A FIRST ASSESSMENT OF THE POTENTIAL DISTRIBUTION OF PEATLANDS IN UZBEKISTAN

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cover picture: Grazing sheep on pastures by the lake Arashan with sloping spring mires in the background (Photo: Leonie Hebermehl)

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A FIRST ASSESSMENT OF THE POTENTIAL DISTRIBUTION OF PEATLANDS IN UZBEKISTAN

THESIS TO THE ACHIEVEMENT OF THE DEGREE:

MASTER OF SCIENCE
LANDSCAPE ECOLOGY AND NATURE CONSERVATION

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UNDER THE SUPERVISION OF
DR. ALEXANDRA BARTHELMES & DR. SABRINA RILKE

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Abstract

In arid regions, peatlands provide diverse crucial ecosystem services, like provisioning services, water regulation, and habitats. Despite this, they have received little scientific attention so far. For Uzbekistan, hardly any information on this topic yet exists. This thesis explores whether peatlands occur in Uzbekistan, as well as their potential distribution and characteristics in the country.

Based on a literature review and environmental proxy data, areas with the potential for peat formation were identified. Using remote sensing data, probable sites of peatland occurrence were determined and mapped for representative study areas. In a field survey, 30 sites were studied regarding geographical features, vegetation and soil characteristics.

The mapping of the mountain areas revealed 22 km^2 of probable peatlands, characterized by an overall small patch size. The sites were located at slopes or in the valley floors and often grouped as peatland complexes. The minerotrophic sedge fens detected during the field survey occurred as sloping mires and surface flow mires, with layers of shallow peat (>30% OM) and half-peat (10–30% OM). Maximum peat depth was 70 cm, and max. OM content 73%.

In the lowland, 10.5 km^2 of probable peatlands were mapped in the Syr Darya floodplain. They were located mostly at oxbows or in wet depressions. The reed dominated floodplain mires studied in-situ provided layers of peat and half-peat of up to 45 cm and max. 60% OM, but mostly OM contents below 20%.

Land use change, land reclamation, anthropogenic changes in the hydrological systems, and climate change are causing degradation and loss of peatlands. Further research and targeted conservation measures are needed to better understand and protect peatlands and the ecosystem services they provide.

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1 Introduction

Anthropogenic global change put enormous pressures on ecosystems worldwide. Among the most vulnerable ecosystems are wetlands, of which 85% have been lost in the last 300 years and 54% since 1990 (IPBES 2019). At the same time, wetlands provide many ecosystem services, from carbon storage and climate regulation, water purification and flood control, provision of raw materials to cultural services like tourism or spiritual services (BONN ET AL. 2016), which can contribute to biodiversity conservation (ALBRECHT & RATAMÄKI 2016). They also provide urgently necessary habitat for wetland species, since many of these are adapted to the unique conditions. The importance of wetlands has been recognized on a global level through the 'Ramsar Convention' (RAMSAR CONVENTION ON WETLANDS 1971, UNESCO 1971), and the Convention on Biological Diversity (CBD; SECRETARIAT ON THE CONVENTION ON BIOLOGICAL DIVERSITY 2020).

Among wetlands, peatlands play a special role. They alone may make up half of the categories of wetlands listed in the Ramsar Convention (MALTBY ET AL. 1992, GLOBAL ENVIRONMENT CENTRE & WETLANDS INTERNATIONAL 2008). Despite covering only 3% of the Earth's surface, they potentially store 21% of the global amount of soil organic carbon (SCHARLEMANN ET AL. 2014). As long as the high water table is maintained, the anoxic conditions ensure the accumulation of organic material as peat soil instead of its decomposition, thus removing carbon from the atmosphere (MOORE 2002). Several recent publications have highlighted the potential of peatlands for the mitigation of climate change (e.g. LEIFELD & MENICHETTI 2018, HARENDA et al. 2017, SEDDON et al. 2019, RUMPEL et al. 2018). Peatlands are characterized by a complex relationship between plants, water and peat, that react vulnerable to human disturbances (GLOBAL ENVIRONMENT CENTRE & WETLANDS INTERNATIONAL 2008).

At the same time a severe lack of knowledge on the distribution and status of, as well as threats to peatlands exists (BARTHELMES & JOOSTEN 2018, JOOSTEN 2004, MINASNY et al. 2019). Peatlands are highly diverse ecosystems with varying characteristics and a broad variety of land use types. As such, they are often not recognized and overlooked (GLOBAL ENVIRONMENT CENTRE & WETLANDS INTERNATIONAL 2008). More research is needed to understand their functions and design adequate measures to protect peatlands and their services, or to restore them. This problem is even more pronounced for peatlands in arid regions with continental climate, where the water regulating functions are even more crucial (MINAYEVA et al. 2005, MINAYEVA et al. 2018). Also, for the montane peatlands of Central Asia[1], a considerable lack of research has been reported (NOWAK et al. 2016).

[1] Within this work 'Central Asia' is used as an umbrella term for the countries Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan, all of which are former Soviert republics.

Scientific knowledge on peatlands is also deficient for Uzbekistan; no data on peatland distribution exist to date. The country is located in Central Asia, a region characterized by arid or semi-arid climates with a pronounced continentality. The scarcity of water drives ecosystems in the country: the main biomes are steppes and deserts, both characterized by very low amounts of precipitation (TOJIBAEV et al. 2014).

