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The fluvial landscape of lower Mesopotamia: an overview of geomorphology and human impact

IMCG Bulletin 2021-3: May – June 2021
Pages 6-20

The Deurnese Peel peatland, the Netherlands, one year after the fire. Photo: Hans Joosten.

IMCG Bulletin 2021-3: May – June 2021

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The fluvial landscape of lower Mesopotamia: an overview of geomorphology and human impact

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Introduction

It is well-known that Mesopotamia means "between the rivers" (from the Greek μέσος – mesos: middle - and ποταμός – potamos: river, see Finkelstein 1962). Indeed, eastern/southeastern Iraq consists predominantly of fluvial landscapes of the rivers Tigris and Euphrates, whereas in adjacent southwestern Iran - directly north of the Persian Gulf – landforms have been shaped by the Karun River. Anthropogenic impact on the landscape has been intensive since the early/middle Holocene. Numerous wars and social instability have hampered earth-scientific and archaeological survey in the region since the 1980s, and consequently relevant knowledge is not at the present-day international standard. During the last two decades, however, research could be intensified greatly, and numerous gaps are now being closed (Master & Woldai 2004, 2007; UNEP 2009; Hritz et al. 2012a; Adamo & Al-Ansari 2020m), despite that field survey still is not safe.

Recently, we initiated a research program on the perception of mires/peatlands/wetlands by ancient cultures (De Klerk & Joosten 2019), and the various Mesopotamian societies play an important role in this respect. Reconstructing the wetland perception of these ancient cultures requires a thorough understanding of the landscape, its development, and the human interaction with that landscape. Earlier studies have dealt with the geology and geomorphology of Iraq and adjacent areas, but none of these suffices completely for our purposes because of their different research contexts.

For that reason, we studied various geological/geomorphological publications of the relevant regions and made a compilation geomorphological map (Fig. 1) that focusses on fluvial landscape types relevant for an understanding of the human-wetland interaction. Most processed studies base on satellite imagery (mostly Landsat and CORONA; cf. Walstra et al. 2010a/b, 2011; Jotheri & Allen 2020; Nadali 2021) for which groundtruthing was hardly possible because of safety considerations. Transliterated spelling of geographical names in this paper is standardised after the English edition of GoogleEarth (version of May 2021), historical topographical names are standardised after Bryce & Birkett-Rees (2016).

Around the rivers

The western part of Iraq consists of deserts and rocky plateaus consisting of or underlain by Tertiary limestone, marl, gypsum, and dolomite deposits (Sissakian & Fouad 2015). In the desert, many wadis only transport water during rare high precipitation events. Various wadis run to the dry lake of the Al-Nukhib depression that, consequently, contains water only incidentally; other wadis run to the Mesopotamian floodplain (Aqrawi et al. 2006). The Zagros mountains lie to the east and northeast of the floodplain, and extensive foothills – which are also underlain by calcareous deposits (Saleh et al. 2020) – lay between the mountains and the Tigris River. Various alluvial fans in front of the foothills were predominantly formed during the Pleistocene (Aqrawi et al. 2006; Yacoub 2011a/b; Sissakian et al. 2020a/b). Extensive fans ("megafans") along the lower Karun River in the Iranian part of lower Mesopotamia originate from the mid or late Holocene (Heyvaert et al. 2013). The alluvial fan east of Razazza Lake – actually a wadi fan – dates to the Pleistocene (Yacoub 2011b). The fan of the Wadi Al Batin stretches to the coast and also covers part of Kuwait (Morozova 2005; Sissakian et al. 2014), but in papers on the geology of Kuwait its extension does not fit that as indicated in geo(morpho)logical data from Iraq (see Gunatilaka 1986; Al-Sulaimi & Mukhopadhyay 2000). Most research indicates along the Tigris River in the northern part of the fluvial landscape an area of river incision with prominent terraces (dark-green areal in Fig. 1). Yacoub (2011a/b), however, identified these terraces as a large alluvial fan from early and middle Pleistocene age (see Yacoub 2011a who discusses the different opinions and underlying thoughts).

