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RESEARCH ARTICLE

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The eastern shores of the Baltic Sea in the Early Holocene according to natural and cultural relict data

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Exploration of the underwater landscape in Lithuanian waters, in the eastern part of the Baltic Sea, allowed identification of trees stumps in growth position, peat sediments, and traces of people that were living in the now flooded landscape. The exploration has been concentrated on localisation of the former Early Holocene coasts. Based on new data about sediment layers of the Preboreal–Atlantis I, palynological and dendrohronological analysis, identified vegetation species, and dating of wood and peat samples by radiocarbon methods the Baltic Sea water level dynamics during the stages Yoldia Sea–Early Litorina Sea could be identified. There are traces of the eroded coasts of the Yoldia Sea at a depth of 39–43 m, which were also observed at depths of 44 and 47 m. During the Ancylus Lake transgression, the RF-I lagoons and small lakes with the peat layer and the surrounding forests were submerged. The water level could have even risen to 10–9 m below present sea level. The water drop during the Ancylus Lake regression is evidenced by a peat layer dated to 9,150–8,520 cal BP, and similar radiocarbon dating of an oak stump. The changes of the species composition of trees are indicative of the noticeable climate changes during the period 11,410–7,900 cal BP. Litorina transgression is marked by a tree stump found at a depth of 14.5 m dated to 7,900–7,660 cal BP. The preference of the Early Holocene population to the coastal zone is evidenced by poles driven into the seabed (one was dated to 9,510–9,460 cal BP) that were detected at a depth of 11 m and the T-shaped antler axes dated to the Early Neolithic, washed ashore from the Litorina Sea coastal Stone Age settlements.

KEYWORDS
Baltic Sea level, fluctuation, Lithuania, Mesolithic, submerged coasts, underwater archaeology, underwater relict forests

1 | INTRODUCTION

In recent years, the history of the submerged eastern Baltic Sea has become an object of great archaeological and geological interest. Exploration has concentrated on the identification of former Early Holocene (Yoldia Sea, Lake Ancylus, and Early Litorina Sea stages on the Baltic Sea history) shores, the reconstruction of their underwater landscape, and the potential

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development of Mesolithic–Early Neolithic settlements along the Lithuanian coast (Gelumbauskaitė, 2009; Gelumbauskaitė & Šečkus, 2005; Girininkas, 2009; Rimkus, 2019; Žulkus & Girininkas, 2014).

The Underwater Research Centre of the Institute of Baltic Sea Region History and Archaeology at Klaipėda University has been exploring the Baltic Sea bed using remote sensing and direct research methods. Studies carried out in Lithuanian waters from 2002 to 2017 revealed the flooded landscape of the Early Holocene with relics of a forest in three areas (RF-I, RF-II, and RF-III). Surveys were made on the seabed with side scan sonar and multi-beam echo sounders to interpret the locations of relict trees, to make detailed bathymetric measurements, to identify underwater relict forest tree stumps and trunks, and to find the locations of in situ remains of humus or peat layers. A detailed image of the seabed relief was made to identify the former position of the Yoldia Sea. Tree-ring and pollen analysis, and radiocarbon dating on material gathered during underwater research were carried out in order to identify flooded Baltic Sea coastlines, their time of settlement, and fluctuations in the sea level (Žulkus, 2017; Žulkus & Girininkas, 2012; Žulkus et al., 2015).

2 | STUDY AREA

Recent investigations of underwater archaeology by the Underwater Research Centre of Klaipėda University supplied new data allowing us to reconstruct Baltic Sea relict coasts, fluctuations in the water level, the Early Holocene coastal landscape, and settlements. The relict coasts of the Baltic Sea have been explored in the western (Andrén et al., 2011; Berglund et al., 2005; Hansson et al., 2017) and southern (Harf & Meyer, 2011; Schmölcke et al., 2006; Uścinowicz et al., 2011) parts. Recent investigations of the underwater landscape in Lithuanian territorial waters were carried out in three zones (Figure 1) at Juodkrantė (RF-I), Melnragė (RF-II), and Klaipėda/Smiltynė (RF-III-1) and Klaipėda (RF-III-B, RF-III-C).

In the area RF-I (55° 31′000″–55° 31′500 N; 020° 57′400–021° 03′000 E), at depths of 15–30 m, the Baltic seabed is relatively flat and sandy. There were multiple 2–3 m high mounds, with hollows between them. Here, a peat layer found in situ showed the existence of wetlands, maybe small lakes, 4–5 km from the then coast. In some hollows, there are fewer forest relicts. Relict trees and peat bogs are preserved in an area of 8 km^2 at depths of 24–30 m. In the RF-I area, several groups of relict trees (RF-I-A–RF-I-H) are located within 0.25–2 km of each other. There are a few stumps and fallen trunks with exposed roots in each group. The remains of the trees in the individual groups were very close to each other. In the central part of the investigated area, at a depth of 29 m, peat layers were discovered in situ (RF-I-P, RF-I-P-2).

The remains of relict forests also exist in other underwater areas. Stumps were found at Klaipėda, 3 km from the shore at a depth of 14.5 m (55° 45′560 N; 021° 03′116 E) on the bottom with boulders (RF-II).

Three groups of stumps (RF-III) and a peat layer (RF-III-C-P1) were found at Klaipėda, 1.3 km from the shore at a depth of 11–12 m, in the flat sandy seabed. RF-III-1 is located at coordinates 55° 41′292 N, 021° 04′864 E; a group of tree stumps and the remains of five poles (RF-III-B) are located at coordinates 55° 43′511 N, 021° 04′444 E. The next group of tree stumps (RF-III-C) is found at the coordinates 55° 43′507 N, 021° 04′529 E (Girininkas & Žulkus, 2017; Žulkus et al., 2015).

The research data were published in Lithuanian (Bitinas et al., 2003; Girininkas & Žulkus, 2017; Žulkus, 2012; Žulkus & Girininkas, 2012) and foreign (Žulkus & Girininkas, 2014; Žulkus et al., 2015) scientific journals. The exploration of underwater landscapes in the submerged areas RF-I, RF-II-1, and RF-III-1 not only allowed us to determine specific formation patterns of the Baltic Sea coast and fluctuations in the water level, but also to identify the landscape of the historic coasts and changes in natural conditions that influenced patterns of life of the Mesolithic–Early Neolithic population.

3 | AVAILABLE DATA ON CHANGES IN THE WATER LEVEL OF THE EASTERN BALTIC SEA

According to the available scientific data, the formation of the coasts of the Baltic Sea and water level fluctuations in the eastern part of the Baltic Sea in the Early Holocene followed a very specific pattern. Settlements in the deltas of old rivers, bays, peninsulas, or straits, and their position in the western (Hansson, 2018; Jöns et al., 2007) and eastern (Girininkas & Žulkus, 2017) coastal zones of the Baltic Sea, were identical in their topography. The Early Holocene (Mesolithic) sites found in the southwest part of the Baltic Sea are at a depth of 5 m, in very rare cases at a depth of 10 m, below the present water level (Harf & Meyer, 2011; Jöns et al., 2007); whereas in western (southeast Sweden; Hansson, 2018) and eastern parts of the Baltic Sea (at the quondam River Danė mouth; Girininkas & Žulkus, 2017) they are found at a depth of 12 m. The present work, based on data from underwater archaeological, radiocarbon, dendrochronological, palynological, and sedimentological investigations conducted before 2017, is devoted to specifying Early Holocene fluctuations in the water level, coastal development, and population patterns in the eastern part of the Baltic Sea.