By implication it also drives human livelihoods, which heavily depend on the availability and distribution of the scarce water resources (RAKHMATULLAEV et al. 2003). The devastation of major ecosystems through the Aral Sea crisis (MICKLIN 2007, MICKLIN 2010) is perhaps the most drastic result of unsustainable use of natural resources in the region (UNITED NATIONS 2010). But also on smaller scales the local population heavily relies on wetlands which leads to increasing pressures on and threats to them. The lack of knowledge on Central Asian wetlands (incl. peatlands) and their current state has been recognized by the IUCN's Committee on Ecosystem Management which lists as its No. 1 target for its work: *"To prepare a list of important Threatened Wetland Ecosystems of Central Asia regional Countries."* (IUCN 2018)

This thesis aims to contribute to the knowledge on Central Asian wetlands through locating, assessing and describing potential peatlands and their distribution in Uzbekistan. For a comprehensive overview on existing information, the thesis combines different methods:

1) A literature review of available scientific and non-scientific texts provides an overview on previous research on peatlands and organic soils;

2) Suitable proxy information available as GIS-data has been accessed and integrated to determine regions in Uzbekistan of potential peatland distribution;

3) Satellite imagery has been used to manually map potential peatlands in the high probability regions identified in step 2;

4) A field study in July 2019 has been used to sample 30 locations identified and mapped during the previous desk study.

The study regions and sites investigated were selected to represent different geographic zones, characterized by varying climates and altitudes, providing a broad overview of peatlands in Uzbekistan. During the field study, I recorded the general site conditions as well as plant diversity, and soil characteristics, allowing first insights on the general characteristics of the studied peatland types. Based on the findings, first conclusions can be drawn on peatlands, their ecosystem services and their overall condition and conservation status.

This study does not follow the traditional scientific method of formulating and investigating several hypotheses. Rather it serves as a baseline in that it establishes a foundation of knowledge for further work.

This thesis is the result of a cooperation between the Global Peat Database (GPD) and the Michael Succow Foundation. The study was initiated and supported by the CADI (Central Asian Desert Initiative) and the CAViF project (Central Asian Virtual Flora), both implemented by the Michael Succow Foundation. CAViF is currently realizing the establishment of a digital flora of Uzbekistan, in cooperation with the National Herbarium of Uzbekistan (TASH). The database of the Flora of Uzbekistan is a crucial tool for the monitoring of conservation efforts and identifying biodiversity hotspots and for education (TOJIBAEV et al. 2014). The project is based on the FloraGREIF, a web-based virtual plant-database and herbarium, which was successfully implemented for Mongolia (cf. RILKE & NAJMI 2011; RILKE et al. 2013).

The results will also be contributing to the Global Peat Database (GPD), a project of the International Mire Conservation Group (IMCG) which is managed by the Greifswald Mire Centre. The GPD coordinates the collection of data on the distribution and state of peatlands globally, including the integration of the data into a continuously updated Geographical Information System (GIS). By adding to the GPD, this research hopefully expands the global knowledge on peatland distribution.

1.1 State of research

Wetlands in Central Asia, and peatlands in particular, have received very little attention from the scientific community so far. The search string *wetland* AND "Central Asia"* yields 70 results in the ISI Web of Science Core Collection (Internet: https://apps.webofknowledge.com/), as compared to over 2,800 results for *wetland* AND Europe** (both search strings were last checked on 20/12/2020). For search strings related to peatlands *AND "Central Asia"*, specifically, publications are even fewer (Table 1). The search string *(mire* OR peatland) AND "Uzbekistan"* yields only a single result, a paper on a vegetation database published in 2017 (NOWAK et al. 2017). However, the authors mention Uzbekistan as one of the places with lacking data. The geographically broader string *(mire* OR peatland) AND "Central Asia"* seems more promising with 17 results (excluding the category Political Science). But a closer look reveals that only one paper focuses on peatlands as ecosystems (ALJES et al. 2016), and one other on peatland-related land degradation (YU et al. 2017). The remaining 15 papers contain research related to climate and the reconstruction of climate and vegetation dynamics (e.g. paleoecology). The alternative search strings with *(mire* OR peatland) AND* "Inner Asia" or "Middle Asia" do not provide relevant results.

Table 1: Search results for publications on peatlands, delivered by ISI Web of Science Core Collection (© Clarivate Analytics). All search strings were last checked on 20/12/2020.

Search string (ISI Web of Science):	No. of results	No. of relevant results
(mire* OR peatland) AND Uzbekistan	1	0
(mire* OR peatland) AND "Central Asia"	17	2
(mire* OR peatland) AND "Inner Asia"	0	0
(mire* OR peatland) AND "Middle Asia"	2	0

More extensive research on peatlands in arid climates was conducted for Mongolia (MINAYEVA et al. 2018, MINAYEVA et al. 2017, MINAYEVA 2012, LU et al. 2009). Their results have been adapted as recommendations for actions, to implement wise use and conservation strategies for these ecosystems, like in the '*Assessment Report on Strategic Planning for Peatlands in Mongolia'* (ASIAN DEVELOPMENT BANK TECHNICAL ASSISTANCE 2017) and the '*Strategic Planning for Peatland Conservation and Wise Use in Mongolia'* (WETLANDS INTERNATIONAL 2017).

An inventory of the high-altitude peatlands of Kyrgyzstan was done under the KIRMO project, in close cooperation with the Michael Succow Foundation, with related publications of ALJES et al. (2016), MÜLLER et al. (2016), and HEINICKE (2003). The syntaxonomy of Kyrgyz peatland vegetation was studied by NOWAK et al. (2016). Other previous research focused on vegetation and syntaxonomy of montane spring mires in the Irano-Turanian mountains (Iran, Tajikistan, Kyrgyzstan) by NAQINEZHAD et al. (under review).

