by the Adriatic, Ionian, Aegean, Marmara and Black Sea. Several proxies are used for the sea level reconstruction. Geomorphology can be used for the reconstruction, based on mapping the submerged abrasion platforms and notches, which require stabile water level for a longer period (Benjamin, et al., 2017). On the other hand, there are some useful proxies as corals, seawater δ 18O, benthic δ 18Osw and planktonic δ 18Osw (Spratt, Lisiecki, 2016). Oxygen has three isotopes 16O, 17O, and 18O which have the same number of protons but different number of neutrons (Wright, 2000). Measuring δ 18O from the shells can provide the information of sa-

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linity, temperature and global ice volume (Lisiecki, Raymo, 2005; Wright, 2000). There are examples when the planktonic foraminifera were extinct due to the salinity increase above their lethal level (Hemleben, et al., 1996) during the Last Glacial Maximum (LGM) when the sea level dropped, thus leaving the multi proxy data analysis necessary for the reconstruction (Rohling, at al., 1998). Sediments deposited at the bottom of the sea can suffer from biological and biochemical perturbations (Anastasakis, Piper, 2013; Rohling, et al., 2014), so it is not easy to find suitable location for core sampling. The Eastern Mediterranean basin has the favorable conditions, where the planktonic δ 18Osw was synthesized back to the Messinian salinity crisis 5.33 Myr ago (Lourens, at el., 1996). In some cases using the primary principle of superposition is not recommended, as the shoreline in Marine Isotope Stage (MIS) 5e was above the today's coast, leaving the older strata above the sea level (Hearty, 2007).

During the Pleistocene the Balkan Peninsula was characterized as sensitive to both Mediterranean and continental climate. The development of cambisols in Central Balkan Peninsula during the MIS 7 proves the effect of Mediterranean climate (Obreht, et al., 2016). But how close was the Mediterranean Sea? In this paper the description of the sea level variation will be divided into Adriatic, Ionian, Aegean, Marmara, and Black Sea basins. Used stratigraphy is MIS (Emiliani, 1955), as it is the most commonly used in Quaternary records after the development of time scale by radiocarbon and U/Th dating (Wright, 2000). The water of all of the basins is controlled by eustatic global sea level, which is related to changes in riverine and melt water input, and it is a consequence of climate. The $\delta\ ^{18}O_{calcite}$ was proved to be fluctuating on global scale due to different volume of ice sheet by Shackleton (1967). Isotope records are not a time scale. Thus, for cores to be interpreted in a correct chronostratigraphy they should be dated or correlated with magnetic susceptibility or by tephrochronology. Also, it is very important to base isotope measurements on entirely one species, as different foraminifera have variations in themselves and it also changes during the life span due to speed rate of growing (Wright, 2000; Rohling, et al., 2014). The global oxygen isotopic data provides evidence of eustatic sea level change, with uncertainty up to ±20 m or even ± 30 m (Anastasakis, Piper, 2013; Siddall, et al., 2003).

The mollusks have been a useful tool for reconstructing the palaeo environments (Alexandrowicz, Alexandrowicz, 1995), as they easily fossilize and have a great abundance over geological strata. They are described as one of the most successful organisms on Earth, reaching the 85.000 number of species and additional 100.000 fossil species (Selley, 2005; Joseph, 2016). Usually the decrease of one abundant species can lead to conclusion that the environment suffered a significant change. In nowadays it can be the result of human activity (Brannik et al., 2004) as is happened in the Pontocaspian system (Black sea, Caspian sea, Azov Sea and Aral Sea). In the Mediterranean Sea the allochthonous species were introduced by the ships several centuries ago, but probably the main change occurred after the opening of the Suez channel, resulting in additional 955 alien species present in the Mediterranean Sea, of which 134 are invasive (Goffredo, Dubinsky, 2013).

Despite of human induced assemblage shift, there are climatically driven (natural) changes in Mediterranean biota. The known one is "Senegalese fauna" which entered the Mediterranean Sea during the last interglacial, MIS 5e, leaving a trace of a warmer temperature then today's (Hearty, et al., 2007). The coastal species are the most vulnerable ones, as the water level can leave them exposed and cause shallow water habit destruction (van de Velde, 2020). When the sea level dropped in the last glaciation, the marine organisms were experiencing a population bottleneck, as the basins were physically separated (Ludt, Rocha, 2015). The mollusks species are used for easy distinguishing between aquatic or terrestrial environment during the sediment deposition (Amorosi, et al., 2017; Brunović, et al., 2020). The changes in aquatic mollusks assemblage can tell about the changes in salinity, as it is the case in Marmara Sea (Sperling, et al., 2003).

The changes in assemblage of terrestrial mollusks are the indicator of vegetation switch and can be climatically forced (Puisségur, 1976). Some mollusks reveal severe dry climate (e.g. *Pupilla loessica*) and are extinct in the interglacial period (Horsák, et al., 2010). Sudden appearance of the terrestrial mollusks can mean possible corridors to early human migrations. The presence of some terrestrial Upper Pleistocene mollusks is already compared with dispersal of Aurignacian, Gravettian and Solutrean-Upper Magdalenian lithic cultures (Moine, 2014). Mollusks are useful for the environmental reconstruction even when they are being exploited by the early humans, as their shells are also preserved in the caves, as showed in the southern Spain in the MIS 5 (Cortés-Sánchez, et al., 2011).

The following chapters will focus on the Balkan Peninsula and the changes that major sea basins experienced in the Upper Pleistocene, based on the different proxies approach.

ADRIATIC SEA

The Adriatic basin is divided into three parts, from north to south these are: the shallowest part covered by Po sediments; the Mid Adriatic Deep (MAD) reaching down to -260 m (Figure 1), which is a remarkable location for taking core samples; and the more than 1200 m deep southern basin.

In the MIS 5e the western Italy had higher sea level by +8 m, demonstrated in Salento peninsula, Bari, Pescara, and Rimini (Benjamin, et al., 2017). The Lošinj Channel between Croatian island Lošinj and Cres had marine conditions (Brunović, et al., 2020). On the other hand, the Gulf of Trieste and Venetian Lagoon were probably 2 m lower. The evidence of sea level in MIS 4 and MIS 3 can be found in the caves located in Croatian coast. It is difficult to find the sediments, as the sea level was lower than today's, and they are hard to reach as no such detailed bathymetry exists. After the end of the glacial the rising sea level eroded the surface geomorphology (Benjamin, et al., 2017). There are 140 submarine caves in the eastern Adriatic coast, where the speleothems can be sampled (Surić, et al., 2009). At some islands, the growing of speleothems was restricted due to sea level rise in MIS 5.

During the MIS 4 the sea level was -90 m lower (Brunović, et al., 2020). The sea level was lower for -80 m 65 k years ago, leaving the dry landscape of Adriatic basin with humid continental climate, which is today present in Velebit mountain (Surić, et al., 2021).