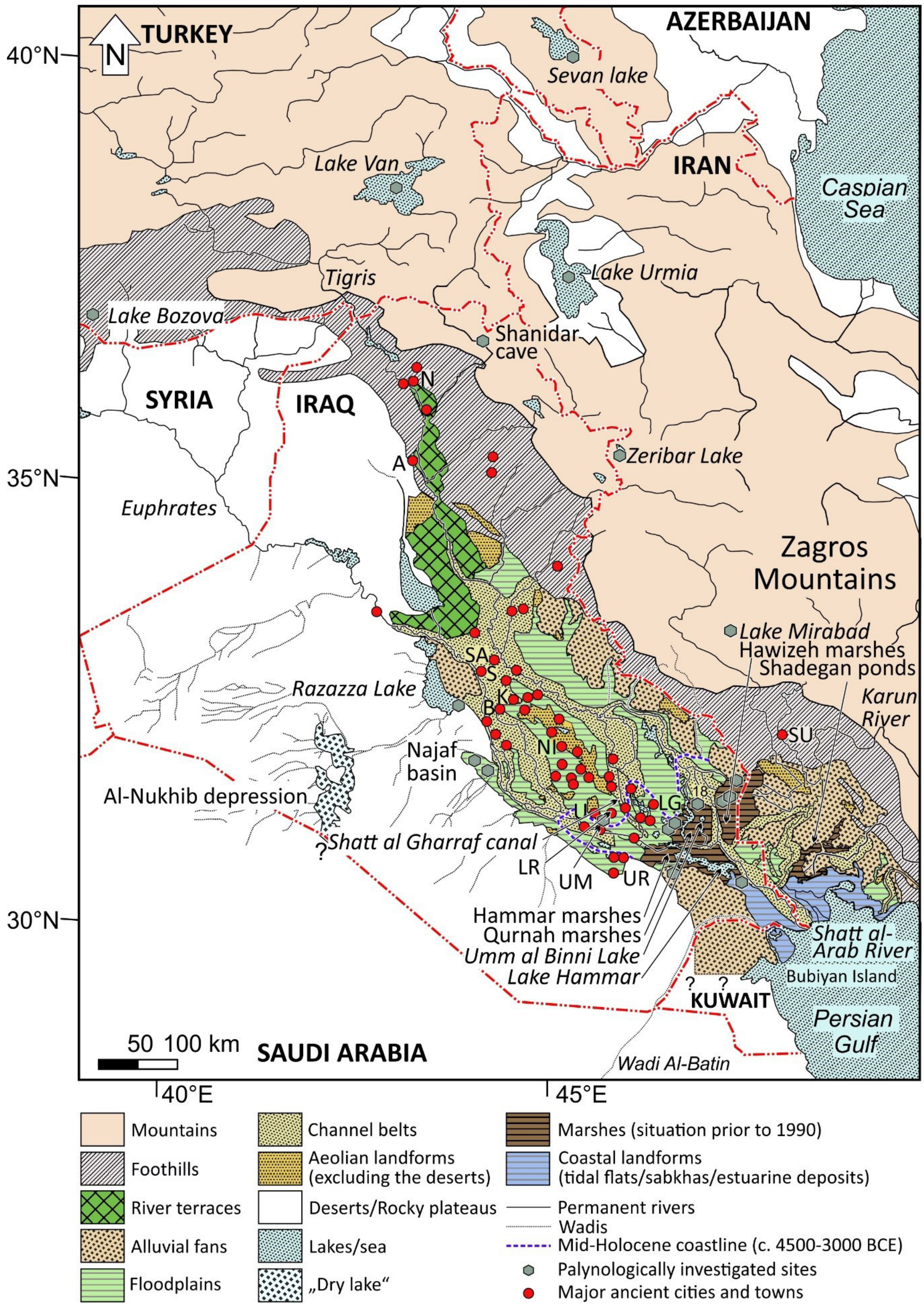

Fig. 1: Geomorphology of Mesopotamia and the location of major settlements. Compiled after: Aqrawi (1997), Al-Sulaimi & Mukhopadhyay (2000), Pournelle (2003, 2017), Morozova (2005), Aqrawi et al. (2006), Heyvaert & Baeteman (2007), Walstra et al. (2010a), Yacoub (2011b), Heyvaert et al. (2013), Sissakian & Fouad (2015), Azhdari & Bironro (2018), Sissakian et al. (2020a/b/e), counterchecked with satellite images from GoogleEarth (2020-edition). Locations of major settlements compiled after Morozova (2005) and Frahm (2013): A: Ashur; K: Kish; LG: Lagash; LR: Larsa; N: Nineveh; NI: Nippur; S: Sippar; SA: Sippar Amnanum; SU: Susa; UM: Tel Umm al-Aqrab.

The southern Mesopotamian fluvial landscape

Total thickness of Holocene sediments in lower Mesopotamia is around 15-20 m (Yacoub 2011b; Jotheri 2016; Sissakian et al. 2020). The early and mid-Holocene development of the landscape was predominantly ruled by sea level rise (Al–Sheikhly et al. 2017; Pournelle 2017). Sissakian et al. (2020d) discussed various theories from the 20th and early 21st centuries CE on sea level changes and note that there is absolutely no consensus. To us, the scenario that the highest sea level - and thus the maximum inland extent of the Persian Gulf - was reached around 4500 BCE appears the most likely. The extent of the Gulf changed only minimally by alluvial infill along its northwestern shore until a larger relative marine regression after c. 3000 BCE allowed the progradation of the alluvial landscape (cf. Pournelle 2017; Sissakian et al. 2020d). Apart from fluvial and sea level dynamics, also tectonic subsidence influenced the elevation of the landscape (Sissakian et al. 2020c).

Channel belts

Various sandy belts across Mesopotamia reflect different river courses, which were partly synchronously active. Widening of the belts will relate to lateral fluvial extension. The large volumes of sediments transported by the rivers caused a rapid filling-in of the channels, which resulted in a continuous rise of the riverbeds up to several meters above the surrounding floodbasins (Verhoeven 1998; Adamo & Al-Ansari 2000c).