1.2 Regional context

1.2.1 Geography and climate of Uzbekistan

Uzbekistan is located in the heart of Central Asia. It is a doubly landlocked state that shares its borders with 5 countries: Kazakhstan (north), Kyrgyzstan and Tajikistan (west), Afghanistan (south) and Turkmenistan (south). It covers an area of ca. 447,400 km^2 (WORLD BANK 2018) and extends between the latitudes 37° and 46° north and longitudes 56° and 73° east. Uzbekistan is divided into 12 provinces and 1 autonomous republic (BELOLIPOV et al. 2013). With a population of 23.3 million, the country is densely populated compared with other Central Asian republics (DAVIESSON & FET 2001).

The climate of Uzbekistan (Figure 1 - next page) is continental to harsh-continental, and generally characterized by low precipitation (70–100 mm per year), while excluding some high mountains where precipitation exceeds 1,200 mm per year (BELOLIPOV et al. 2013). The ecosystems found in these arid climates react particularly sensitive towards anthropogenic disturbances and climate change (BESHKO et al. 2016). According to the UNESCO '*World desertification map*' and the UN '*Convention to Combat Desertification*', Uzbekistan's territory is undergoing intense desertification and drought phenomena, ranking 0.03 to 0.02 in the aridity indices (UNDP 2015, CHUB 2007, UNEP 1999).

Most of the country is characterized by steppes and deserts (79%) that are taking over towards the middle-eastern parts. The winter-cold desert biomes of western Central Asia are characterized by a unique biota and a rich biodiversity with many endemic species (FAO 2017). Towards the west, mountains and foothills rise from the Tien Shan and Pamir Alau mountain massifs (BELOLIPOV et al. 2013). All valleys are fed by these glaciated mountains, providing the water of the two major Central Asian rivers, Syr Darya and Amu Darya. Both are of utmost importance for the water supply and agricultural production of Uzbekistan and adjacent countries (ASIAN DEVELOPMENT BANK 2011, BESHKO et al. 2016). The water resources, including surface water and groundwater, are distributed unevenly across the country (BESHKO et al. 2016). In the mountains, a dense hydrological network is present as a web of streams, fed by the meltwater of glaciers and mountain springs. In the lowlands, only a few streams and rivers cross the plains. Since a considerable part of the water is spent for irrigation, they mostly end in blind channels (BESHKO et al. 2016).

The vegetation of Uzbekistan can be divided into four major biomes: arid plain deserts (*'Chul'*), foothills *('Adyr')*, mountains (*'Tai'*), and alpine zones (*'Yailau'*) (BELOLIPOV et al. 2013). Due to the diversity of soils and climatic conditions, a rich biodiversity is distributed along these altitudinal zones (cf. Annex 1).

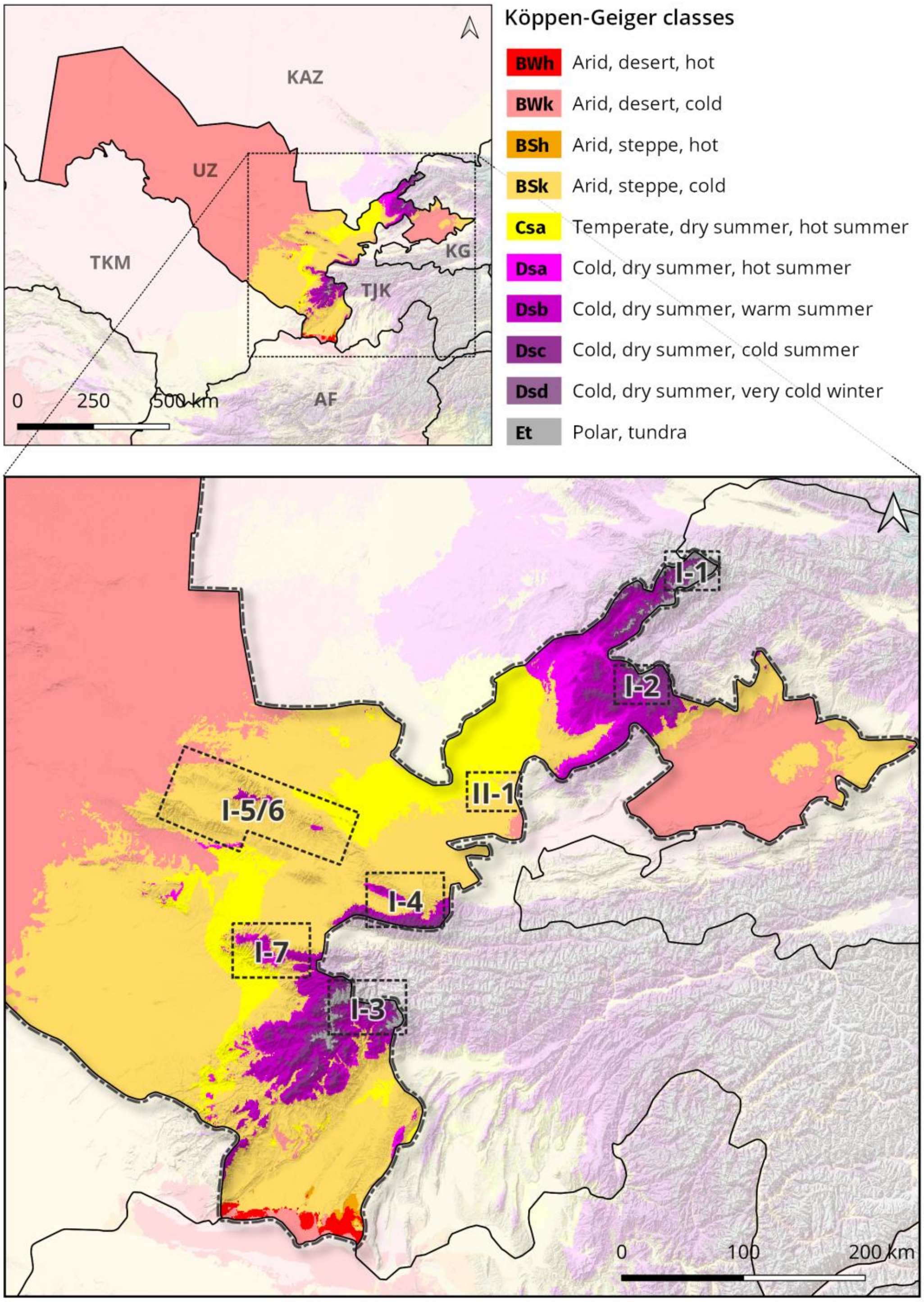

Figure 1: Köppen-Geiger climate classes (after BECK et al. 2018) of Uzbekistan, with study regions.