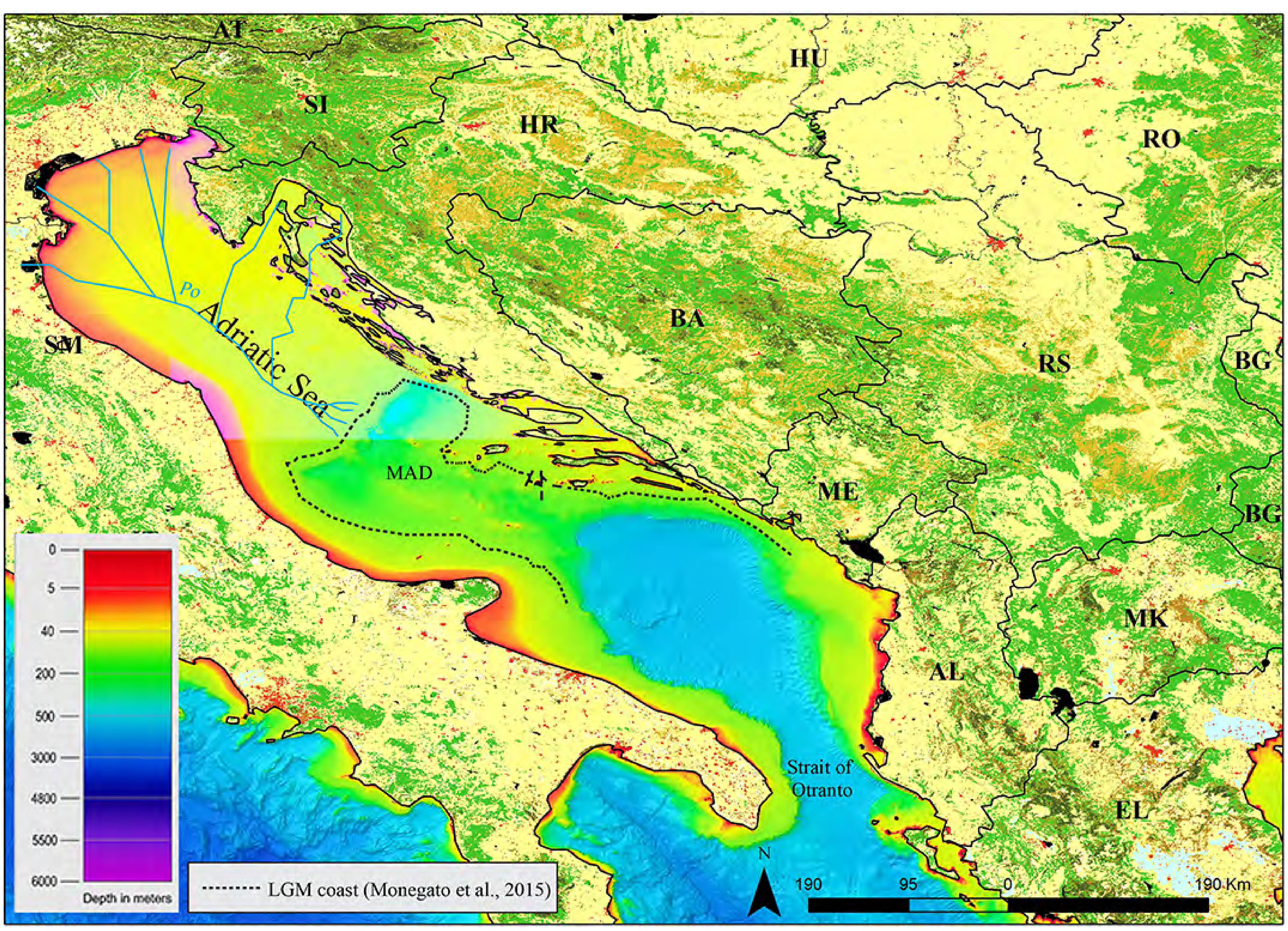

Figure 1. Adriatic basin with the paleo coast at Last Glacial Maximum based on Monegato, et al., 2015. Continental data obtained from Corine land cover 2006 (https://land.copernicus.eu/pan-european/corine-land-cover/clc-2006?tab=mapview); bathymetry obtained from EMODnet (https://www.emodnet-bathymetry.eu/)

Short high stand of water was present before 52 k years, with -60 m sea level. At 46k years ago Lošinj channel was entering a lacustrine phase from a polje, while Kvarnerić bay had marine conditions, separated from the Lošinj lake by now non existing isthmus (Brunović, et al., 2020). Other transgressions occurred in the MIS 3, with the amplitudes up to 30 m, before 55 k, 45 k, and 38 k years (Benjamin, et al., 2017). The MIS 3 is at the depth of -35 m to -40 m today and it has two horizons considered to be a soil as they are organic rich (Ronchi, et al., 2017).

At the transition to MIS 2, Lošinj channel was a polje again (Benjamin, et al., 2017).The drainage basin of the Po river during the MIS 2 was twice as large (Maselli, et al., 2011), creating what is known as Mega Po, as the sea level dropped to -120 m (Ronchi, et al., 2017). The Croatian island of Vis situated 45 km from the coast (today a geopark) was covered with sand dunes, as Neretva and Cetina rivers transported the periglacial material. Cetina was flowing around the eastern side of the Brač, filling at least four depressions in the form of lake between the Brač and Hvar, before entering the Adriatic Sea, about 20 km northern from Vis. Neretva was flowing between the Hvar and Korčula, making its delta near the island of Sušac. This is why the Vis was influenced by both of the rivers. It was debated how old were the dunes, as the sands from the island of Hvar were dated to MIS 5/6. The eolian sands from Vis are 10 m deep, including the LGM, Heinrich event 1, with the uppermost age of m 3.6 ± 0.3 ka. The terrestrial mollusk which lived on it at the time of deposition was *Vertigo pygmaea*. There is also evidence of tephra input (Wacha, et al., 2019). The island of Susak had the loess accumulating during the last glacial, with the sand interruption between 46.4±2.7 ka and 42.2±2.4 ka, indicating stronger winds (Wacha, et al., 2011).

From 32 k to 15 k years ago, Mega Po created wedge of 40 km in the MAD. The LGM period was allowing the loess formation at the Croatian coast, and the Po plain. Cooling was less intense than in Carpathian basin, which means that the Alps and Dinaric Alps served as a protection against cold air masses from the north, and were also a barrier for the dust transport from the Adriatic basin to Carpathian basin (Ludwig, et al., 2021). Distance from the shelf to the present day coast is 300 km. It was once a place with river valleys which transported the eroded material which filled them up, and represents available sediment record of the low stands. There are recognizable paleo lagoons at the depths of -90 m (15-14.3 ka), -65 m (12.9-11.5 ka), -42 m (11-10 ka), -34 m (10-9.5 ka), -22 m -18m (9-8 ka), and -15 m to -12 m (7.5 ka) (Ronchi, et al., 2017).