The higher position of the river level led to regular breaches of the levees and a diversion of a part of the water stream that resulted – on small scales – in crevasse channels and crevasse splays running into the floodbasins (Fig. 2; see Makaske 2001) and – on a large scale – in avulsions. The consequent formation of new parallel channels formed an anastomosing fluvial pattern (cf. Makaske 2001). In lower Iraq five major channel belts occur next to each-other, three belts occur in the Kuran river fans (Fig. 1), and a single belt in front of these leads to the sea. It is likely that various river avulsions were anthropogenically caused, either intentionally or unintentionally (Cole & Gasche 1998; Heyvaert & Baeteman 2008; Heyvaert et al. 2013; Sissakian et al. 2020d). Sissakian et al. (2020c) posed that avulsion may furthermore have been induced by tectonic processes(see also Stouthamer & Berendsen 2000).

Figure 2: Satellite image displaying fan-like crevasse splays with many active and inactive channels leading water from the River Tigris into its western floodbasins. The curved channels appear natural, the straight channels have been anthropogenically modified.

Most belts contain – next to still active river branches – numerous fossil channels (Cole & Gasche 1998; Heyvaert & Baeteman 2008; Jotheri et al. 2016). Verhoeven (1998) speculated that the rivers changed to meandering in the second part of the Holocene by building-out the channel belts of the previously anastomosing river branches. The channel belts of the various branches of the Euphrates River terminate far before the present-day coast of the Persian Gulf (Jotheri 2016, see Fig. 1): fluvial energy will have been too low to build the belts further and slow-flowing water allowed the development of the southeastern marshes. The Tigris had considerably more energy and sediment load because of its steeper gradient (Jotheri 2016) and, thus, was able to build a sandy channel belt through the marshes. A detailed chronology of the various river courses that would allow the reconstruction of the sequence of belts development does not yet exist, but a basis for such a fluvial chronology has been laid by Cole & Gasche (1998) and Jotheri et al. (2016) by comparing written records of various courses.

Floodbasins

The floodbasins lay several metres deeper than the rivers and their levees (see previous text-section). The natural floodbasins will have comprised marshes, lakes and pools.

A dense system of up to several thousand small channels crosses the Mesopotamian floodplains. The channels mostly terminate in the floodbasins, and many will have been natural mire-streams or crevasse channels (Fig. 2). Many channels, however, will have been artificially dug for agriculture to allow irrigation, drainage and transport (see text-section "human impact"; see also Verhoeven 1998; Hritz 2010; Yacoub 2011b; Jotheri 2016, 2018; Wilkinson 2017; Sissakian et al. 2020a/b). By breaching the levees, humans may also have artificially initiated crevasse splay development in order to lead water streams into the floodbasins (Fig. 2).

Floodbasin deposits - for which numerous core data scattered over lower Mesopotamia are available - consist predominantly of clay and silt. Although luxurious reed beds will have grown in the floodbasins (see text-section "vegetation history"), peat is very rare, even in the southeastern marshes (cf. Baeteman 1980; Aqrawi 1997; Verhoeven 1998; Aqrawi et al. 2006; Heyvaert & Baeteman 2007, 2008; Issa 2010; Walstra et al. 2010a; Benni & Al-Tawah 2011; Hritz et al. 2012b; Heyvaert et al. 2013; Jotherti 2016; Jotheri et al. 2016, 2018; Al–Sheikhly et al. 2017; Altaweel et al. 2019; Albadran 2021). Few cm thin layers of dark-coloured mud dominated by remains of *Phragmites* and *Typha* (Aqrawi 1997; Aqrawi et al. 2006) have regularly been erroneously described as peat (Aqrawi 1997). Aqrawi (1997) and Aqrawi et al. (2006) noted that at deeper levels more organic matter occurs: in northeastern Kuwait under Bubiyan Island, for example, peat occurs between 24.5 and 20 m below the present surface and dates to c. 7500-6700 BCE (Gunatilaka 1986 quoting a conference abstract by A.Z. Al-Zamel). In warm and precipitation-poor Mesopotamia, rapid decay of organic matter will have hampered the formation of peat. Furthermore, continuing river sedimentation and intensive agriculture will have frustrated the formation of peat layers. It is not yet known which parts of Mesopotamia were cultivated during which periods, and to what extent natural vegetation types were common.

The southeastern marshes

In front of the rivers, a marsh landscape with vast reeds developed after the retreat of the sea (Fig. 3). This landscape included the large Hammar, Qurna, and Hawizeh marshes, which gradually expanded seaward (Al-Ansari et al. 2012; Jotheri 2016). The precise timing and causes of marsh progradation are a matter of discussion, but it seems that the process started around 3000 BCE (see Aqrawi 1997; Pournelle 2017; Jotheri 2016). This date corresponds with a shift to a drier climate (Altaweel et al. 2019), which may have contributed to decreased river discharge and increased terrestrialisation along the palaeocoast. The name "Sealand" for the marsh region is attested since the mid 2nd millennium BCE (Bagg 2020), which implies that around this time marsh formation had progressed to such extent that a separate landscape was recognisable. The Shadegan marshes in the Iranian part of southeastern Mesopotamia were formed not later than the 10th century CE after the development of a new alluvial ridge had blocked the discharge of water (Walstra et al. 2011).