1.2.2 Peatlands as part of the wetland conservation framework in Uzbekistan

Currently, 5.7% of the Uzbekistan territory are under protection, but only 1.8% are strictly protected (BFN 2015, DAVIESSON & FET 2001). By 2028, the government plans on increasing the protected area coverage to a total of 12% of its territory (IUCN 2020). Four categories of protected areas exist: strict nature reserves (*zapovednik*), national parks, conservation areas (*zakaznik*) and natural monuments (BFN 2015, DAVIESSON & FET 2001) (cf. Annex 2). Since 1995, Uzbekistan has been a member of the *Convention on Biological Diversity* (CBD) (BFN 2015).

Additionally, as part of the *Man and the Biosphere Programme* (MAB) by the UNESCO, the biosphere reserve *Mount Chatkal* was designated in 1978 (UNESCO 2001). Additionally, the riparian floodplains of the lower Amudary were nominated as the proposed *Lower Amudarya Biosphere Reserve*, just recently (BIOSPHERE.CENTER 2020).

Uzbekistan currently has 3 designated *Wetlands of International Importance* ('Ramsar Sites'), with a surface area of 5,904 km² (RAMSAR 2020). These comprise the *Aydar-Arnasay Lakes* system, *Lake Dengizkul, Tudakul* and the *Kuymazar Water Reservoirs* – widely aimed for protecting open water bodies as habitats for waterfowl and migratory birds. Peatland ecosystems do not play a role under RAMSAR. In the *"5th National Report of the Republic of Uzbekistan on Conservation and Biodiversity"* (UNDP 2015), wetlands are discussed primarily as open water bodies (*"[...]plain lakes with marshy coastal sites along the perimeter, which are situated in the zones with insufficient watering. Until recently, they were represented by delta, alluvial and oxbow types..." UNDP 2015*). Other wetland types, such as marshes, fens or peatlands that are included in the wetland concept of the RAMSAR convention (UNESCO 1971), do not find much consideration in the reports (UNDP 2015 & 2018) (Figure 2).

Angren plateau

Figure 2: Picture taken from the UNDP (2015) report, showing what could be classified as fen or another wetland type, but is not specifically identified as such. Photos like this were helpful in finding potential peatland regions (cf. ch. 2.1).

However, the protection of '*Tugai*' (riparian forest) and other floodplain ecosystems, that still exist in small relics along the rivers Amu Darya, Syr Darya, Zerafshan, Chirchik and Akhangaran, are listed among the habitats and ecosystems with the highest priority for Biodiversity conservation in Uzbekistan (UNDP 2015).

1.3 Peatlands – terms and definitions

Terminology and concepts surrounding peatlands are plentiful and often used inconsistently. This chapter provides an overview of the most relevant definitions and terms, as used in this thesis.

'Wetland' has been the umbrella term for the variety of habitats along the transitional zone between land and water since the 1970s (LINDSAY et al. 2016). The Ramsar Convention was adopted 1971 to provide a global framework for wetland protection. Here, wetlands got differentiated into plenty of categories including such for or containing peatlands as 'fens', 'forested peatlands', 'marshes', 'lagoons', or 'alpine wetlands' (UNESCO 1971). In all these habitats, water is the primary factor for plants and animals, with a water table just below the surface or shallow water covering the land (RAMSAR CONVENTION SECRETARIAT 2013).

'Organic soils' have in most of the national or regional classification schemes more than 12–18% SOC (20–30% SOM) dry weight (depending on clay content; cf. BARTHELMES & JOOSTEN 2015). According to BARTHELMES & JOOSTEN (2018), 'organic soils' can be categorized as '*muck'* (the most decomposed form), *'mucky peat*' (the intermediate form), or '*peat'* (the least decomposed form) of organic soil matter.

'Peat' is defined by JOOSTEN & CLARKE (2002) as plant material accumulated *in-situ* ('sedentary') and consists of at least 30% (dry weight) of organic material (OM). This definition has been adopted in this thesis. If the soil sample accounted for 10–30% OM it has been classified as **half-peat**. The differentiation between 'peat' and 'half-peat', as used in this thesis, allows to include lower OM (>10-30%) containing organic soils that would fail the >30% OM threshold of real peat. For peatlands in arid conditions, this classification is deemed more inclusive. The term ‚half-peat' is borrowed from the class 'полуторфянис почвы' – half peaty soils in Russian soil classifications, e.g. that of Mamytov (1995). Succow & Joosten (2001) also differentiates *full-peat*, *half-peat*, and *antorf* based on OM content.

'Peatlands' were heterogeneously defined as having a peat layer ranging from 20 to 100 cm thickness varying across countries and scientific disciplines (CF. BARTHELMES et al. 2015). JOOSTEN & CLARKE (2002) defined 'peatlands' as an area with or without vegetation with a naturally accumulated peat layer at the surface of at least 30 cm depth. While this definition is commonly used to identify peatlands of temperate zones and the tropics, this approach limits peatland research in the more arid climates or in climates of extreme cold (ASIAN DEVELOPMENT BANK TECHNICAL ASSISTANCE 2017). To acknowledge the characteristics and ecosystem functions of peatlands in semi-arid climates and high altitudes, a **30 cm peat layer** situated in the top 100 cm below surface has been applied as minimum to classify a peatland in this thesis.