IONIAN SEA

The geophysical survey of Ionian Islands in Greece during 2014 gave enough evidence of the Ionian paleo coast. In the Vassiliki Bay the four prodeltaic prisms have been found, corresponding with the LGM (MIS 2, 18 k BP), 65 ky (MIS 4), while the other two prisms may be related to 140 ky (MIS 6), and to 270 ky (MIS 8). The MIS 10 landscape is at the depth of 450 m. Deltas of the same age are not found at the same depth because of tectonic movements of this region (Zavitsanou, et al., 2016). In the MIS 2 Kerkira was connected to the mainland, and Gulf of Korinthos was a lake, with the depth of at least 750 m (Figure 2). Lykousis (2009) found that the Gulf of Korinthos subsided 75 m for 107 k years, from MIS 6 to MIS 2.

There is also one speculation about the lake which existed between the Kerkira and mainland, which probably had drainage to south. The Ambracian Gulf was a lake 70 m deep. The western coast of the Peloponnesus was shifted up to 8 km to the west. The Patraikos Gulf was a extended shelf (Perissoratis, Conispoliatis, 2003). Lefkada, Sparti, Skorpios, Meganisi, Kalamos, Kastos Kithros and Petalou were all connected, and also connected to the main land (Zavitsanou, et al., 2016).

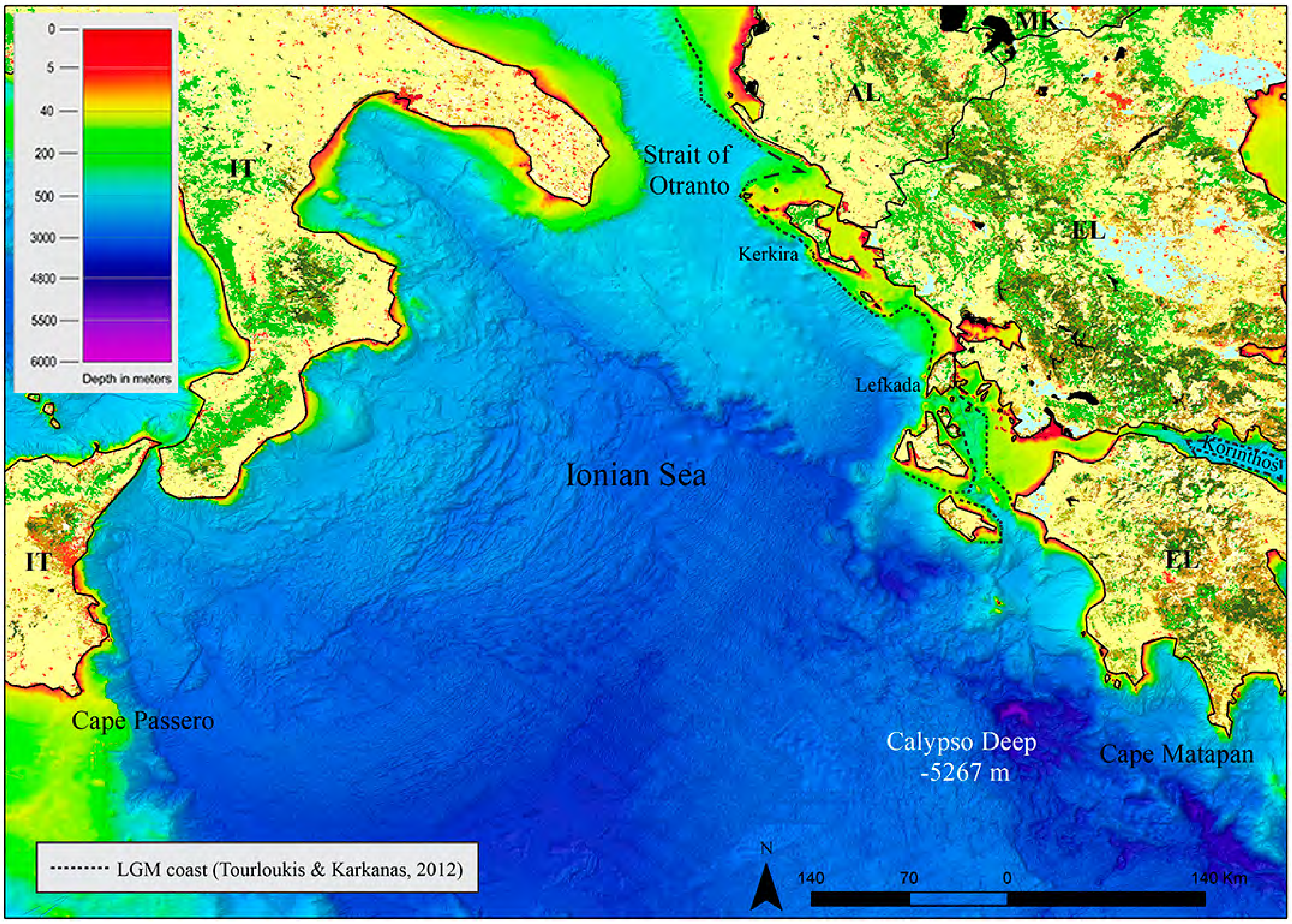

Figure 2. Ionian basin with the paleo coast at Last Glacial Maximum on Balkan Peninsula based on Tourloukis, Karkanas, 2012. Continental data obtained from Corine land cover 2006 (https://land.copernicus.eu/pan-european/corine-land-cover/clc-2006?tab=mapview); bathymetry obtained from EMODnet (https://www.emodnet-bathymetry.eu/)

AEGEAN SEA

Lykousis (2009) calculated that the Gulf of Thessaly had subsided 110m over from MIS 6 to MIS 2 (128ka) and Eastern Cyclades 42.5 m for the same time. The last glacial maximum (MIS 2) caused sea level of Aegean Sea to drop for -115 m (Aksu, et al., 1987), and even by -165 m according to Van Andel and Shackleton (1982). Different sea levels are obtained because not all of the authors include the glacio-hydroisostatic adjustments of the crust due to ice melting. Greek and Turkish coasts which are located in the Aegean Sea are very prone to tectonic movements (Sakellariou, et al., 2017) but are also close to the major ice caps for the isostatic function to be important (Lambeck, 1995). What is now Gulf of Thessaly used to be a plain, including Samothrake and Thasos (Figure 3). Euboea was connected to the land. Sphorades were a peninsula, and Cycladic archipelago was one island (Van Andel, Shackleton, 1982). Today, below the Gulf of Thessaly, five oblique progradational clinoforms are identified, and they are eroded at the top due to wave erosion. At the depth of 116 m below the sea level there is what is believed to be MIS 2 delta. From MIS 6 to MIS 2 the subsidence of the terrain was 110 m (128 ka) (Lykousis, 2009). The MIS 2 depth in the Central Aegean Sea on the Cyclades plateau is determined at 109.5 m, and until MIS 6, the plateau subsided 42.5 m (128 ka).