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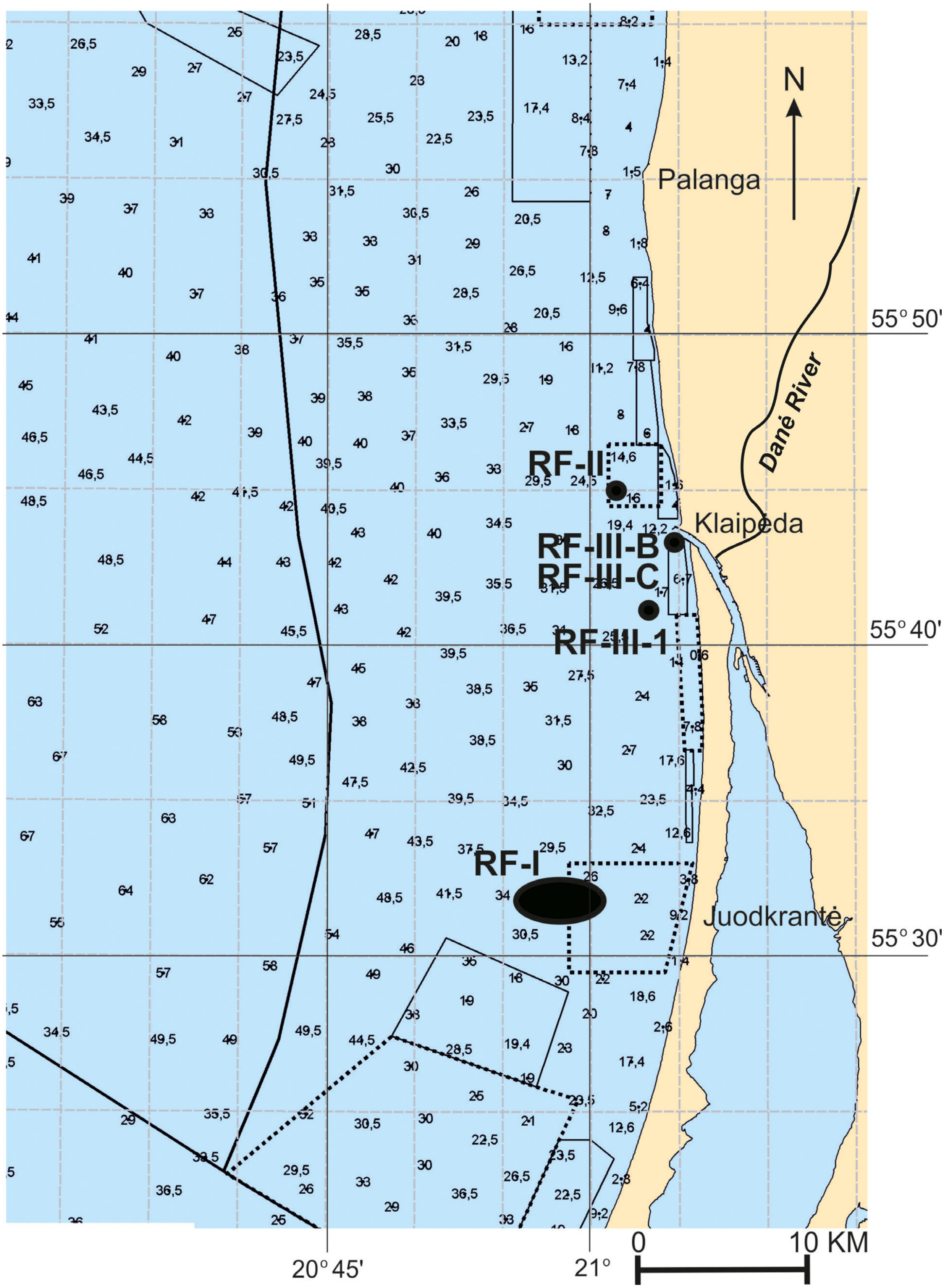

FIGURE 1 Investigation areas of underwater landscapes and archaeological sites (black circles and elipse) in Lithuanian territorial waters in the Baltic Sea: Juodkrantė (RF-I), Melnragė (RF-II), Klaipėda (Smiltynė; RF-III-1), and Klaipėda (RF-III-B, RF-III-C). The black lines indicate areas previously studied.

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At the beginning of the Preboreal, the transformation of the Baltic Ice Lake into the Yoldia Sea strongly influenced the evolution of the Baltic Sea coast. The first drainage of the Baltic Ice Lake took place at *c*. 13,000 cal BP in the Billingen uplands. Later, at the end of Younger Dryas, the waters of the Baltic Ice Lake again broke free in the Billingen uplands. The lake level then dropped 25 m, and the comparatively warm salty Atlantic water surged into the former glacial lake, gradually transforming it into the Yoldia Sea (Rosentau et al., 2017).

After the second break free into the Atlantic Ocean, the sea level dropped again. The shorelines of that period are found at depths of 40–50 m below present sea level (m b.s.l.), and even deeper (Björck, 1995; Björck et al., 2008; Damušytė, 2011; Gelumbauskaitė, 2009; Gelumbauskaitė & Šečkus, 2005; Kabailienė, 2006; Rosentau et al., 2017; Šečkus, 2009). This Baltic Ice Lake drainage marks the beginning of the Holocene.

During the Yoldia Sea stage, saline water entered from the Kattegat for about 200–350 years, through the narrow and shallow Strait of Närke (in middle Sweden) into the Baltic. The Yoldia Sea (11,700–10,700 cal BP) ended with the disappearance of the Middle Sweden Strait due to glacioisostatic rebound (Björck, 1995; Rosentau et al., 2017). The connection between the Yoldia Sea and the ocean ended. Lithuanian geologists assume that the fluctuations in the sea level on the Lithuanian coast coincide with the water level fluctuations on the northwest shores of the Baltic (Gelumbauskaitė & Šečkus, 2005). The Yoldia Sea regression reached its maximum at about 11,000–10,700 cal BP, and according to geoseismic data, the sea level on the Lithuanian coast could have been between 33 and 55 m b.s.l. (Gelumbauskaitė & Šečkus, 2005). In southeast Sweden, in the Hanö Bay, the remains of a submerged landscape can be found down to depths of almost 25 m b.s.l. The Yoldia lowstand reached its minimum level at 24–25 m b.s.l. just before 10,800 cal BP (Hansson et al., 2017). On the Lithuanian coast, several authors have studied and discussed the shorelines and displacement shore formations of the first phase of the Ancylus Lake (transgression) at –6 to –4 m b.s.l. (8,700–8,500 ^{14}C BP, about 9,750–9,550 cal BP) and the second (regression) at –35 to –43 m b.s.l. (8,000–7,800–7,450 ^{14}C BP, about 8,800–8,250 cal BP). The considerable drop in the water level on the Lithuanian coast during the Ancylus regression phase remains the most discussed question (Gelumbauskaitė, 2009).

In the territorial waters of Lithuania, even older pines, dated within the interval 11,410–11,060 cal BP, with roots ingrown in the seabed, were found by the northern edge of the Curonian Plateau at Juodkrantė (RF-I-E-I; RF-I-B-2; RF-I-B-5; Žulkus & Girininkas, 2012; Žulkus et al., 2015; Table 1). They are relicts of the sparse growth of trees during the Yoldia Sea lowstand in the first half of the Preboreal not far from the then seacoast.