In contrast to the Tigris, the Euphrates had insufficient energy and suspended matter (cf. Jotheri 2016) to build up sandy belts in the marshes: the water probably flew dispersed through the fens. Adamo & Al-Amsari (2020g) note that in the Sassanid period, i.e. around 600 CE, the marshes reached their largest extent. After 1991 CE the Saddam Hussein regime drained almost the complete marsh area (see text-section "human impact"). Whereas also the marshes do not contain significant amounts of peat (see text-section “floodbasin”), they have a surficial layer of dark organic-rich sandy silt of 10-50 cm thick (Yacoub 2011b; Albadran 2021).

Figure 3: Reed marshes in the undrained remnant of the Al Hawizeh marsh, with a pathway for boat navigation. Photograph: Curtis J. Richardson (Duke University Wetland Center).

The estuary

Near the coast, the Euphrates, Tigris and Karun rivers join and continue to flow in a single channel – known as the Shatt al-Arab river that partly forms the border between Iraq and Iran - through an estuary into the Persian Gulf. In and around the estuary the landscape consists predominantly of tidal flats, tidal channels and marine sabkhas (salt flats) (Yacoub 2011a/b).

Desertification and salinization

A major geomorphological process in the Mesopotamian fluvial area with its dry and hot climate is desertification with wind easily blowing sand and dust into the basins (Yacoub 2011b). After the channel belt in the central part of Mesopotamia (with the ancient city of Nippur) became inactive, the sandy deposits were reactivated by wind that modified the belt (Al-Ameri & Jassim 2011; Yacoub 2011b; Sissakian et al. 2020e). Some aeolian landforms also developed on the alluvial fans along the Iraqi/Iranian border.

Evaporation results in salinization and the formation of salt flats (inland-sabkha; not displayed in Fig. 1) in the lakes and the floodbasins, and also in an increasing salt content of the groundwater (Adams 1981; Jabbar et al. 2010; Yacoub 2011b; Adamo & Al-Ansari 2020c; Abdullah et al. 2020c; Sissakian et al. 2020e). For example, the Najaf basin - indicated as a part of the floodplain in Fig. 1 - in recent times changed to an inland sabkha (Benni & Al-Tawah 2011). Minor salt crusts occur frequently in the landscape. A decrease of the already rare precipitation as a result of ongoing global warming will increase desertification and salinization in the future (Sissakian et al. 2020e).

Vegetation history

High-resolution palaeoecological data are available from lakes in the mountains surrounding the Mesopotamian lowland, including from Lakes Mirabad (Van Zeist & Bottema 1977), Zeribar (e.g. Van Zeist & Bottema 1977) and Urmia (e.g. Bottema 1986; Djamali et al. 2008) in Iran, from Sevan Lake in Armenia (Leroy et al. 2016; Robles et al. 2020), and from Lakes Van (e.g. Van Zeist & Woldring 1978; Wick et al. 2003) and Bozova (S. Bottema in the European Pollen Database) in Turkey. In the northeastern Iraqian mountains palaeoecological studies were carried-out in the Shanidar cave, a well-known site with remains of Neanderthals (Solecki & Leroi-Gourhan 1961; Al-Ameri et al. 2011). These studies provide detailed information on the palaeoenvironment of the Near East in general but are hardly relevant for reconstructing the wetland vegetation in lower Mesopotamia.

Various pollen diagrams from the Iraqian lowlands exist but their low temporal resolution, few identified pollen types and methodological uncertainties provide only crude insights in the vegetation development of the fluvial landscape. Data from Razazza Lake indicate how a Weichselian steppe vegetation (represented by high amounts of pollen attributable to Chenopodiaceae) was succeeded by a vegetation of Poaceae (grasses), *Quercus* (oak) and *Polypodium* (polypody) (Alrawi et al. 2005). The pollen diagram from "Core 18" in the north of the southeastern mires shows a marked decrease of pollen attributable to Chenopodiaceae also, corresponding to rises in pollen attributable to grasses and palm trees (Al-Ameri et al. 2001; Al-Ameri & Jassim 2011) that were interpreted as the Pleistocene-Holocene transition (Al-Ameri et al. 2001; Al-Ameri & Jassim 2011). In the present-day inland sabkha of the Najaf basin, the lower parts of two cores contain mainly pollen attributable to pine (*Pinus*) and grasses (Benni & Al-Tawah 2011) which were interpreted as indicating a somewhat moister climate. Various 1-m cores from the marshes show predominantly pollen attributable to grasses, *Crinum* and *Tofieldia* with incidental occurrences of pollen attributable to Typhaceae (cattail family) and *Isonandra* (Al-Ameri & Jassim 2011). A profile from an ancient river channel at the Tel Umm al-Aqrab site dating back to c. 3000 BCE shows much pollen attributable to *Typha* and grasses, which may reflect reedbeds along the river, whereas furthermore a dryland (levee?) vegetation can be inferred with palms and date palms, and in earlier times *Carpinus* (hornbeam). Phytolith analyses at various sites indicate for the early and mid-Holocene the presence of grasses, sedges and reeds. *Arundo donax* (giant cane/elephant grass/wild cane/giant reed) could be identified as a reed species, while oak (*Quercus*) and date palm (*Phoenix dactylifera*) were important tree species in the earlier Holocene (Altaweel et al. 2019). Whereas oak disappeared in the early Holocene (Altaweel et al. 2019), date palm remained and was important as a food resource (Bouchaud et al. 2012; Fig. 4).