Karpatos and Makronisi were one island. The coast at the north of the Aegean Sea was shifted southward for 30 km. Limnos, Chios and Dodecanese Island were connected to Turkey and were separated with rivers flowing from Asia Minor (Perissoratis, Conispoliatis, 2003).

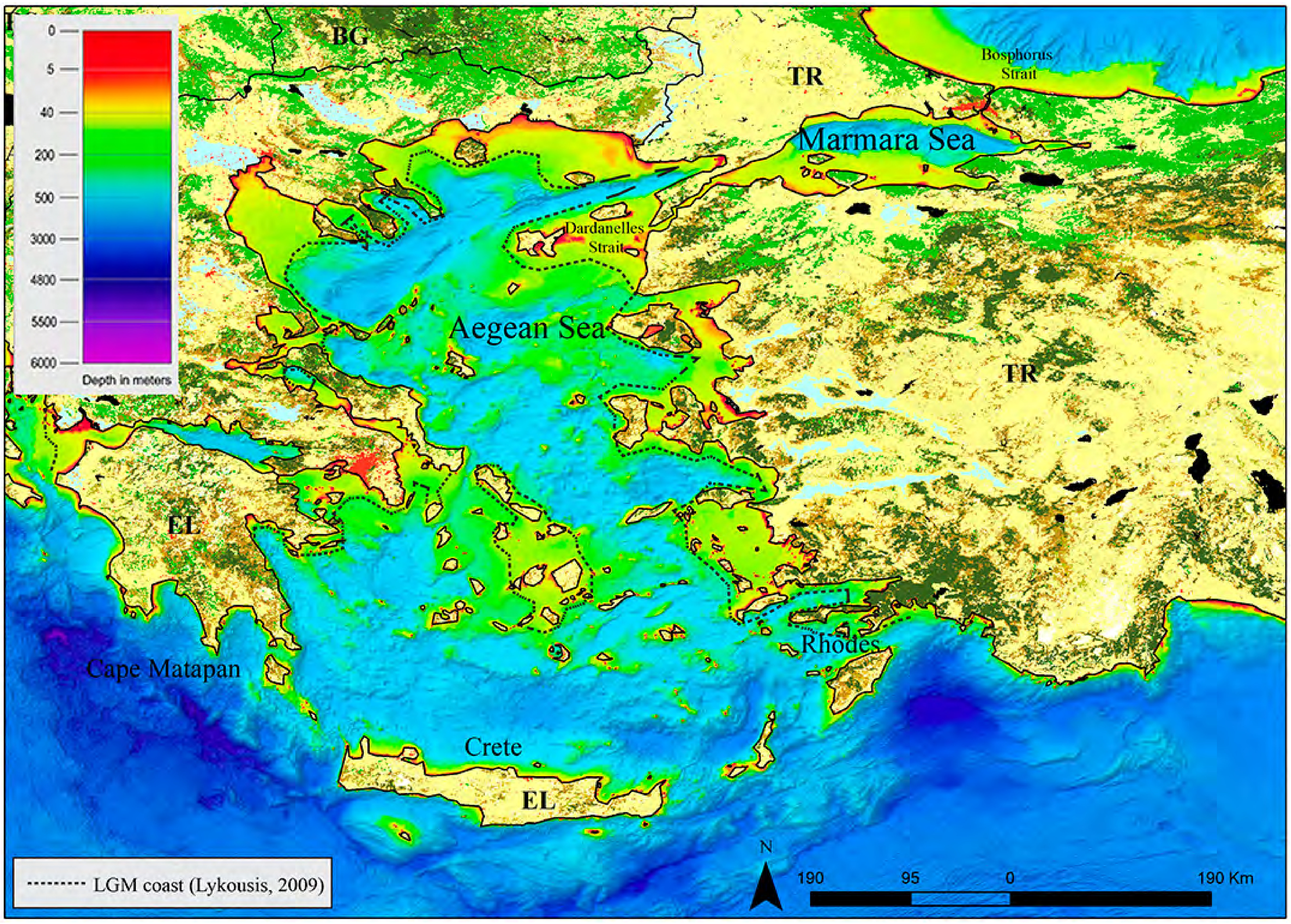

Figure 3. Aegean basin with the paleo coast at Last Glacial Maximum based on Lykousis, 2009. Continental data obtained from Corine land cover 2006 (https://land.copernicus.eu/pan-european/corine-land-cover/clc-2006?tab=mapview); bathymetry obtained from EMODnet (https://www.emodnet-bathymetry.eu/)

MARMARA SEA

The records of the two cores in the Marmara Sea tell us a story of this basin for 171 ka. It is proven that the Aegean Sea and Marmara Sea were disconnected between 171 and 134 ka BP, which belongs to MIS 6. In the next 2 ka BP the basins became connected, with the end of Termination II. The sedimentation rate was ~10.5 mm/kyr at MIS 5, which is relatively low, and can be explained by the warmer and humid climate which allowed the vegetation to develop and cut the erosion. Another proposed hypothesis is that the rising sea levels caused landward migration of the coastline, which means that the core was further away from the river mouths. The connection between the Marmara Sea and Aegean Sea existed though the MIS 5, with the exception between ~93.9-86.6 ka BP and ~71-75 ka BP (Çağatay, et al., 2019). The dynamics of the sedimentation in Marmara Sea is well studied based on the tephrochronology of the continuous core covering the last 67 ka (Çağatay, et al., 2015), belonging to MIS 1-4. This record was developing under lacustrine conditions, and was disconnected from the Mediterranean Sea.

In the Middle Pleniglacial (MIS 3), the lake level was the highest, and it is assumed that the Dardanelles had higher sill depth than today (65 m) (Çağatay, et al., 2019). When taking in consideration the 0.45 mm/y uplift of the Dardanelles, before 30 ka it had the depth of 83.5 m. It is proposed that the Black Sea was connected through Bosphorus to Marmara Sea by the river (Aksu, et al., 2002). The salinity of Marmara Sea was lower at MIS 3 than today, even though it had connection to Aegean Sea, because the precipitation was increased in Eastern Mediterranean basin, filling and deepening the lakes of today's Turkey (Roberts, 1983).