Based on the classification of the water source, peatlands can be distinguished into two main types:

'Bog' (ombrotrophic): The mire is entirely rain fed, thus the vegetation obtains no solutes from the ground. Plant species, such as peat mosses (*Sphagnum* spec.), ericaceous species, carnivorous plants and cotton grasses are adapted to these nutrient poor and acidic conditions.

'Fen' (minerotrophic): Waterlogged by groundwater or by surface water, the water is enriched by the solutes from the bedrock or subsoil. Nutrient levels of fens can be very diverse. Fens display a variety of forms, with vegetation ranging from moss carpets to sedge stands or to tropical forests. (LINDSAY 2016).

'Mire' is a peatland where peat is currently formed and accumulating (JOOSTEN et al. 2017). It is in this context used as an all-embracing term for peatland ecosystems, associated with peat formation (LINDSAY 2016). Thus, for a mire, it is easier to reject the criteria of peat depth (ASIAN DEVELOPMENT BANK TECHNICAL ASSISTANCE 2017).

'Boloto' (≈ *mire, swamp*) has been in most scientific fields and branches defined using the definition of GOST (1973) were "boloto" is a "a natural formation that occupies part of the land surface and represents peat depositions saturated with water and covered by specific mire vegetation." However, in botany for example, the presence of a peat layer is not a compulsory attribute of a "*boloto*" NITSENKO (1967) and "*torfyanoye boloto*" ('peat bog') was suggested as term to exclude variant semantic interpretation. It has become customary in recent years. The Russian word "*boloto*" is actually a geographical term that characterizes a specific landscape with specific vegetation, humidity, and soil processes. "*Torfjannyje boloto*" can be equaled with a "boloto on a peatland", independent of whether the prevalent vegetation can produce peat or not. Agronomists, however, may use the same expression to indicate a "*torfjannaja počva*", i.e. a peat soil (PJAVTSCHENKO IN LARGIN 1960).

Histosol: also includes areas of shallow peat layers (≥ 10 cm), when these layers are directly situated on top of rock or ice. Histosols cover a variety of peat types, including sedge/reed peat (fen) or moss peat (bog). In Russian soil classifications, the term *peat soil* is used synonymously (FAO 2015).

Soil organic matter (SOM) and organic carbon (SOC): Soil Organic Carbon (SOC) is the carbon share on the entire Soil Organic Matter (SOM). The latter range from living organisms to decaying plant material or charcoal (GRIFFIN et al. 2013).

2 Methods

Given the scarcity of information on peatlands in Uzbekistan and the exploratory nature of this work, different methods are needed to answer the research questions. BARTHELMES & JOOSTEN (2018) offers a scientific and technical guidance for locating and assessing peatlands, which serves as a methodological framework for this study. Following this guidance, the methods comprise three steps:

(1) Preparatory desk study (Chapter 2.1 to 2.4)
   a. Compilation of proxy data, from literature and geodatabases (Chapter 2.1, 2.3)
   b. mapping of potential peatlands, based high resolution satellite images and geospatial information, like indices and a DEM analysis (Chapter 2.4)

(2) Field work (Chapter 2.5)

(3) Laboratory analysis of the field data (Chapter 2.5)

The thematic and spatial scope is at first set on a broad, nationwide scale, then narrows down to representative regions, and finally to probable peatland locations some of which could be studied during the field survey.

2.1 Compilation of proxy data

Since high resolution spatial data or literature on peatlands for many countries in Central Asia (including Uzbekistan) is rare, proxy data is essential for the indication of regions that may host peatlands. This proxy data includes information on e.g. bedrock, soil, vegetation, land cover and land use or topographical features (BARTHELMES et al. 2015).

Meta-study of available literature and geo-databases:

As the first step of the literature search, several scientific search engines have been screened for publications on wetlands, agriculture (e.g. ISI Web of Science: https://apps.webofknowledge.com/; Google Scholar: https://scholar.google.com/).

Following the guidance (BARTHELMES 2015), other databases have been accessed for thematic geospatial data on e.g. land use, soil characteristics or wetland distribution: *The International Soil Reference and Information Centre* (ISRIC World Soil Information), the *Food and Agriculture Organization of the United Nations* (FAO) Repository, the *World Soil Survey Archive and Catalogue* (WOSSAC) and the *Global Wetlands Map* (v.3) by the *Sustainable Wetlands Adaptation and Mitigation Program* (SWAMP). For climate data, the new global maps of the Köppen-Geiger climate classification (1 km resolution) by BECK et al. (2018) were used, because they offer a higher accuracy and more detail than previous climate classifications.

Beside material available online, large amounts of scientific knowledge, especially older work is not available on the internet, or only becoming available gradually (GUTHRIE 1998, RIEGER 2010). The studied literature for this thesis included several titles published decades ago by Soviet scientists. These hard copies were available in the 'Peatland Library', a literature collection by Prof. H. Joosten (University of Greifswald). Some other, often historical, titles (such as the extensive 'Flora Uzbekistan') were available digitally as scanned PDFs. Several books covered the topics *land use*, *vegetation*, *land cover* and *geography* of former USSR states in Central Asia, including Uzbekistan. From them, information on e.g. wetlands, land use of mountain meadows, vegetation (e.g. reed stands or wet meadows), or the localization of wetland indicator plant) have been extracted. However, this data needs to be treated with caution – large-scale land use changes led to the drainage of wetlands over the past decades, rendering some historical sources obsolete for present-day research. Up-to-date botanical books have been provided by the botanists of the Tashkent Botanical Institute.