The latest investigations of the peat layer (RF-I-P-2), dated 12,180–10,570 cal BP (Table 1), showed that the spectrum of spores and pollen is dominated by pine (*Pinus*) and birch (*Betula*). The pollen of deciduous trees (*Corylus*, *Quercus*, *Alnus*, *Ulmus*, *Populus*) is sparse (Žulkus & Girininkas, 2012; Žulkus et al., 2015). Spruce (*Picea*) is represented by isolated pollen. The content of pollen from grass in the sediment is low, and dominated by *Cyperaceae* and *Poaceae*. The developing dense deciduous forests often displaced these species of plant, ousting them from their habitats. This fact indicates a rather open landscape at the early stage of peat deposition. The presence of relict hydrophytic plants in sediments indicates the local conditions. It is obvious that the area of the lagoon had rather thick plant cover: *Menyanthes trifoliate* was growing in the shallow areas, and *Typhaceae* and *Polypodiaceaea* in wetter areas. True, the early Preboreal climate was rather cool, which is proven by the presence of megaspores of *Selaginela selaginoides* L, which thrived during the Dryas III (Žulkus et al., 2015). The palaeobotanical data allow us to assume that the sediment was deposited at the beginning of the Holocene, i.e., from the middle of the Preboreal until the transition stage from Preboreal to Boreal I.

It is interesting to note that there are other radiocarbon dates (Table 1) of peat (RF-I-P) obtained from the RF-I area which match the Ancylus Lake regression time, i.e., a time interval between 9,150–8,520 cal BP, when the water level in Ancylus Lake did not exceed 29–31 m b.s.l. (Girininkas & Žulkus, 2017; Žulkus et al., 2015).

At a depth of 29–31 m b.s.l., lagoons and small lakes were traced in the RF-I area parallel to the Ancylus Lake shore (Figure 2). The areas surrounding the lagoons were overgrown with sparse pine forests, whereas peat deposition took place within the small lakes. During diving, in one of the explored lagoons (RF-I-P-2), a peat layer up to 25 cm thick was found, which was deposited during a long time-span during the Ancylus Lake and at the very beginning of the Litorina Sea (Žulkus et al., 2015). It is not yet clear whether there is a hiatus. The formation of the lower part of the peat layer started at the end of the maximal Yoldia Sea regression and the beginning of the Ancylus Lake transgression. The deposition of the peat layer RF-I-P continued during the Ancylus Lake regression, and ended at the beginning of the early stage of the Litorina Sea (9,150–8,520 cal BP). At the time of the peat deposition, the lagoon lake was surrounded by sparse vegetation.

Diatomic analysis showed that these lagoons were isolated from the sea. *Fragilaria* diatoms were dominant among the epiphytic species of plants. Their dominance was closely associated with factors occurring when maritime coastal lagoons

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TABLE 1 Radiocarbon age of peats and relicts of trees from underwater landscapes in the submerged areas: RF-I, RF-II, and RF-III

No	Area	Material dated	Depth (m b.s.l.)	Lab ID	^{14}C age	cal BP (1 sigma)
1	RF-I-A	Pine	27	Vs-1372	9,160 ± 60	10,500–10,220
2	RF-I-C-1	Pine	24/25	Vs-2019	9,180 ± 110	10,670–10,170
3	RF-I-B	Pine	25	Vs-2018	9,170 ± 100	10,590–10,170
4	RF-I-B-5	Pine	25	Vs-2254	9,555 ± 100	11,190–10,640
5	RF-I-C-3	Pine	24/25	Vs-2255	9,300 ± 90	10,710–10,250
6	RF-I-E-1	Pine	29/30	Vs-2257	9,770 ± 95	11,410–10,760
7	RF-I-B-2	Pine	25	Vs-2272	9,685 ± 65	11,240–11,060
8	RF-I-B-4	Pine	25	Vs-2273	9,410 ± 95	10,890–10,370
9	RF-I-P (RF-I-X)	Peat	29	Vs-2275	7,970 ± 125	9,150–8,520
10	RF-I-P-2	Peat	29	Vs-2634	9,860 ± 250	12,180–10,570
11	RF-III-B-1	Pine pile (probabl.fishing weir)	11	Vs-2746	8,450 ± 40	9,510–9,460
12	RF-III-B-2	Pine (?)	11	Vs-2747	8,505 ± 60	9,530–9,480
13	RF-I-I(2)	Oak the inner part of the tree	25	Vs-2749	8,035 ± 50	9,000–8,800
14	RF-I-I(2)	Oak the outer part of the tree	25	Vs-2750	7,995 ± 55	8,970–8,760
15	RF-III-C-2	Pine	12	Vs-2759	8,435 ± 40	9,500–9,450
16	RF-III-C-1	Pine in peat	12	Vs-2760	8,580 ± 40	9,560–9,530
17	RF-III-C-P1	Peat	12	Vs-2761	8,205 ± 40	9,240–9,090
18	RF-III-C-P1	Peat	12	Vs-2762	8,240 ± 40	9,280–9,150
19	RF-II-1	Pine	14,5	Vs-1388	6,930 ± 130	7,900–7,660
20	RF-III-1	Pine	11	Vs-1765	8,560 ± 80	9,630–9,500

Note. The ^{14}C data were calibrated using the OxCal 4.3 program (Bronk Ramsey, 2017) with the IntCal13 atmospheric curve (Reimer et al., 2013). The outer parts of the trees were mainly sampled for ^{14}C dating. The dates 1–10 have been published (Žulkus et al., 2015).

transformed into maritime coastal lakes. Evidently, the lagoon identified in the RF-I area formed during the transitory stage, i.e., the Yoldia Sea regression and the Ancylus Lake transgression (Žulkus et al., 2015).

4 | NEW DATA ON CHANGES IN THE WATER LEVEL OF THE EASTERN BALTIC SEA AFTER RESEARCH

Below follows new data on the coastal evolution and changes in natural conditions in the eastern part of the Baltic Sea, obtained by exploration of the RF-I area of the Baltic Sea at Juodkrantė.

There is a question about the boundaries of the Yoldia Sea. Exploration using side scan sonar showed small terraces on the seabed at a depth of 29–30 m. They are traces of eroded coasts. In 2010, 15–15.5 km from the recent coast, relict formations of the present coast were discovered on the western edge of the RF-I area. In a vertical sector at a depth of 37–39 m, an unusual underwater relief (Figure 3) reflected in the side scan sonar images. Apparently, it represents the remnants of the eroded coast. The remnants were discovered in a sector stretching from north to south (020° 53′848 E and 020° 52′500 E sailing from east to west). Traces of eroded terraces were detected at a depth of 39 m. A low unbroken underwater terrace, stretching from north to south, was discovered further to the west (into the sea) at a depth of 43 m. Underwater ridges and small terraces, looking like formations of eroded coasts, were also observed at depths of 44 and 47 m. In 2012, an attempt was made to explore the unusual relief under the water. The diving coordinates were 55° 31′557 N, 20° 53′537 E. The depth at this point is 38 m. The bed is composed of sand. It is even, without any formations resembling those detected by sonar. It is obvious that the irregularities in relief detected by the sonar are quite far removed from each other. Therefore, larger areas should be explored in the future. According to the data obtained, the ancient boundary of the Yoldia Sea was situated northwest of the explored RF-I area, and was eroded during the Ancylus Lake transgression.