Figure 4: Date palm plantation along the Euphrates River. Photograph: Curtis J. Richardson (Duke University Wetland Center).

Archaeobotanical studies near Sippar demonstrated the past presence of date palm, poplar (*Populus*) and Tamarisk (*Tamarix*) (Van Zeist 1984). The genus *Populus* includes various typically riverine tree species that may have grown on the river levees and whose wood was frequently used for construction (Van Zeist 1984; Ghazanfar & McDaniel 2016). The genus *Tamarix* includes many species that occur predominantly in dry desert/steppe habitats but also along riverbanks (Ghazanfar & McDaniel 2016): the plants can tolerate the rather salty soils, which are currently widespread (Ohrtman & Lair 2013). Furthermore, charcoal of *Pinus halepenis*-type was found, which probably derives from *P. brutia* (Turkish pine), the only pine species native in Iraq (Van Zeist 1984; Ghazanfar & McDaniel 2016). For former levee forests along the Tigris and Euphrates Willcox (1992) named *Salix* (willow), *Populus euphratica* (Euphrates poplar), *Fraxinus syriaca* (Syrian ash), *Platanus orientalis* (old world sycamore), *Juglans regia* (walnut tree), *Vitex agnus-castus* (chaste tree), and *Tamarix aphylla* (athel tamarisk).

Wetland plants identified in archaeobotanical studies from the Sippar and Abu Tbeirah areas that will have grown in the reedbeds include *Arundo donax*, *Bolboschoenus maritimus* (sea clubrush), *Cyperus* (e.g. *C. rotundus*), and *Typha angustifolia* (Van Zeist 1984; Romano et al. 2021). Probably these species were used as raw material for the construction of utilities (see Romano et al. 2021). Crop plants remains found at Sippar, Kish and Ur include *Hordeum* (barley), *Triticum dicoccum* (emmer wheat), *T. durum/aestivum* (i.e. common wheat or durum), *Lens culinaris* (lentil), *Pisum sativum* (pea), *Coriandrum sativum* (coriander), *Cuminum cyminum* (cumin), *Allium sativum* (garlic), *Pistacia* cf. *atlantica* (pystachio) and *Pyrus malus* (apple tree) (Field 1932; Ellison et al. 1978; Van Zeist 1984). Not all these plants will have occurred in ancient Mesopotamia: various of their products will have been imported from abroad (Van Zeist 1984).

Wetland fauna

Inherent to wetlands, animal live consists of numerous mollusc, fish, fowl, turtle, and small mammal species (Veldhuis 2004; Bagg 2020; Albadran 2021; Esmaeili 2021; Jawad 2021a; Salim et al. 2021). Wild (i.e., not-domesticated) large mammal species include grey wolf, long-fingered bat, smooth-coated otter, honey badger, striped hyena, jungle cat (also known as reed or swamp cat), wild boar, lion, goitered gazelle, crested porcupine, and roe deer, which all have been attested to thrive until recently (Bagg 2020; Jawad 2021a).

Human impact

Agriculture in the Fertile Crescent, including Mesopotamia, started around 11000 BCE (Haywood 2005; Bryce & Birkett-Reese 2016). Not later than the 7th millennium BCE the lower Tigris and Euphrates floodplains started to be inhabited by people of the so-called Ubaid culture (Bryce & Birkett-Reese 2016; Radner 2017; Adamo & Al-Ansari 2020b). During the Ubaid 2 period (4880-4500 BCE) numerous artificial canals were constructed that must have supported irrigation-based agriculture (Adamo & Al-Ansari 2020b). Rapid urbanisation – following the increase of agricultural production– is inferred for the Ubaid 3 period (4500-4000 BCE) and continued in the subsequent Uruk and Jemdet Nasr periods (4000-2900 BCE). During these latter periods, the various Sumerian city states developed (Adamo & Al-Ansari 2020b), including Ur and Uruk, which were located along the coast of that time (Fig. 1). A centralised authority must have developed in the city states of the 4th millennium BCE to coordinate regional canal construction and maintenance (Frahm 2013; Adamo & Al-Ansari 2020b; Nadali 2021), which may have triggered the development of writing around 3400-3200 BCE (Haywood 2005; Haarmann 2017). Simultaneously, geometry and trigonometry and tools for land measurement developed in order to calculate areas of agricultural fields and volumes of harvested products (Adamo & Al-Ansari 2020c). Frequent floods required protection works such as dikes and overflow areas (Cole & Gasche 1998; Heyvaert & Baeteman 2008; Abdullah et al. 2020b; Adamo & Al-Ansari 2020c). This incited many conflicts and wars between the city states, which all put their own interests above those of their neighbours (Adamo & Al-Ansari 2020c; Nadali 2021).