Other sources

So-called 'grey literature' was used during the study, especially for the definition of proposed study regions. This included unpublished reports and photo documentations from recent research of local botanists (e.g. Natalya Beshko from the Uzbekistan Academy of Sciences). A botanical excursion to the Pskem alley, for example, sparked the idea for this research topic, when members from the Michael Succow Foundation (Jens Wunderlich and Rustam Murzakhanov) unexpectedly found promising wetlands in the area. Further included were official reports about different environmental or agricultural development programs by international organizations (IOs). Since the overall amount of up-to-date scientific information to determine fiend potential peatland locations was very low, online databases with geo-tagged pictures, such as Google Earth, were searched. For a discussion of the credibility and usefulness of these data sources, cf. chapter 4.3.

2.2 Integration of geodata for a national peatland probability map

All GIS work was conducted in QGIS 3.14, an open source, professional desktop GIS. Geodata obtained from online databases (Chapter 2.1) was imported into a GIS project. For this, two historical soil maps (Annex 3 & Annex 4) were manually georeferenced. The FAO's '*Digital Soil Map of the World*' was added as raster data. Additional data have been included through the 'QuickMapServices' plugin of QGIS, which grants access to a vast compilation of Russian topographic maps from '*Topomap (marshruty.ru)*', covering scales from 1:100,000–1:50,000.

The relevant proxy features (Table 2) from the collated digital maps were manually digitized as polygons, in a projected coordinate reference system (Projection: UTM 42N, Datum: ETRS89). A scoring system was applied to evaluate the reliability of the data sources to indicate peatland occurrence (initially based on the methods developed by MALPICA-PIÑEROS 2018 & VILLEGAS-MEJÍA 2018). Because of the data scarcity, the weighing of the source types proposed by MALPICA-PIÑEROS (2018) and VILLEGAS-MEJÍA (2018) have been dispensed to a simplified ranking with the values denoting:

1: very good peat indication; **2**: medium peat indication and **3**: little peat indication.

Table 2: Data sources and their respective features, as they were displayed in the legend of the respective maps. The features listed in this table were digitized and displayed by the score of their ranking in a peatland probability map.

PROXIES				
Rank	**Name of source**	**Orig. format**	**Scale**	**Year**
	Почвенная Карта Уцбекистой ССР *(Soil map of USSR Uzbekistan)*	Scanned map	1:1,500,000	1960
1	- Болотные *(swamps)*			
3	- Болотные солончаковые *(salt swamps)*			
2	- Лугово-Болотные *(meadow swamps)*			
2	- Луговые и болотные засоленные о незасоленные пойменные *(Meadows and swamps, saline or non-saline, in floodplains)*			
	Почвенная Карта Среднеазиатских Республик (*Soil map of Soviet Central Asia*)	Scanned map	1:2,500,000	1970
2	- Болотные луговые аллувиальные […] *(meadow swamps, alluvial)*			
2	- Луговые и болотные пойменно-аллувиальные […] (*meadows and swamps in alluvial floodplains)*			
	FAO – The Digital Soil Map of the World	WMS	1:5,000,000	1995
3	- Calcaric Fluvisols			
3	- Eutric Fluvisols			
2	- Calcaric Gleysols			
2	- Eutric Gleysols			
3	- Gleyic Solonchaks			
	CIFOR Tropical and Subtropical Wetlands Distribution v.2	geoTIFF	231 m (limited to 40°N)	n.y.
1	- Swamps, incl. bogs with peat (30)			
2	- Floodouts on alluvial deposits, peat forming (60)			
3	- General marshes, no peat formation but organic matter accumulation (80)			
	Topomap (marshruty.ru)	WMS	1:100,000 – 1:50,000	n.y.
	- wetland signature			
NEGATIVE PROXIES:				
	FAO Global Map of Irrigation Areas v.5.0	ESRI Shapefile	5 arc minute grid cell	n.y.
	All irrigated areas			

2.3 Selection and description of the selected study regions

The study regions were chosen based on the results of the desk study (cf. ch. 3.1.). They aim to reflect the geographical diversity of landscapes potentially bearing peatlands in Uzbekistan and cover a broad range of biogeographical regions, geological landscape units, altitudes, and climates. The study regions are concentrated in the eastern part of Uzbekistan which offers the highest diversity, with mountain ranges of the Western **Tien Shan** and the Western extremities of the **Pamir Alay**. Towards the north-west, the Pamir-Alai mountain range fades into the desert and some last isolated foothill ranges, like the **Zerafshan** Mountains in the **Urgut** region, or the **Nuratau** and **Aktau** mountains, in the north. The upper course of the **Syr Darya** crosses the lowland parts of eastern Uzbekistan, accompanied by meanders and oxbow lakes. Besides fertile, irrigated cropland, with cotton fields and paddy fields for rice cultivation, orchards, and settlements, vast steppe lands are used for grazing (BESHKO et al. 2016).

A total of **7** study regions were defined, six are located in the highlands (I) and one in the lowland (II; (Figure 3). The naming of the study regions is loosely oriented on 'the scheme of phytochoria', as described by BESHKO et al. (2016).

Figure 3: Location of study regions. HIGHLAND: I-1 Pskem Valley; I-2 Angren Plateau; I-3 Gissar Mountains; I-4 North-Turkestan; I-5/6 Nuratau/Aktau; I-7 Urgut; LOWLAND: II-1 Syr Darya.