Ancylus Lake existed until 9,800 cal BP. For 1,000 years, i.e., 10,300–9,000 cal BP, the surplus water from Ancylus Lake drained into the ocean through the River Dana, which carved its channel through the Darss Sill and Store Belt

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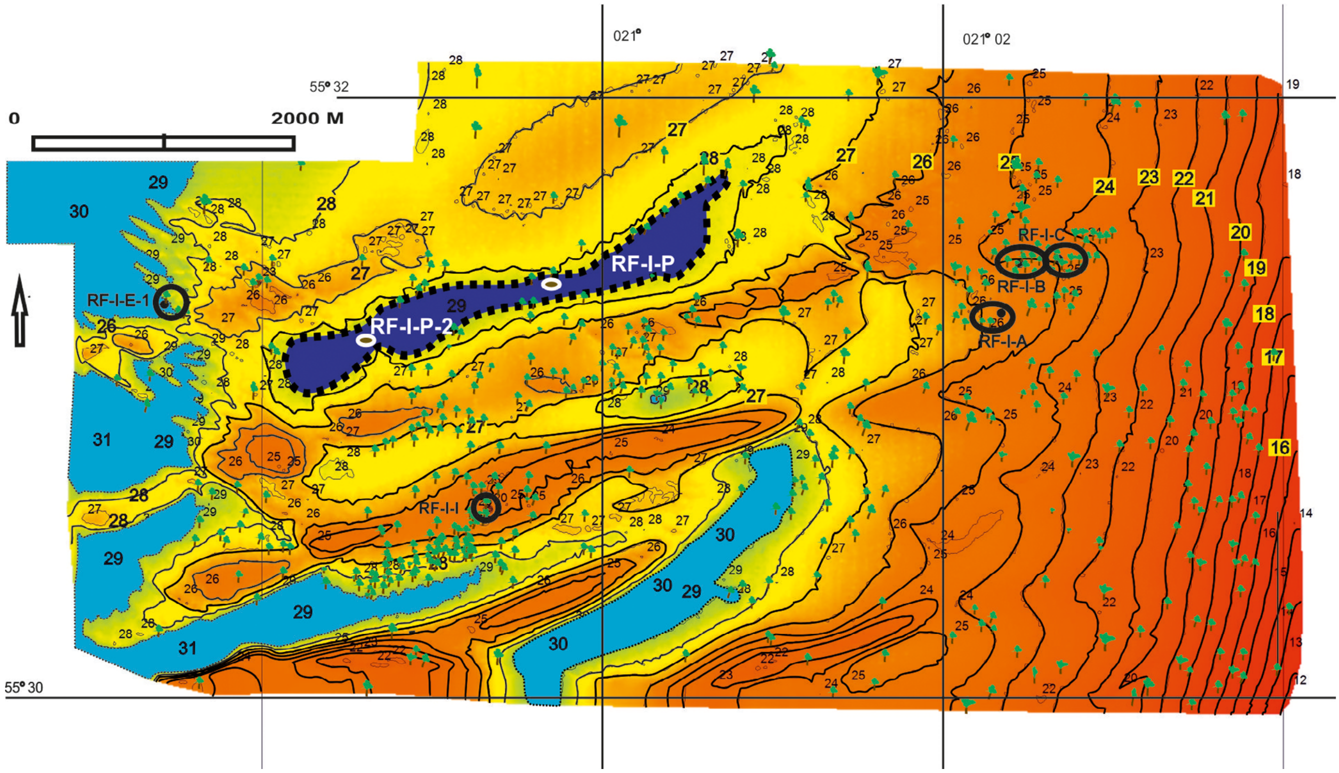

FIGURE 2 The seabed relief in the RF-I area. RF-I-A, RF-I-B, RF-I-C, RF-I-E-1, RF-I-I: investigated relict tree groups. RF-I-P, RF-I-P-2: peat sampling points. Surveys were made on the seabed with side scan sonar and multi-beam echo sounders. Depths highlighted in blue are below 29 m b.s.l. (after Žulkus et al., 2015).

hydrographic thresholds, until the final erosion of its banks. At that time, the Øresund Sound sank, and together with the Store Belt threshold, connected Ancylus Lake with the Atlantic Ocean (Björck et al., 2008; Lemke et al., 2001).

During the Littorina transgression, the RF-I lagoon, together with the peat layer and the surrounding forests, was submerged. The water level could have risen from 29 to 31 m b.s.l. and even to 10–9 m b.s.l. This is proven by the remnants of a probable fishing weir in the then mouth of the River Danė found at a depth of 11 m b.s.l. in the RF-III-B-1 area and dated to 9,510–9,460 cal BP. At the time under consideration, the fishing weirs were usually placed at a depth of no less than 1–2 m (Fischer, 2018b), implying that the then water level was 10–9 m b.s.l. The slowly rising water could have submerged the trees (remnants dated to 9,530–9,480 cal BP) growing on the banks. The rising water at the mouth of the Danė created short-lasting conditions for the formation of peat (dated to 9,240–9,090 cal BP; Table 1). The possible negligible fluctuations in water level within an interval of 2–3 m are suggested by several stumps with ingrown roots in the seabed found 3 km from the recent sea shore in the exploration area RF-II-1 near Melnragė at a depth of 14.5 m. They are dated to 7,900–7,660 cal BP, being almost contemporary with the ancient trees growing in the exploration area RF-III, dated to 9,630–9,500 cal BP. The fluctuations in the depths with discovered tree stumps are recorded by geological investigations (Gelumbauskaitė, 2009). An analogous fluctuation curve for Baltic Sea water at the Hanö submarine settlement by Swedish scientists was also obtained (Nilsson et al., 2018).

It is interesting to note that a similar fishing weir to that in the exploration area RF-III-B, dated to 9,510–9,460 cal BP and matching the artefacts of the then population, was found at a depth of 6–12 m b.s.l. in the Haväng Settlement near the mouth of the River Verkeån, which existed in Hanö Bay in the southeast of Sweden (Fischer, 2018a, 2018b; Hansson, 2018; Nilsson et al., 2018). The natural conditions in the underwater landscape are identical to the historic mouth of the Danė near Klaipėda.

The rapid drop in water to 29 m b.s.l. is evidenced by a peat layer, formed at a depth of 29 m b.s.l. and dated to 9,150–8,520 cal BP, and a similar radiocarbon date of an oak stump, found in the RF-I area (in the same lagoon in the western part of which peat from the time of the Ancylus Lake regression was recorded; Girininkas & Žulkus, 2017; Figure 4). These dates and the changes of the composition of species of trees indicate noticeable changes in the climate between about 9,000 and about 7,700 BP, when mixed forests, including oak woods, started to grow on the coast. Similar