The state of Akkad (2350-2150 BCE) unified the lower Mesopotamian peoples in a single empire (Adamo & Al-Ansari 2020c), which made large-scale hydrological regulation more efficient. The climate anomaly of c. 2200-2000 BCE – the so-called 4.2 ka event that in the Near East was characterised by severe drought (Riehl 2008, 2017; Höflmayer 2017; Kaniewski et al. 2018; Robles et al. 2020) - may have aided in the collapse of the Akkadian empire (Cullen et al. 2000; Bar-Matthews & Ayalon 2011; Weiss 2017). Subsequently, the Sumerian state of the Ur III dynasty (c. 2150-2000 BCE) ruled major parts of lower Mesopotamia (Adamo & Al-Ansari 2020c). Gradual immigration of the Amorite people out of Canaan resulted in an increasing Semitic population, which eventually took-over the rule of Mesopotamia (Burke 2017). Although Sumerian culture was preserved, the Sumerian language was replaced with the Semitic Babylonian language (Adamo & Al-Ansari 2020d). King Hammurabi (c. 1810-1750 BCE) developed the legal "Hammurabi code", which included many articles on agriculture and hydrological management (Adamo & Al-Ansari 2020d) and, thus, gave land-use a jurisdictional basis. At this time, the Old Assyrian empire flanked the Tigris and Euphrates Rivers upstream of Babylonia (Bryce & Birkett-Reese 2016; Adamo & Al-Ansari 2020b). Kassite people – which had immigrated from the Zagros mountains (Haywood 2005) – subsequently provided the ruling class of Babylonia (Bryce & Birkett-Reese 2016; Adamo & Al-Ansari 2020d). Being located at some distance from the Mediterranean coast, Mesopotamia did not suffer directly from the mysterious Sea Peoples - which ransacked the eastern Mediterranean coasts in the first half of the 12th

century BCE - but was subject to the subsequent general societal unrest in the Near East (Haywood 2005; Bryce & Birkett-Reese 2016). Elamite people - from the western ranges of the Zagros mountains and its foothills - took-over the rule of the Babylonian country around 1150 BCE (Haywood 2005; Adamo & Al-Ansari 2020d), after which the armies of the Neo-Assyrian empire conquered lower Mesopotamia (Adamo & Al-Ansari 2020d/e/f). Starting in the 9th century BCE the Semitic Chaldean people from the Western Levant immigrated into the southeastern marshes (Adamo & Al-Ansari 2020f) and overtook Babylonia from the Assyrians in 626 BCE to rule the so-called Neo-Babylonian empire. In 539 BCE the Persian Achaemenids annexed Babylonia. Adamo & Al-Ansari (2020f) remarked that the Neo-Babylonian and Achaemenid periods were characterised by growth of wealth and the resettlement and cultivation of long-abandoned areas. The armies of Alexander the Great invaded in 336 BCE (Haywood 2005; Adamo & Al-Ansari 2020f) and after the division of his empire under his military commanders, general Seleucus integrated Babylonia in the Seleucid empire (Adamo & Al-Ansari 2020g). Regional military instability resulted in tensions and wars, and Mesopotamia became part of the Parthian empire in 141 BCE and of the Sasanian empire in 224 CE (Adamo & Al-Ansari 2020g). This empire perished in 652 CE after which Islamic empires controlled the Mesopotamian area following immigration from Arabia (Adamo & Al-Ansari 2020g/h/i). The new ruling class introduced the name Iraq, which may have been derived from the city-name Uruk (Adamo & Al-Ansari 2020h). A cultural decline took place in the late 1st millennium CE because of social and economic instability, rapid change of rulers, and frequent wars (Adamo & Al-Ansari 2020l). The situation even worsened after the Mongolian invasion of 1258 CE resulting in an ever declining economic and agricultural system and numerous invasions. Only after the defeat of the Ottoman empire in 1918 and the establishment of the modern state Iraq in 1920 the country became sufficiently stable to provide its inhabitants again with some prosperity until new wars and social unrests started in the 1980s (Adamo & Al-Ansari 2020m).

Although the rulers and the ruling class changed frequently, agricultural techniques remained rather similar over the millennia. The new rulers primarily wanted a share in the prosperity of the country and were not hostile towards the lower Mesopotamian cultures in which they assimilated (Haywood 2005). One remarkable technical change was the introduction of animal power to move water in the first millennium BCE (Ahram 2021).

Settlements in the riverine landscape were primarily erected on river levees or connected crevasse splays (Adams 1981; Morozova 2005; Yacoub 2011b; Sissakian & Fouad 2015; Jotheri et al. 2016, 2018). In addition to being positioned at these higher landscape elements, various cities were built on artificial hillocks ('tells'), which increased their height even further (Yacoub 2011a; Alhawi et al. 2017; Altaweel et al. 2019; Sissakian et al. 2020a). Settlements were predominantly oriented towards the branches of the Euphrates, which had a smaller discharge and a lower flow velocity than the Tigris: the latter also had less predictable and more violent floods (Adams 1981; Verhoeven 1998; Morozova 2005; Adamo & Al-Ansari 2020c). Furthermore, the general east-west slope of the lower Mesopotamian plain made drainage and irrigation more effective in the western regions (Adamo & Al-Ansari 2020c). In the southeastern marshes settlements were erected on artificial floating islands that sustained a solid habitation (Al-Ansari et al. 2012) with a lifestyle that persisted among the Marsh Arabs up to the destruction of the marshes in the 1990s (see Thesiger 1964; Young 1977; Al-Ansari et al. 2012; Jawad 2021b).