The sea level in Last Glacial Maximum was lower for -100 m (Figure 4) in the Marmara Sea (MIS 2) (Aksu, et al., 2002). In the MIS 2 the recessive phase was causing the formation of erosional terraces (Aksu, et

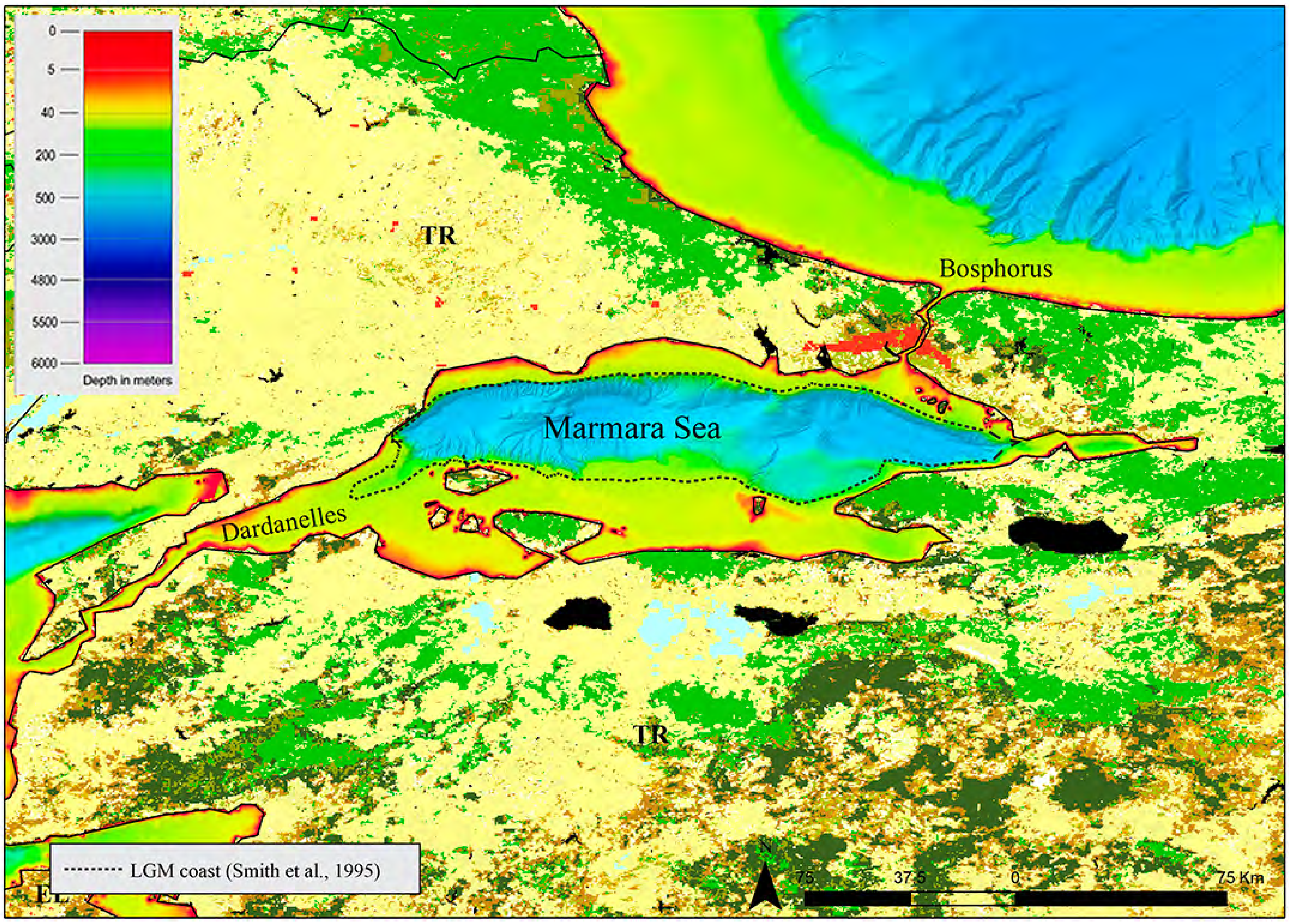

Figure 4. Ionian basin with the paleo coast at Last Glacial Maximum based on Smith, et al., 1995. Continental data obtained from Corine land cover 2006 (https://land.copernicus.eu/pan-european/corine-land-cover/clc-2006?tab=mapview); bathymetry obtained from EMODnet (https://www.emodnet-bathymetry.eu/)

al., 1999). The marine transgression was determined to be at 12.55±0.35 cal ka BP. The reason why the shelf is three times longer at the south is because the rivers which flow through Turkey (Biga, Gonen, Simav) have larger basins and bring more material (Smith, et al., 1995).

BLACK SEA

As the ice caps restricted the northward river flows, much of the water ended in Caspian or Black Sea basin. During the Pleistocene the Black Sea had experienced the lacustrine environment. Fossilized fauna represents abrupt changes from fresh, brackish to salt water. Several systematic survey of the Black Sea shelf have been preformed, GeoEcoMar Institute in the nineteen's on Romanian shelf, BlaSON cruises in 1998 and 2002, ASEMBLAGE2 in 2004 (Lericolais, et al., 2009). The core sampling of the Arkhangelsky Ridge on Black Sea can provide data up to the MIS 6, which were deposited in the lacustrine conditions (Nowaczyk, et al., 2021). During the beginning of MIS 5 the Mediterranean Sea was connected to the Black Sea, but there was no connection from Caspian to Black Sea. By the end of MIS 5 the overflow between Caspian and Black Sea happened, and it is known as Hyrcanian transgression.

Early Pleniglacial has left the Black Sea isolated and the freshening of the water began, but lasted shortly as the Mediterranean and the Black Sea connected, as well as Caspian Sea through Manych strait again in interstadial MIS 3. It is interesting to note that the overflow in MIS 3 happened from the Black Sea towards the Bosphorus. While the last loess horizon of L1LL1 was developing in the Pannonian basin, and the climate went back to glacial conditions, the Manych strait entered continental phase, and left the Caspian Sea isolated from the Black Sea (Barannik, et al., 2004). The LGM caused lowering of the Black sea level for -110 m (Ryan,