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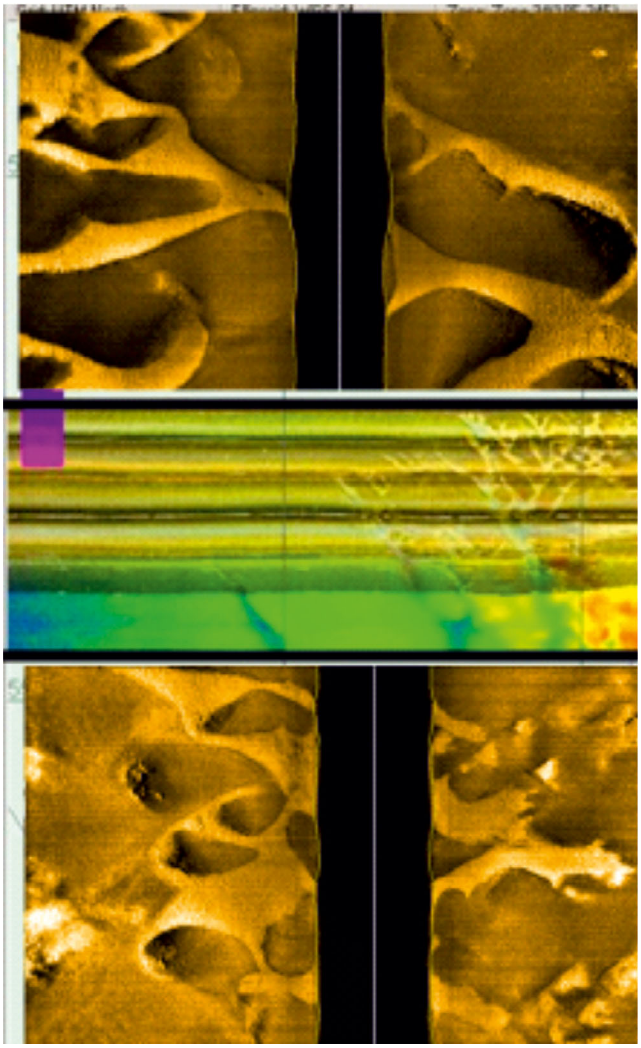

FIGURE 3 An underwater relief reflected by side scan sonar on the western edge of the explored area RF-I at a depth of 37–39 m (expected traces of the Yoldia Sea coast).

changes were recorded in the underwater settlements in the southwest part of the Baltic Sea (Lübke et al., 2011). At the end of the Boreal, the pine forests in the western part of Lithuania were supplanted by alder (*Alnus*) gaining dominance in the peatbog environment (Kabailienė, 2006). The palynological analysis of peat samples taken from the RF-I-P area (dated from about 10,090 cal BP to about 8,850 cal BP) supports this assumption (Žulkus & Girininkas, 2012).

The underwater archaeological exploration of the RF-I area shows that the formation of peat started 9,150–8,520 cal BP. It seems the first transgression of the early stage of the Litorina Sea took place some time later, because the time-span of 200 years was too short for the formation of the 20 cm thick peat layer. The first transgression of the early stage of the Litorina Sea, within the limits of minor error, could be the one indicated by L.Ž. Gelumbauskaitė. Moreover, the stumps discovered in the Bay of Gdansk at a depth of 16–17 m b.s.l. and dated to 9,020–8,600 cal BP also evidence the low water level of the Baltic Sea during the formation of peat in the RF-I area (Uścinowicz et al., 2011).

5 | THE ARCHAEOLOGICAL RECORD

No Early Mesolithic or Early Neolithic (Yoldia Sea and Litorina Sea stages) settlements have been discovered in the east Baltic coastal section between the Gulf of Riga and the mouth of the River Vistula. There is a question as to their possible locations. According to data from archaeological explorations, the Early Mesolithic settlements in the territory of Lithuania are found 50–80 km from the recent coast of the Baltic Sea, i.e., in the Žemaičiai Upland (Girininkas, 2009; Ostrauskas, 1996). In Latvia, such settlements are situated between Daugava and Lielupė, about 25–50 km (Zvejnieki II settlement)

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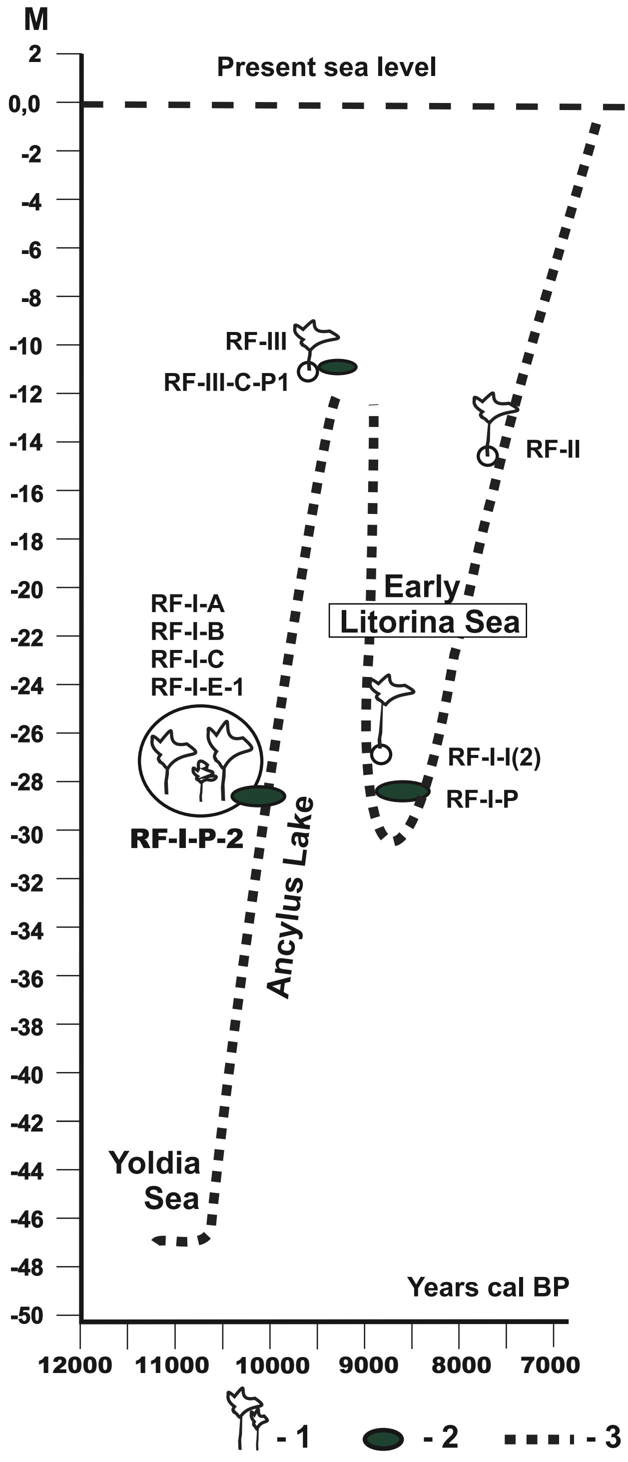

FIGURE 4 A reconstruction of the fluctuation of the water level of the Baltic Sea basin during the Early Holocene (after Girininkas & Žulkus, 2017, with additions). Legend: 1 – submerged forest; 2 – peat layers; 3 – relative sea level curve.

from the recent coast. No such settlements have been found in the territory of the Kaliningrad Region and the coastal zone of the Polish Gdansk Bay. Recently, an attempt has been made by Polish archaeologists exploring the settlements of Bay Coast culture to prove the existence of Early Neolithic or transitory Late Mesolithic/Neolithic settlements dated to 5,570 ± 40 cal BP (Kabaciński et al., 2011; Król, 2015; Ruta, 1997).