2.3.1 Pskem Valley

The region (I-1 in Figure 3) is located in the very east as a narrow appendix of the country in the mountainous area of the western Tien Shan. The Pskem mountains (south) and Ugam mountains (north) are forming the natural border region between Uzbekistan and Kyrgyzstan. Here, the river Oygaying, a tributary of the Pskem river, has its origins (NAZARALIYV & JUMABAEVA 2019). It flows through a narrow gorge, framed by glaciated mountains, which are part of the study area. The whole area belongs to the *Ugam-Chatkal National Park,* the largest nature protection complex in Uzbekistan (BRADEN 1986, SCARNECCHIA 2004). About 95% of the precipitation in Pskem valley falls between October and May. Precipitation averages at 800 mm, with high intra-annual variability. The average annual temperature is 9.5°C (NAMARA et al. 2009). Between the 1960s and 2010 an increase in temperatures of 0.5–2°C led to a 16–23% shrinkage of glaciers in this area (GLAZIRIN & SEMAKOVA 2019, SEMAKOVA 2015)

2.3.2 Angren Plateau

The Angren Plateau (I-2 in Figure 3) is located in the Chatkal mountain range. To the east, it forms the natural border between Uzbekistan and Kyrgyzstan. For this reason, permits are required to cross the military post that guards the region's inner-country border zones. The glaciated mountains form the watershed of the Arashan river, which flows through a landscape shaped by countless little streams that end in a deep canyon, where they unify to form the Okharangon river. Due to the plateau character of the region, the relief of the central part is less extreme and characterised by some flatter areas with hills and gentle valleys. Half of the study region is under the protection of two designated reserves: the *Ugam-Chatkal National Park* and the *Chatkalskiy State Nature Reserve* (BRADEN 1986). The flora of the Chatkal mountain reserve is part of the western Tien Shan floristic district and extremely rich in species (SCARNECCHIA 2004).

2.3.3 Gissar Mountains

This study region (I-3 in Figure 3) is located in the very east of the Gissar range, the western extremity of the Pamir-Alay, stretching over southern-Uzbek and western-Tajik territory. The rocky mountainscape of the Gissar mountains, with steep valleys, glaciers and alpine rivers, also includes the highest mountain of Uzbekistan, *Khazret Sultan* (4,643 m). Precipitation is mostly bound to winter and spring, and reaches up to 2,000 mm in the glaciated parts (FET & FET n.d.) Parts of the area are under protection by the *Ghissarskiy State Nature Reserve* (LEMENKOVA 2018, SCARNECCHIA 2004). Numerous rare species and distinctive ecosystems are preserved here, including the endangered and elusive snow leopards (*Panthera uncia*). Besides the richness in biodiversity, the region’s unique geological features and cultural heritage are outstanding making the nature reserves also part of the *World*

Heritage Site 'Gissar Mountains' (LETHIER 2020). Access to the reserve is restricted, it can only be visited for scientific research.

2.3.4 Turkestan mountains

The Turkestan range (I-4 in Figure 3) forms the natural border Uzbekistan and Tajikistan. The study region is located in the north-western part of these mountains, including the *Zaamin National Park* and the *Zaamin Nature Reserve* (*'Zaamin Zapovednik'*), which is one of the oldest protected areas in Central Asia (BESHKO et al. 2016). Precipitation is considerably lower compared to the Gissar region, with 1,000 mm annually (FET & FET n.d.). The elevation in this region ranges from 600–700 m a.s.l. to 4,029 m, thus, representing the complete profile of altitudinal belts. Though botanical research for the hard to reach border region is still incomplete, it is estimated to harbor about 1,500 plant species (BESHKO et al. 2016). Characteristic for the region and its protected areas are the mountain pines (*Juniperus*) ecosystems (1,760–3,500 m a.s.l.), that are intended for nomination as UNESCO World Heritage site (UNESCO 2008).

2.3.5 Nuratau/Aktau Foothills

The relic mountain ranges in this study *region* (I-5/5 in Figure 3)*)* are located in the transitional zone between the mountain systems of Pamir-Alay and Tien Shan, and the arid plains of the Turan lowland (BESHKO et al. 2016). The Nuratau mountains reach over 2,100 m a.s.l. (GINTZBURGER 2003). Climate conditions are defined by the hot, very dry summers and mild winters. The xerophytic vegetation benefits from the arid conditions and general water scarcity. Almost all altitudinal belts and landscape types of Central Asia are present here, including plains, foothills, low and middle mountains; only the alpine belt is missing. Human activities have shaped the landscapes for centuries. Linked to the historical land use is the establishment of the Nuratau Walnut reserve, which conserves walnut gallery forests, that represent an original cultural landscape. Since the 1960s, intensive grazing pressure and cutting of bushes and trees have led to the degradation of vegetation (BESHKO et al. 2016).

2.3.6 Urgut (Zerafshan Mountains)

The foothills from study region (I-7 in Figure 3) are situated in the Urgut region and belong to the western extremities of the Zerafshan ridge, which is part of the IUCN and WWF '*world list of centers of plant diversity*'. Under the semi-arid climate conditions, the landscape includes piedmonts, as well as lower and middle mountain belts (BESHKO et al. 2016). The elevation range is relatively low in comparison to other highland study regions, which explains the overall smaller biodiversity. As a result of a history of centuries long history of anthropogenic pressure, the vegetation is significantly degraded. However, it comprises a transitional character with an exceptional species composition and hosts numerous endemic and endangered species (BESHKO et al. 2016).

2.3.7 Syr Darya River

The Syr Darya (II-1 in Figure 3) follows a meandering course along her middle reaches, crossing the wavy, hilly landscape of the Hunger Steppe and alluvial plains (BESHKO et al. 2016, TALTAKOV & KAZAKH 2016). The river frequently changes its bed, resulting in the formation of oxbow lakes. However, many lakes situated in the flood plains have disappeared or decreased in size as a result of water withdrawal for irrigation (UNDP 2015). The climate is characterized by hot and dry summers and very mild winters. Almost the entire region around the Syr Darya floodplain is dominated by anthropogenic landscapes (BESHKO et al. 2016), covered by extensive, irrigated cropland, dominated by cotton and accompanied by rice cultivation (TALTAKOV & KAZAKH 2016). Only a few plots of natural ecosystems remain, such as small undeveloped areas of the Dalverzin Sands, relic stands of Tugai vegetation and small salt marshes in terrain depressions (BESHKO et al. 2016).