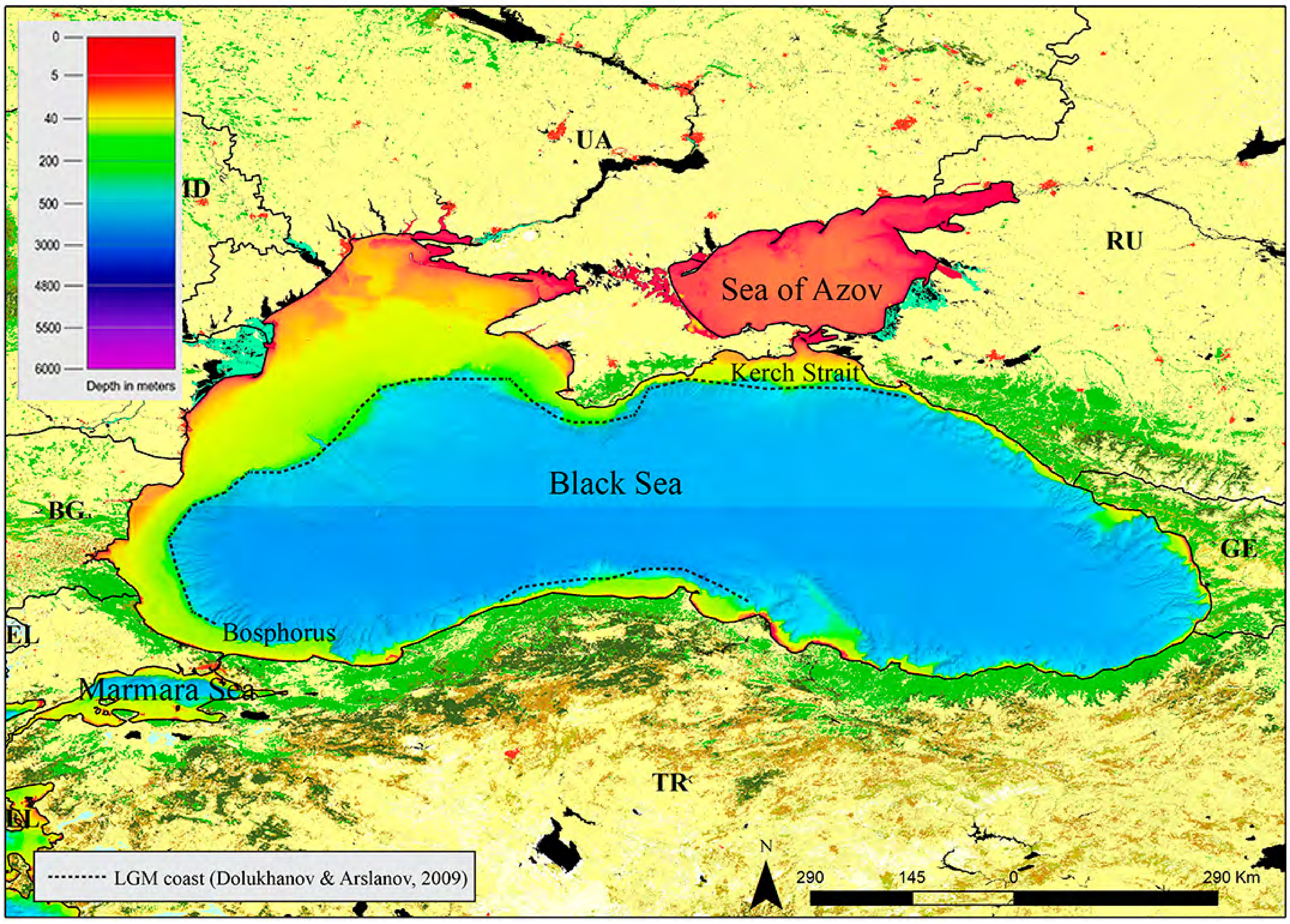

Figure 5. Black Sea basin with the paleo coast at Last Glacial Maximum based on Dolukhanov, Arslanov, 2009. Continental data obtained from Corine land cover 2006 (https://land.copernicus.eu/pan-european/corine-land-cover/clc-2006?tab=mapview); bathymetry obtained from EMODnet (https://www.emodnet-bathymetry.eu/)

et al., 1997). Submerged terraces of the Kerch-Taman region which are now at the depth of -110 m and similar terraces on Bulgarian and northern Turkey's shelf are believed to be the paleo coast of the LGM (Lericolais, et al., 2009) (Figure 5). The overflow in the Holocene happened from the Black Sea towards the Bosphorus, and it is still connected today. Today, the Black Sea could raise its surface for 94 cm annually, if it was not connected to Bosphorus, due to Danube, Dniester, Dnieper, Southern Bug and Don River water input (Aksu et al., 2002). There is also opposite theory which was proposed earlier, where the water was coming from the Marmara Sea towards the Black Sea, covering 100.000 km2 of shelf, and causing the migration of Neolithic foragers (Ryan, et al., 1997). This is the catastrophic flood hypothesis which includes up to 60 cm rise of sea level per day, filling the whole basin in a few years. The refilling of the Black Sea basin remains unclear with the numerous studies still trying to resolve for and against arguments of catastrophic event. Major evidence for opposing this hypothesis is the very stabile Danube delta which shows no such evidence of erosion (Panin, Popescu, 2007).

CONCLUSION

This review is focusing on the Balkan coast, surrounded by Adriatic, Ionian, Aegean, Marmara, and Black Sea during the Upper Pleistocene. Many authors tried to reconstruct the coast based on different proxies. In some basins the geomorphologic method of finding the submerged coasts is relatively easy due to lack of major fault systems which transform the depths in short times. In other, the tectonic movements left puzzles of notches, canyons, and abrasive plains at different depths, leading to multi proxy analysis. The largest contrast to today's condition was present at the last glacial maximum, with the sea level drop of about 120 m. It can be concluded that the shallow basins experienced the greatest environmental changes due to climate shifts of the last glacial. Croatian coast made of carbonate rocks was fluctuating between karst polje, fluvial, lacustrine, or marine environment. Ionian coast has great slope gradient. Thus, the changes were limited to the very small areas close to the continent, as Gulf of Korinthos and Ambracian Gulf. Some of the Ionian Islands were connected to the main land. Numerous islands in the Aegean Sea were joined together as Cyclades platform, Dodecanese Island, and others were incorporated in the continent. The Marmara Sea had a lacustrine environment. There are still unsolved questions of when did the connection exist between Black and Marmara Sea. Other debates are based on the direction of water inflow though Bosphorus, including the potential catastrophic flood hypothesis. Although this paper did not include human migratory data often exposed sea beds were allowing human migrations, as they were covered by vegetation based on pollen evidence.

REFERENCES

Aksu, A. E., Hiscott, R. N., Kaminski, M. A., Mudie, P. J., Gillespie, H., Abrajano, T., & Yaşar, D. (2002). Last glacial–Holocene paleoceanography of the Black Sea and Marmara Sea: stable isotopic, foraminiferal and coccolith evidence. *Marine Geology*, 190(1-2), 119-149.

Aksu, A. E., Piper, D. J. W., & Konuk, T. (1987). Late Quaternary tectonic and sedimentary history of outer Izmir and Candarli bays, western Turkey. *Marine Geology*, 76, 89-104.