Lithuanian archaeologists regard these dates as belonging to the beginning of the Middle Neolithic. Why do Polish archaeologists date these settlements to the Mesolithic or Early Neolithic? They believe, despite the fact that these settlements yielded ceramic artefacts but no attributes of economic activity, they belong to the Late Mesolithic or transitory period Mesolithic/Neolithic. Following this pattern of economic and chronological Early Holocene evolution, the Middle Neolithic Šventoji settlements in the Lithuanian coastal area should also be dated to the Late Mesolithic or Early Neolithic because traces of economic activity in them, as distinct from eastern Lithuania, are sparse, or absent altogether (Girininkas & Daugnora, 2015). Polish (Król, 2015), Lithuanian (Piličiauskas, 2016; Piličiauskas et al., 2017), and Danish (Andersen, 1995; Zvelebil, 1998) archaeologists do not take into consideration some specific features of the economic activity of the Baltic coastal population. The most important of them is the cost-effectiveness of the hunter-gatherer (southwest and southeast Baltic) economy in the Early and Middle Neolithic, due to the ecological effect of the coastal zone. Hunters and gatherers would trade seal, fish, amber, etc. for items of the production economy. A similar ecological-economic situation in the Baltic coastal zone presumably also existed in the Early Mesolithic and Early Neolithic. For this reason, the settlements of the Bay of Gdansk mentioned by Polish researchers should be dated to the beginning of the Middle Neolithic. The conclusion may be drawn that settlements on the edge of the Bay of Gdansk cannot be identified as Early Mesolithic or Early Neolithic (Kabaciński, 2001).

Middle and Late Mesolithic settlements were uncovered not far from the recent Baltic Sea coast (Bērziņš, 2000, 2004; Domańska, 1992; Grigaliūnas, 2013; Kabaciński et al., 2008). These settlements were associated with the slow transgression of the early stage of the Litorina Sea (Figure 4), and are found closer to the present Baltic Sea coast. Early Mesolithic and Early Neolithic settlements have so far not been found near the present southeast Baltic Sea coast. Where are they?

In the present coastal stretch of the Baltic Sea, when the water level was more than 30 m b.s.l., living conditions were not bad, but from an economic point of view, considerably worse than the ones in the coastal territories of the Yoldia Sea and Ancylus Lake. For the Early Mesolithic population, the ecological economic niche of coasts was of great importance. It strongly influenced the hunter-gatherer economy. The coastal stretch of the Yoldia Sea was rich in lagoons and bays with inflowing rivers. The conditions for hunting, gathering, and fishing to prosper were especially good. At that time, the first seals appeared in the brackish waters of the Baltic Sea (Schmölcke, 2008, 2013). When the water level dropped, most of the Early Mesolithic population moved from the Baltic Ice Lake coast to the Yoldia Sea coast, which today are 29–30 m b.s.l.

The preference of the Early Holocene population for the coastal zone, or the coastal ecological-economic niche, is evidenced by poles driven into the seabed, which were presumably designed as fishing equipment. Poles (one pile was dated to 9,510–9,460 cal BP) were detected in 2017 at a depth of 11 m b.s.l. in the exploration area RF-III-B-1. This underwater object is one of the most ancient man-made objects found in the underwater sections of the historic coast of the Baltic Sea. The fishing weir found in the Haväng Settlement near the mouth of the River Verkeån, which existed in Hanö Bay in southeast Sweden, was dated to 8,500–8,400 cal BP and 9,100–8,800 cal BP (Fischer, 2018a; Hansson et al., 2018). The natural conditions of the underwater landscape of this settlement are identical to the ones in the then mouth of the River Danė.

Presumably, a similar ecological and economic situation in southeast Baltic territory also existed in the Early Neolithic. Early Neolithic settlements are also absent in the coastal stretch of the present Baltic Sea (Bērziņš, 2008; Rimantienė, 2005). Today, they would be submerged by the Baltic Sea, because between the first and the second transgression stages of the Litorina Sea, the coastline was situated further to the west, which is proven by the tree stump found in the exploration area RF-II and dated to the Late Mesolithic–Early Neolithic; 7,900–7,660 cal BP. Apparently, the T-shaped axes and osteological material (Figure 5) dated to the Early Neolithic (7,167–6,966 cal BP, KIA-53036) were washed ashore by the Baltic Sea from coastal Stone Age settlements of the Litorina Sea.

6 | DISCUSSION

The recent investigations by the Underwater Research Centre of Klaipėda University have supplied new data for the reconstruction of Baltic Sea relict shores, fluctuations in the water level, and the Early Holocene coastal landscape and settlements. The new data are open to more than one interpretation, and leaves some unanswered questions.

First, we should point out the striking preservation of pine forests on the seabed at a depth of 24–30 m. This circumstance is exclusive. Submerged tree stumps are fairly common in Swedish, German, Danish, and Polish waters, but they mostly represent only stray finds (Rosentau et al., 2017). Mass assemblages of stumps and stems of relict forest have not been found anywhere in the Baltic Sea, except in Lithuanian and Swedish (Hansson, 2018) territorial waters. While discussing the circumstances of the relict forest preservation in the exploration area RF-I, it is important to remember that the exploration was conducted in a comparatively small area on the northern edge of the large Curonian Plateau. What possibilities can be suggested by future investigations?

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FIGURE 5 A T-shaped antler axe dated to the Early Neolithic, which was washed ashore in the Baltic Sea from Litorina Sea coastal Stone Age settlements north of Klaipėda (photograph Algirdas Girininkas).

As has been mentioned, all the pine trunks detected so far, broken or rooted out, are oriented west-east perpendicular to the present coast. According to research carried out in 2011 and 2012, their roots are exposed to the west (Žulkus & Girininkas, 2012). During hurricanes in the Baltic Sea, pines in the coastal zone are rooted out in the same way they were rooted out in the explored underwater area, i.e., from west to east. Recent storm waves also erode the coast and root out pines, but they are never oriented in one direction. The idea of the instant demise of the forest is not supported by the available data from dendrochronological analysis. The dates of the flattening of four relict pines in the RF-I area differ from each other by 32 years (Žulkus & Girininkas, 2012). Perhaps some trees survived even after submergence until the next natural cataclysm. A certain time-span passed between the flattening and the full immersion of the trees. The time-span was too short for the pines to rot,[1] but sufficiently long for their saturation with water and sinking when the specific gravity of pine (863 kg L^{-1} m^{-3}) exceeded the specific gravity of water. It is strange that the heads of pines have so far not been detected; only the broken stumps with roots. In addition, while analysing the circumstances of the submergence of the forest under consideration, we should bear in mind the orientation of the relict trunks. One possible conclusion is that the forest area was later again, and maybe several times, devastated by some kind of natural cataclysm, and submerged again during a transgression.

Could it be a tsunami? Varve analysis of the last few decades allows us to make this assumption. The Swedish researcher Nils-Axell Mörner has presented data about strong post-glacial seismic activity in Scandinavia, and registered traces of 17 ancient earthquakes. These earthquakes generated tsunami waves as high as 20 m. The dates of the registered earthquakes, 11,600, 11,200, 10,430, 10,400, 9,663, 9,428, 9,291 varve-years BP (Mörner, 2008; Mörner & Dawson, 2011), are within the same calibrated ^{14}C dating interval of the relict forest in the RF-I area (Table 1). In the author's opinion, the earthquakes on the northeast coast of Sweden, and the waves generated by them, could have reached the shores of the gulfs of Bothnia and Finland. The east and southeast shores of the Baltic Sea have not been investigated from this respect, but the mentioned factor cannot be ignored.

The speed of the rise of the water level during the Ancylus Lake transgression remains under discussion. How long did the lowest water body last? What were the rates of the rise in the water level during the second Ancylus Lake transgression? Was the rise even or sporadic? The known answers to these questions are different. The circumstance that so many relict trees have been preserved in situ at Juodkrantė, but the remnants of eroded coasts at a depth of 24–30 m are very few, indicates a rapid rise in the water level.