Hydrological works were indispensable to make the floodbasins suitable for agriculture. Using remote sensing, Hritz (2010) identified some 5000 archaeological sites, whereas Jotheri (2016) found even 8000 sites along the numerous minor channels crossing the floodbasins (although various of these sites post-date the ancient societies relevant for our study). Irrigation was in general gravity based, meaning that the canals run from the higher alluvial belts into the lower floodbasins (Adamo & Al-Ansari 2020h). Whereas remote sensing reveals a dense network of irrigation canals in the floodbasins, it is unknown which canals date to which period, and which were active simultaneously. The extent of agriculture and population structures during specific cultural periods is, therefore, unknown (see Cole & Gasche 1998). It can be expected that - although techniques remained similar - expanding population and thus a greater need for food resulted in the increase of canals and agricultural fields in the course of time, and in canals becoming increasingly longer and wider (Adamo & Al-Ansari 2020e/f). By creating levee breaches humans may have artificially initiated crevasse channels/splays in the floodbasins as inception for irrigation canals (see Fig. 2). Furthermore, canals possibly also developed from preferred travel routes with boats (Fig. 3) or by water buffalo herding (so-called "hollow ways", see Jotheri et al. 2019). A major

achievement among the hydrological works was the Lumna-gimdug canal – the present-day Shatt Al Gharraf River – which runs over almost 200 km, connects Tigris with the Euphrates, and was first incepted in the mid-3rd century CE after which it was gradually enlarged (Adamo & Al-Ansari 2020c). The hydrological techniques were so successful that the Assyrian rulers imported them in their own core territory around Ashur and Nineveh to supply the cities more effectively with water (Adamo & Al-Ansari 2020e). After a flood around 629/627 BCE the Tigris was cut-off from its main branch and re-directed into the Lumna-gimdug irrigation canal that subsequently became its principal course (Adamo & Al-Ansari 2020c/h). The damage could not be repaired, and the eastern floodbasins lost their water supply (Adamo & Al-Ansari 2020h).
According to Adamo & Al-Ansari (2020g), neglect of the southern Tigris dikes in the 6th century CE resulted in breaks, and inflow of the Tigris water in the surrounding floodbasins triggered a further expansion of the southeastern marshes. After the start of the Islamic period in 652 CE irrigation works reached their maximum pre-industrial extent (Adamo & Al-Ansari 2020h), and exotic crops like rice, sugarcane or cotton flourished. Afterwards, canals continued to be constructed and became increasingly larger in size (Adamo & Al-Ansari 2020i/j/k).
After the cultural decline in the late 1st millennium CE the landscape became neglected, and canals and their maintenance deteriorated (Adamo & Al-Ansare 2020l; Ahram 2021). It was not until the 20th century that the country started to prosper again, and new barrages and dams were constructed for hydrological regulation (Abdullah et al. 2019a/b, 2020a/b). The lower marshes were widely destroyed by hydrological projects, especially in the 1990s, to facilitate agriculture, urban expansion, and oil exploration (Richardson & Hussain 2006; UNEP 2009; Jabbar et al. 2010; Al-Ansari & Knuttson 2011; Yacoub 2011a; Lonergan 2012; Jawad 2021a; Ahram 2021). But there were military reasons for this destruction as well: after the 'Battle of the marshes' in 1984 CE during the first Gulf war, violent campaigns against the Marsh Arabs started in 1991 during the second Gulf war (Al-Ansari et al. 2012; Lonergan 2012; Bagg 2020; Ahram 2021). Consequently, the former marsh area became highly contaminated with munition and poison gas (Al-Ansari & Knutsson 2011; Al-Ansari et al. 2012; Fig. 5). Due to the drainage, the aeolian input caused an expansion of dune areas, and the drying-out facilitated expansion of inland sabkhas (Jabbar et al. 2010; Yacoub 2011b). Since 2003 projects are in progress to restore the areas as much as possible (Richardson & Hussain 2006; UNEP 2009; Jabbar et al. 2010; Yacoub 2011a/b; Al-Ansari et al. 2012; Lonergan 2012; Jawad 2021c).

Figure 5: The dried-out Al Hawizeh marsh (near the Iraqi/Iranian border) with tank treads remaining from warfare. Photograph: Curtis J. Richardson (Duke University Wetland Center).

Dating of vegetation phases, river activity and human impact

The scarcity of organic matter makes radiocarbon-dating – which could provide a chronology for landscape developmental phases - a challenge. Until now in most cases shell remains have been dated (e.g. Aqrawi 1993,

1995; Jotheri et al. 2016, 2018; Bogemans et al. 2017a/b), which may be subject to an aging hardwater effect (Bogemans et al. 2017). Although various calcareous deposits persist in the deeper underground of the regions around the Mesopotamian floodplain (Saleh et al. 2020), these were assumed to be too far away to have any effect on the carbonates in the shells, and therefore a hardwater effect would be negligible (e.g. Hritz et al. 2012b). This hypothesis is in contrast with the studies of Maulood & Hassan (2021) and Salman et al. (2021) who found that the water in the southeastern marshes was very calcareous in the 1980s which it will also have been in the past. Bogemans et al. (2017a/b) also dated root material that – penetrating from a higher younger level – may also provide unreliable results (Törnqvist et al. 1992). Some organic-rich sediment layers have also been dated (Aqrawi 1995; Heyvaert & Baeteman 2007; Hritz et al. 2012b; Bogemans 2017a/b), but without knowledge what precisely makes-up the amorphous organic matter the reliability of the dates remains unknown. The alternative could be to date pollen concentrates (see Regnell 1992), although this method is also subject to possible errors of which the causes are still unknown (Kilian et al. 2002; De Klerk & Brumlich 2018).
For the time being, thus, the precise dates of vegetation phases and river activity are still only roughly known, but numerous archaeological remains in the floodplain sediments allow dating specific periods rather accurately.