Aksu, A. E., Hiscott, R. N., & Yaşar, D. (1999). Oscillating Quaternary water levels of the Marmara Sea and vigorous outflow into the Aegean Sea from the Marmara Sea–Black Sea drainage corridor. *Marine Geology*, 153(1-4), 275-302.

Alexandrowicz, S. W., & Alexandrowicz, W. P. (1995). Molluscan fauna of the Upper Vistulian and early Holocene sediments of South Poland. *Biuletyn Peryglacjalny*, 34.

Amorosi, A., Bruno, L., Campo, B., Morelli, A., Rossi, V., Scarponi, D., ... & Drexler, T. M. (2017). Global sea-level control on local parasequence architecture from the Holocene record of the Po Plain, Italy. *Marine and Petroleum Geology*, 87, 99-111.

Anastasakis, G., & Piper, D. J. (2013). The changing architecture of sea-level lowstand deposits across the Mid-Pleistocene Transition: South Evoikos Gulf, Greece. *Quaternary Science Reviews*, 73, 103-114.

Barannik, V., Borysova, O., & Stolberg, F. (2004). The Caspian Sea region: environmental change. *AMBIO: A Journal of the Human Environment*, 33(1), 45-51.

Benjamin, J., Rovere, A., Fontana, A., Furlani, S., Vacchi, M., Inglis, R. H., ... & Gehrels, R. (2017). Late Quaternary sea-level changes and early human societies in the central and eastern Mediterranean Basin: An interdisciplinary review. *Quaternary International*, 449, 29-57.

Brunović, D., Miko, S., Hasan, O., Papatheodorou, G., Ilijanić, N., Miserocchi, S., ... & Geraga, M. (2020). Late Pleistocene and Holocene paleoenvironmental reconstruction of a drowned karst isolation basin (Lošinj Channel, NE Adriatic Sea). Palaeogeography, Palaeoclimatology, Palaeoecology, 544, 109587.

Cohen, K. M., Finney, S. C., Gibbard, P. L., & Fan, J. X. (2013). The ICS international chronostratigraphic chart. *Episodes*, 36(3), 199-204.

Cortés-Sánchez, M., Morales-Muñiz, A., Simón-Vallejo, M. D., Lozano-Francisco, M. C., Vera-Peláez, J. L., Finlayson, C., ... & Bicho, N. F. (2011). Earliest known use of marine resources by Neanderthals. *PloS one*, 6(9), e24026.

Çağatay, M. N., Wulf, S., Sancar, Ü., Özmaral, A., Vidal, L., Henry, P., Appelt, O., Gasperini, L. (2015). The tephra record from the sea of Marmara for the last ca. 70ka and its palaeoceanographic implications. Marine geology,361, 96-110.

Çağatay, M. N., Eriş, K. K., Makaroğlu, Ö., Yakupoğlu, N., Henry, P., Leroy, S. A., Uçarkus, G., Sakınç, M., Yalamaz, B., Bozyigit, C., Kende, J. (2019). The sea of Marmara during marine isotope stages 5 and 6. *Quaternary Science Reviews*, 220, 124-141.

Dolukhanov, P. M., & Arslanov, K. A. (2009). Ecological crises and early human migrations in the Black Sea area. *Quaternary International*, 197(1-2), 35-42.
Emiliani, C. (1955). Pleistocene temperatures. *The Journal of geology*, 63(6), 538-578.
Hearty, P. J., Hollin, J. T., Neumann, A. C., O'Leary, M. J., & McCulloch, M. (2007). Global sea-level fluctuations during the Last Interglaciation (MIS 5e). *Quaternary Science Reviews*, 26(17-18), 2090-2112.
Hemleben, C., Meischner, D., Zahn, R., Almogi-Labin, A., Erlenkeuser, H., & Hiller, B. (1996). Three hundred eighty thousand year long stable isotope and faunal records from the Red Sea: Influence of global sea level change on hydrography. *Paleoceanography*, 11(2), 147-156.
Horsák, M., Chytrý, M., Pokryszko, B. M., Danihelka, J., Ermakov, N., Hájek, M., ... & Valachovič, M. (2010). Habitats of relict terrestrial snails in southern Siberia: lessons for the reconstruction of palaeoenvironments of full-glacial Europe. *Journal of Biogeography*, 37(8), 1450-1462.
Joseph, A. (2016). Investigating Seafloors and Oceans: From Mud Volcanoes to Giant Squid. Elsevier.
Lambeck, K., & Chappell, J. (2001). Sea level change through the last glacial cycle. *Science*, 292(5517), 679-686.
Lambeck, K. (1995). Late Pleistocene and Holocene sea-level change in Greece and south-western Turkey: a separation of eustatic, isostatic and tectonic contributions. *Geophysical Journal International*, 122(3), 1022-1044.
Lericolais, G., Bulois, C., Gillet, H., & Guichard, F. (2009). High frequency sea level fluctuations recorded in the Black Sea since the LGM. *Global and Planetary Change*, 66(1-2), 65-75.
Lourens, L. J., Antonarakou, A., Hilgen, F. J., Van Hoof, A. A. M., Vergnaud-Grazzini, C., & Zachariasse, W. J. (1996). Evaluation of the Plio-Pleistocene astronomical timescale. *Paleoceanography*, 11(4), 391-413.
Lisiecki, L. E., & Raymo, M. E. (2005). A Pliocene-Pleistocene stack of 57 globally distributed benthic δ18O records. *Paleoceanography*, 20(1).
Ludt, W. B., & Rocha, L. A. (2015). Shifting seas: The impacts of Pleistocene sea-level fluctuations on the evolution of tropical marine taxa. *Journal of Biogeography*, 42(1), 25-38.
Ludwig, P., Gavrilov, M. B., Markovic, S. B., Ujvari, G., & Lehmkuhl, F. (2021). Simulated regional dust cycle in the Carpathian Basin and the Adriatic Sea region during the Last Glacial Maximum. *Quaternary International*, 581, 114-127.
Lykousis, V. (2009). Sea-level changes and shelf break prograding sequences during the last 400 ka in the Aegean margins: subsidence rates and palaeogeographic implications. *Continental Shelf Research*, 29(16), 2037-2044.
Maselli, V., Hutton, E. W., Kettner, A. J., Syvitski, J. P., & Trincardi, F. (2011). High-frequency sea level and sediment supply fluctuations during Termination I: an integrated sequence-stratigraphy and modeling approach from the Adriatic Sea (Central Mediterranean). *Marine Geology*, 287(1-4), 54-70.
Moine, O. (2014). Weichselian Upper Pleniglacial environmental variability in north-western Europe reconstructed from terrestrial mollusc faunas and its relationship with the presence/absence of human settlements. *Quaternary international*, 337, 90-113.
Monegato, G., Ravazzi, C., Culiberg, M., Pini, R., Bavec, M., Calderoni, G., ... & Perego, R. (2015). Sedimentary evolution and persistence of open forests between the south-eastern Alpine fringe and the Northern Dinarides during the Last Glacial Maximum. *Palaeogeography, palaeoclimatology, palaeoecology*, 436, 23-40.
Nowaczyk, N. R., Liu, J., Plessen, B., Wegwerth, A., & Arz, H. W. (2021). A high-resolution paleosecular variation record for marine isotope stage 6 from Southeastern Black Sea sediments. *Journal of Geophysical Research: Solid Earth,* 126(3), e2020JB021350.
Obreht, I., Zeeden, C., Hambach, U., Veres, D., Marković, S. B., Bösken, J., ... & Lehmkuhl, F. (2016). Tracing the influence of Mediterranean climate on Southeastern Europe during the past 350,000 years. *Scientific Reports*, 6(1), 1-10.
Panin, N., & Popescu, I. (2007). The northwestern Black Sea: climatic and sea-level changes in the Late Quaternary. In *The Black Sea flood question: changes in coastline, climate, and human settlement* (pp. 387-404). Springer, Dordrecht.