How long did this forest grow? The forest relicts in the exploration area cover a period of about a 1,000 years (Table 1). Presumably, this is associated with the Ancylus Lake transgression and the beginning of the Litorina transgression. The underwater pine forest explored was comparatively young. The biological ages of the discovered trees are 103, 117, 121, and 138 years. The rotten trees on the seabed visually accounted for a small part of the stumps and trunks, which implies the comparatively "young" age of the forest. A more accurate age of the relict forest on the Curonian Plateau could be determined based on additional and more precise ^{14}C and biological age data.

Are the coastal formations 15–15.5 km from the coast at a depth of 37 m the oldest relict coasts of the lowest stand of the Baltic Sea? What are the precise dates of their existence? Our data support the opinion that the lowest water stand of

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the Yoldia Sea was 50 m b.s.l. True, precise dates of the Yoldia Sea shore in Lithuanian territorial waters have not yet been suggested. We have also so far failed to specify them.

The discovery of the Yoldia Sea shore and the data from the offshore sediment analysis are important for establishing the salinity of the water of the Yoldia Sea in its eastern part. The proposition that the water in the eastern part of the Yoldia Sea was fresh, or of very low salinity, due to the short existence of this stage (Vaikutienė, 2004), based on the fact that freshwater diatoms were detected at a depth of 35 m, may be incorrect. We know that at the time under consideration, this area was not submerged, and represented the coast. The coast was situated more than 5 km further to the west. True, the analysed diatoms from a depth of 35 m may have belonged to freshwater lakes, which are not dated but are believed to have belonged to the Ancylus Lake shores. The salty water of the Yoldia Sea could be evidenced by changes in the seal population. During the Yoldia Sea and Ancylus Lake stages, the Baltic Sea was inhabited only by *Phoca hispida* seals. Other species, grey seals (*Halichoerus grypus*) and harbour seals (*Phoca vitulina*), appeared with the first Litorina Sea transgression. Seals of the latter species were found in the settlements of Šventoji, which date back to the Middle Neolithic period (Girininkas & Daugnora, 2015).

The well preserved relict forest in the RF-I area implies that since the flooding of these trees, the water level in this area has never dropped below 24 m b.s.l. Otherwise, the pine trunks and stumps would have been destroyed, or covered with younger sediment. But this has not happened. Pine stumps were found in RF-I at the same depth as the peat found in RF-I-P-2 deposited during the Ancylus Lake regression. Slightly to the east in RF-I-P, a 20 cm thick peat layer was deposited between the Ancylus Lake regression and the Early Litorina Sea transgression (Figure 4). How long did it last? The drop in water level during the Ancylus Lake regression could be determined after dating the furthest east (closer to the shore) trunks and stumps of the relict forest (RF-I area). The dates of isolated stumps found in other places, 1.3 km from the shore near Smiltynė at a depth of 11 m (RF-III-1), and 3 km from the shore near Melnragė (RF-II-1) at a depth of 14.5 m, are respectively 9,630–9,500 cal BP and 7,900–7,660 cal BP (Table 1). The first date correlates with the beginning of the early stage of the Litorina Sea, whereas the second date correlates with the maximal water stand during the Litorina Sea transgression.

Discussions about changes in water level often concentrate on submerged or elevated coasts. It is known that tectonic movements on the Baltic shores are rather variable. In our opinion, the reference point for fluctuations of the water level in the Baltic Sea should be the water level instead of the shores. Establishing absolute water levels and their dates is problematic because sedimentation is sometimes very patchy in the Baltic Sea, thus sediment cores recoved very closely can be tricky to correlate. Considerably narrower data could be expected from dating cultural layers and relict trees instead of geological layers. These trees could provide benchmark dates, which would serve as a basis for establishing fluctuations in the water level of the Baltic Sea from the stage of the Baltic Ice Lake.

The large explored area of the seabed in the RF-I area is situated on the northern edge of the Curonian Plateau. A reconstruction of the relict Ancylus Lake shore is possible based on the radiocarbon, palynological, and dendrochronological analysis of relict trees and peat taken at a depth of 25–30 m b.s.l.

How is this time-span interpreted by geologists, and where is our data at variance with the geological data? Some Lithuanian geologists maintain that during the Ancylus transgression period the explored Ancylus Lake shore existed again as dry land (Gelumbauskaitė, 2009). Other geologists assume that the relict dry coast also existed in the time-span at the end of the Ancylus and the beginning of the Litorina transgression (8,000–7,600 cal BP; Damušytė, 2011). We believe that the flattened relict shore forest of the Ancylus Lake stage stayed submerged from 12,180–10,570 cal BP to 9,150–8,520 cal BP, when, in the early stage of the Litorina Sea with a low water level, peat formation processes resumed in the lagoon lakes (RF-I-P area). At that time, Early Litorina Sea sediments might have buried and preserved the Ancylus coastal forest. The peat formation process in RF-I-P was rather short, and lasted up to 300 years. Later, the lagoon was submerged by the early Litorina Sea transgression. The submersion was not sudden. The slow early Litorina Sea transgression left time for the development of forest vegetation along the rising coast. This is proven by radiocarbon dating (about 9,000–8,760 cal BP) of the oak found in the RF-I area (here the average of two dates is taken, Table 1).

Later, after 7,900–7,660 cal BP (RF-II-1), the water never dropped below the RF-I lagoon 29 m b.s.l., which, presumably, allowed the preservation of the relict forest. In the area RF-III, that is, at the very end of the Ancylus Lake transgression and the beginning of the early stage of the Litorina Sea, the transgression was short, and could have lasted for 350–250 years. The obtained investigation data, although at variance with the data of Lithuanian geologists on relative fluctuations in water level, are very important for palaeogeographical conclusions, and for planning further marine geological and underwater archaeological investigations.

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7 | INVESTIGATION PROSPECTS

The relict forest explored on the seabed near Juodkrantė (RF-I) represents only part of the landscape that developed on the Curonian Plateau during the Yoldia–Ancylus period. It is not known how many pieces of this landscape have been preserved. It is also unclear whether elements of the relict landscape have been preserved at depths shallower than 16–15 m.

In 2017, using a multi-beam echo sounder, around 150 km^2 of the seabed southwest of the exploration area RF-I on the northern edge of the Curonian Plateau was scanned. The scanning was conducted in order to evaluate the possibility for dredging sand for the replenishment of beaches. The seabed in this area contains relict coast formations similar to the ones discovered in the RF-I area: flat coastal hills and remnants of possibly relict small lagoons and lake lets (Figure 6). The underwater northern slope of the plateau is steep, plunging from 20 m to almost 50 m in depth. This area may be suitable for searching for ancient relicts of the Baltic Sea.

The establishment of the Ancylus–Litorina hydrographic framework could facilitate the search for prehistoric settlements. Due to the presumed presence of the ancient River Minija delta in this area (Damušytė, 2011), the exploration of the seabed north of the underwater Curonian Plateau near Juodkrantė is promising.