Possible meteor impact
The Umm al Binni lake in the Qurna marshes has – because of its near circular basin with an elevated rim and a c. 500 m wide ring around the lake – been proposed to be a meteor crater, tentatively dated to between c. 3000-2000 BCE (Master 2001; Master & Woldai 2004, 2007). It has even more tentatively been correlated to c. 2350 BCE ash layers found in Syria and in a marine sediment core near Oman (Master & Woldai 2004). The impact – if the assumption is correct – must have had a large effect on the contemporaneous landscape and population. The spot was in the 3rd millennium BCE still covered by the Persian Gulf in front of the expanding alluvial landscape: if it would have triggered a tsunami that reached far into the Mesopotamian lands, it may have been the event on which the Great Flood stories of the 'Gilgamesh-epic' – according to Foster (2019) first conceived around 2100 BCE – and the 'Atra-hasis' – from the early 2nd millennium BCE (Dalley 2008) - are modelled (Master & Woldai 2004). Indeed, the 11th tablet of the Gilgamesh epos has the deluge story start with a reference to a large cloud and a thundering sound (Foster 2019).
The evidence of Umm al Binni being an impact crater is, however, scant and ambiguous, which Master & Woldai (2004, 2007) stressed themselves. They expressed their regret that because of ongoing political instability the necessary field investigations were impossible in the 2000s. Sissakian & Al-Bahadily (2018) and Sissakian et al. (2020c) evaluated the theory with help of satellite imagery and noted that many surface structures that should have occurred at an impact crater are absent. They posed that tectonic activities and human impact shaped the lake, but they could also not visit the structure in the field because of safety concerns. Indeed, there are some indications that a meteorite impacted in the Near East around 2360-2340 BCE that influenced or even destructed human societies (Baillie & McAneney 2015; see Courty 1998), but it is at present only a matter of speculation where the impact took place.

Concluding remarks
In the course of time, starting in the early or mid-Holocene, the land "between the rivers" lost its natural character and was transformed into an increasingly cultural landscape with an intensive interaction of human and fluvial processes. Already early in the Holocene the landscape will have been mainly cultural. When and to what extent natural floodbasin marshes still existed is unknown, but they will have gradually decreased as a consequence of increasing population and expanding agriculture.

Acknowledgements
We are grateful to Curtis J. Richardson (Duke University Wetland Center) for providing various photographs of the Mesopotamian landscape, and to Elias Ramezani (Urmia University) for providing the geological map of the Iranian Khozestan province.

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A note on the definition, identification and delineation of peatland

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Over the last months, various countries and institutions have been revisiting the definition of 'peatland' as a basis for mapping. Evidently, there is a clear relation between the definition (where are we talking about?) and the mapping (where do we find it?). C.A. Weber, the factual founder of peatland science, already observed in 1903 that without clear definition you cannot map the resource reliably nor collect accurate statistics. However, peatland mapping inevitably runs into the problem that no globally accepted pragmatic definition of 'peatland' exists. How to choose or construct the 'right' definition among all existing and possible definitions, which are often not mutually compatible?
For general use the definitions in the 2021 Ramsar Global Guidelines for Peatland Restoration may be sufficient:

Organic matter: Carbon-hydrogen based material of botanical, faunal, fungal and microbial origin
Peat: Substance largely consisting of dead organic matter, with macroscopic plant remains, that after its production has not been relocated by water or ice or wind (compare sediments, which result from relocation)
Organic soil: Soil with a substantial layer of organic matter at or near the surface
Peatland: Area with a spontaneously accumulated layer of peat at the surface
If you want to make it even simpler, you merge the concepts of 'peat' and 'organic matter' and you call a peatland: "an area with a substantial[1)] layer of spontaneously accumulated organic matter at/near the surface"
[1)] This 'substantial' must be added to prevent that every tree leaf falling on the ground immediately creates a 'peatland'.

If you want to *map* peatlands - for whatever purpose -, you must be more concrete: you have to give a *quantitative* definition of 'peat' and of its minimum thickness for land to be called a 'peatland'. There is where the definitions diverge, often for very pragmatic reasons. Some examples:

- The FAO (2006/7) partial definition of organic soils (Histosols) as "Soils having organic material …10 cm or more thick starting at the soil surface and immediately overlying ice, continuous rock, or fragmental materials,…" is clearly inspired by the impracticality of coring or digging in rocks or ice.
- The common peat depth threshold in the temperate and boreal zones of 30/40cm (or 60cm in case of hardly humified moss peat) is clearly informed by agricultural (and forestry) purposes (deeper than normal plough and crop rooting depth). Development of land techniques over time is reflected in the adjustment of the 'peatland' limit in Germany, which in former times was 20 cm, for a short period also 25 cm and later 30 cm.
- The threshold of 0.7 m for the area of 'peat resources' in Russia has been chosen because peat cannot economically be extracted from shallower peatlands.