Perissoratis, C., & Conispoliatis, N. (2003). The impacts of sea-level changes during latest Pleistocene and Holocene times on the morphology of the Ionian and Aegean seas (SE Alpine Europe). *Marine Geology*, 196(3-4), 145-156.

Puisségur, J. J. (1976). *Mollusques continentaux quaternaires de Bourgogne: significations stratigraphiques et climatiques, rapports avec d'autres faunes boréales de France* (No. 3). Diffusion, Doin.

Roberts, N. (1983). Age, palaeoenvironments, and climatic significance of late Pleistocene Konya Lake, Turkey. *Quaternary research*, 19(2), 154-171.

Ryan, W. B., Pitman III, W. C., Major, C. O., Shimkus, K., Moskalenko, V., Jones, G. A., Dimitrov, P., Gorür, N., Sakinç, M., Yüce, H. (1997). An abrupt drowning of the Black Sea shelf. *Marine geology*, 138(1-2), 119-126.

Rohling, E. J., Fenton, M. J. J. F., Jorissen, F. J., Bertrand, P., Ganssen, G., & Caulet, J. P. (1998). Magnitudes of sea-level lowstands of the past 500,000 years. *Nature*, 394(6689), 162-165.

Rohling, E. J., Foster, G. L., Grant, K. M., Marino, G., Roberts, A. P., Tamisiea, M. E., & Williams, F. (2014). Sea-level and deep-sea-temperature variability over the past 5.3 million years. *Nature*, 508(7497), 477-482.

Ronchi, L., Fontana, A., Correggiari, A., & Asioli, A. (2018). Late Quaternary incised and infilled landforms in the shelf of the northern Adriatic Sea (Italy). *Marine Geology*, 405, 47-67.

Sakellariou, D., Lykousis, V., Geraga, M., Rousakis, G., & Soukisian, T. (2017). Late Pleistocene environmental factors of the Aegean region (Aegean sea including the Hellenic Arc) and the identification of potential areas for seabed prehistoric sites and landscapes. *Submerged Landscapes of the European Continental Shelf: Quaternary Paleoenvironments*, 405-429.

Selley, R. C. (2005). *Encyclopedia of geology*. Elsevier acad. press.

Shackleton, N. (1967). Oxygen isotope analyses and Pleistocene temperatures re-assessed. *Nature*, 215(5096), 15-17.

Siddall, M., Rohling, E. J., Almogi-Labin, A., Hemleben, C., Meischner, D., Schmelzer, I., & Smeed, D. A. (2003). Sea-level fluctuations during the last glacial cycle. *Nature*, 423(6942), 853-858.

Smith, A. D., Taymaz, T., Oktay, F., Yuce, H., Alpar, B., Basaran, H., ... & Simsek, M. (1995). High-resolution seismic profiling in the Sea of Marmara (northwest Turkey): Late Quaternary sedimentation and sea-level changes. *Geological Society of America Bulletin*, 107(8), 923-936.

Sperling, M., Schmiedl, G., Hemleben, C., Emeis, K. C., Erlenkeuser, H., & Grootes, P. M. (2003). Black Sea impact on the formation of eastern Mediterranean sapropel S1? Evidence from the Marmara Sea. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 190, 9-21.

Spratt, R. M., & Lisiecki, L. E. (2016). A Late Pleistocene sea level stack. *Climate of the Past*, 12(4), 1079-1092.

Surić, M., Richards, D. A., Hoffmann, D. L., Tibljaš, D., & Juračić, M. (2009). Sea-level change during MIS 5a based on submerged speleothems from the eastern Adriatic Sea (Croatia). *Marine Geology*, 262(1-4), 62-67.

Surić, M., Bajo, P., Lončarić, R., Lončar, N., Drysdale, R.N., Hellstrom, J.C., Hua, Q. (2021). Speleothem Records of the Hydroclimate Variability throughout the Last Glacial Cycle from Manita peć Cave (Velebit Mountain, Croatia). *Geosciences*, 11(8), 347.

Tourloukis, V., & Karkanas, P. (2012). The Middle Pleistocene archaeological record of Greece and the role of the Aegean in hominin dispersals: new data and interpretations. *Quaternary Science Reviews*, 43, 1-15.

Van Andel, T. H., & Shackleton, J. C. (1982). Late Paleolithic and Mesolithic coastlines of Greece and the Aegean. *Journal of field archaeology*, 9(4), 445-454.

van de Velde, S. (2020). Mollusc species response to drivers in space and time: Rise and demise of the unique Pontocaspian fauna.

Wacha, L., Pavlaković, S. M., Novothny, Á., Crnjaković, M., & Frechen, M. (2011). Luminescence dating of Upper Pleistocene loess from the Island of Susak in Croatia. *Quaternary International*, 234(1-2), 50-61.

Wacha, L., Montanari, A., Lomax, J., Fiebig, M., Lüthgens, C., Korbar, T., & Koeberl, C. (2019). Last Glacial Maximum giant sand dunes on the island of Vis, Croatia. *Koeberl, C., Bice, DM (Eds.)*, 250, 459-470.

Wright, J. D. (2000). Global climate change in marine stable isotope records. In *Quaternary geochronology: Methods and applications* (pp. 671-682). American Geophysical Union.

Zavitsanou, A., Sakellariou, D., Rousakis, G., Georgiou, P., & Galanidou, N. (2016). Paleogeographic reconstruction of the Inner Ionian Sea during Late Pleistocene low sea level stands: preliminary results.
https://www.emodnet-bathymetry.eu/ (Last accessed July 20, 2021.)
https://land.copernicus.eu/pan-european/corine-land-cover/clc-2006?tab=mapview (Last accessed July 20,2021.)

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