According to A. Damušytė (Damušytė, 2011), the delta of the River Danė during the first Litorina Sea transgression might have existed in the submerged area (now the seabed) at Smiltynė. Its precise place is yet not clear. In our opinion, the ancient River Danė channel should be searched for between the relict forest (11 m b.s.l.) in the RF-III-1 area, where one of the stumps was dated to 9,630–9,500 cal BP, and trees found at the same depth but in other areas at the same depth (RF-III-B and RF-III-C). The remnants of a probable fishing weir found in this area and dated to 9,510–9,460 cal BP could imply that the old channel of the River Danė may have been in the environment of the southern jetty of Klaipėda port. Judging from the results of investigations in 2017 (Žulkus, 2017), elements of the relict landscape may be present between RF-III-1 and RF-III-B-C spaced about 5 km from each other. A tree stump dated to 7,900–7,660 cal BP was detected about 6 km north of the entrance channel to Klaipėda port, at a depth of 14.5 m (RF-II-1). It seems that more remnants of relict trees have been preserved in the stony seabed (Žulkus, 2003).

One more area, near Palanga, is promising for exploration. In this area, seabed formations resembling the ones recorded in the RF-I area were visually observed. The area is situated near the mouth of the small Rąžė stream, where a Stone Age settlement of Narva culture was found (Girininkas, 2011). A detailed exploration of the underwater polygon would perhaps reveal so far unknown elements of the relict landscape.

Possible submerged Stone Age settlements were searched for along the River Šventoji. In 2009, side scan sonar produced an image of the bottom in the external harbourage of Šventoji port. Bathymetric measuring was conducted in an area

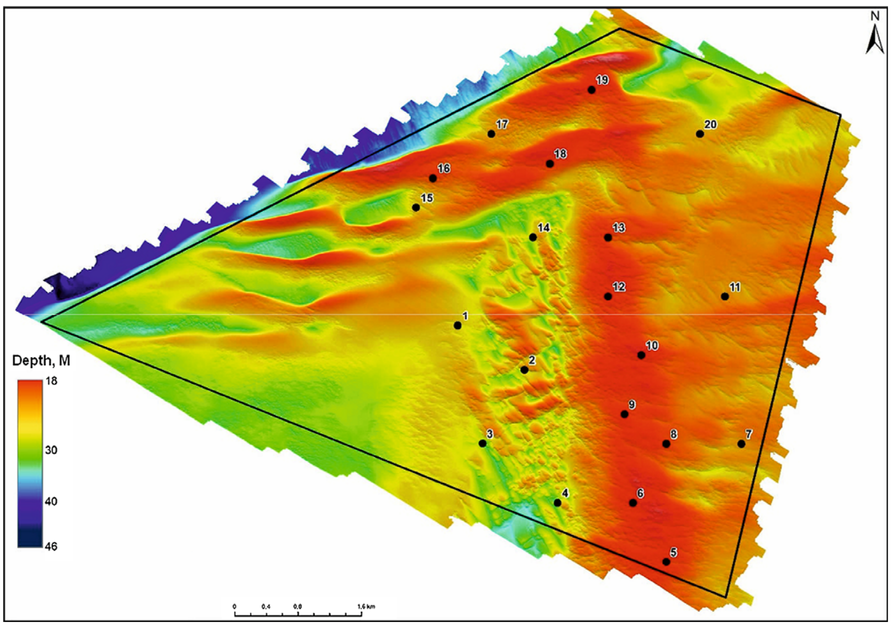

FIGURE 6 The area of dredging sand contains relict coast formations analogous to the ones discovered in the RF-I area. The dots represent sand sampling points (Public Institution Coastal Research and Planning Institute, 2017, fig. 3.4.3.).

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of over 52 km^2. The investigations revealed interesting elements of eroded relict coasts at a depth of 8–20 m. However, traces of the ancient Šventoji channel and oxbow lakes were not detected (Žulkus, 2013). In our opinion, it would be expedient to explore the bottom at a depth of over 20 m.

Is it possible to date the relict forest using the dendrochronological method? At present, the derivative scale of the RF-I relict forest pine embraces only 139 years (Žulkus & Girininkas, 2012). Further investigations, as expected, will considerably extend the scale, but its correlation with absolute dates would remain very complicated. There are no analogous scales of absolute dates in the East European region. The absolute dendrochronological pine scale, including the whole Holocene (from 11,590 BP) and 820 years of the Older Dryas, which was created in Germany (Friedrich, et al., 2004), and the dendrochronologically sampled trees from Haväng (Hansson, 2018), could possibly be used for the precise dating of the RF-I relict forest. A sufficient number of examples of well preserved relict pines would allow for the creation of arbitrary dendroscales, integrating them into the available Europe Holocene absolute scales and determining the precise dates of relict forests. The 50 cm diameter oak trunk discovered in the RF-I area encourages further investigation for the creation of oak dendroscales.

8 | CONCLUSIONS

The exploration of flooded landscape regions in Lithuanian waters, the eastern part of the Baltic Sea, has allowed for the identification of tree stumps, mainly pine (*Pinus sylvestris*) and oak (*Quercus*) in growth position (in situ), peat sediments, and traces of people that were living in the now flooded landscape. Based on *new* data about sediment layers of the Preboreal–Atlantis I, palynological and dendrohronological analysis, vegetation species identified, and the dating of wood and peat samples by radiocarbon method, enabled the identification of the water level dynamics of the Baltic Sea during the Yoldia Sea–Early Litorina Sea stages.

During diving in one of the explored relict lakes (RF-I-P-2), a peat layer was found which was deposited over a long time-span. The formation of the lower part of the peat layer started at the end of the maximal Yoldia Sea regression and the beginning of the Ancylus Lake transgression. The deposition of the peat layer continued during the Ancylus Lake regression, and ended at the beginning of the early stage of the Litorina Sea.

According to the data obtained, the ancient boundary of the Yoldia Sea was situated northwest of the explored area RF-I, and was eroded during the Ancylus Lake transgression. They are traces of eroded shores at a depth of 39–43 m. Underwater ridges and small terraces, resembling formations of eroded coasts, were also observed at depths of 44 and 47 m.

During the Ancylus Lake transgression, the RF-I lagoons and small lakes, together with the peat layer and the surrounding forests, were submerged. The water level could even have risen to 10–9 m b.s.l. This is proven by the remnants of trees and peat formation found at a depth of 11 m b.s.l. in the then mouth of the River Danė (RF-III-B and RF-III-C area) and dated to 9,560–9,090 cal BP.

The rapid water drop to 29 m b.s.l. is evidenced by a peat layer formed at a depth of 29 m b.s.l. and dated to 9,150–8,520 cal BP, and a similar radiocarbon date of an oak stump. These dates and the changes of the composition of species of trees indicate noticeable climate changes between about 10,200 and about 8,500 cal BP.

The Litorina transgression is marked by a tree stump found in the exploration area RF-II-1 near Melnragė, at a depth of 14.5 m, dated to 7,900–7,660 cal BP.

The preference of the Early Holocene population for the coastal zone, or the so-called coastal ecological-economic niche, is evidenced by poles driven into the seabed at a depth of 11 m b.s.l. in the exploration area RF-III-B-1, which were presumably designed as fishing equipment. One pole is dated to 9,510–9,460 cal BP. Apparently, the T-shaped antler axes (Figure 5) dated to the Early Neolithic (7,167–6,966 cal BP, KIA-53036) were washed ashore by the Baltic Sea from Litorina Sea coastal Stone Age settlements.

This area near Klaipėda is promising for exploration. It appears that more remnants of relict trees and ancient man-made objects may be preserved in the seabed.

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DATA AVAILABILITY STATEMENT

Not provided.

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ENDNOTE

[1] In colder climates, the rotting process of pine timber takes time. The climate at the time of the existence of the relict forest under consideration was rather cool (Stančikaitė 2004).

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