2.4 Mapping of probable peatlands

2.4.1 Defining key features

Manual identification and delineation of wetlands from remotely sensed data are commonly used methods (ANDERSON et al. 2012). They allow for the accurate mapping of boundaries and the production of visually appealing maps (ZHANG et al. 2011). Key factors that help in delineating peatlands from surrounding dry-land have already been identified for the tropical settings (LAWSON et al. 2015, BARTHELMES et al. 2015). Because of the different geographical setting of this study, these approaches have been transformed to match the regional and local conditions. Key features to identifying wetlands/potential peatlands based on satellite imagery are:

FOR HIGHLANDS:

- **vegetation type:** green and dense, homogeneous, grass-like
- **vegetation seasonality:** no seasonal vegetation changes, in contrast to the surrounding
- **topographic setting:** gentle slopes, N to W slope aspect, altitudinal range ~ 1,500–2,500 m, relation to water bodies (rivers, lakes)
- **soil features:** dark color, sometimes winding erosion channels, only little sediment load

FOR LOWLANDS:

- **vegetation type:** wet meadows and non-submerged reed stands, excluding open water, submerged reed stands, rice fields (very high NDVI, very green on true-color imagery) and sparse steppe vegetation

- **landscape setting:** transition zones along oxbow lakes and meanders, between water/submerged reed stands and dry-land
- **soil features:** dark color
- **land use (negative proxy):** channels, dykes, dams, terraces and other artificial shapes, indicating agricultural activities and irrigation.

For the mapping of probable peatland locations, different sources have been combined to exploit the maximum potential of freely available data and their advantages: **a)** middle resolution, multispectral satellite imagery, **b)** high and very high resolution (HR, VHR) optical imagery, and **c)** Digital Elevation model (Figure 4).

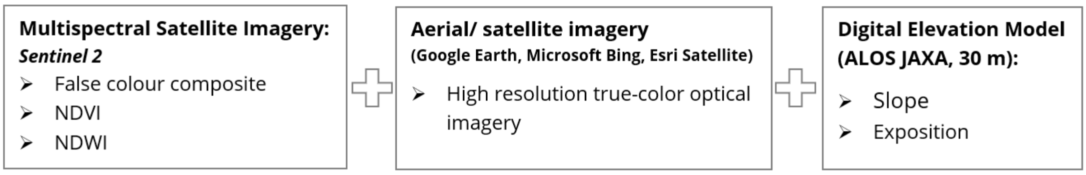

Figure 4: Combination of different remotely sensed and spatial data to create the peatland probability map.

2.4.2 Index-based classification

Peat formation is bound to both continuous water supply and biomass accumulation from vegetation. Indicators for these conditions can function as proxies for the mapping of potential peatland locations, e.g. in highlands. Two indices commonly used in ecological research using earth observation data have been chosen as proxies for the potential occurrence of peatlands (NDVI and NDWI, see below). They were calculated from multispectral Sentinel-2 imagery (Table 4), with scenes captured during summertime. In the summer season, only the vegetation growing on wet sites, such as peatlands, remains green in arid climates. The surrounding steppe vegetation mostly dries out above ground after a short vegetative spring season (ALJES et al. 2014).

Sentinel scenes were downloaded from the Copernicus Open Access Hub (https://scihub.copernicus.eu/dhus/#/home), and selected based on season, timeliness, and the lowest amount of cloud cover. Acquisition dates of the Sentinel scenes were *21/06/2018, 01/07/2018, 14/07/2018, 24/07/2018 and 27/07/2018.*

The **NDVI** (*Normalized Difference Vegetation Index*) is a well-known and widely used index to measure plant cover and plant health and, thus, net primary productivity (ROUSE et al. 1974, ROCCHINI et al. 2016). NDVI values range from -1 to 1. The NDVI is calculated from the bands Near Infrared (NIR) and Red as $\boldsymbol{NDVI} = \frac{NIR-Red}{NIR+Red}$ or, in terms of Sentinel-2 as $\boldsymbol{NDVI} = \frac{Band\ 8-Band\ 4}{Band\ 8+Band\ 4}$ (Table 3:). The range of values to detect potential peatlands needs to exclude sparse vegetation of steppes and very dense, green vegetation of forests or croplands. For the imagery, season and area used, these criteria are met for a range of *0.4–0.9.*

With the **NDWI** (*Normalized Difference Wetness Index*), the water content of vegetation can be estimated (GAO 1996, ROCCHINI et al. 2016). It is commonly used in wetland studies (KAPLAN et al. 2019) and ranges from -1 to 1. The NDWI is calculated as $\boldsymbol{NDWI} = \frac{\boldsymbol{NIR-MIR}}{\boldsymbol{NIR+MIR}}$ or, in terms of Sentinel-2, as $\boldsymbol{NDWI} = \frac{\boldsymbol{Band\ 8-Band\ 12}}{\boldsymbol{Band\ 8+Band\ 12}}$ (Table 3:). The suitable range serving as a proxy for potential peatlands was tested, as for the NDVI, and found to deliver the best results in most regions if set to *0.2–0.5*.

Table 3: Calculation of indices (NDVI, NDWI after ROUSE et al. 1974 and GAO 1996). For details on bands, their wavelengths and resolution see Table 4 below.

Index	Formula	Formula with Sentinel-2 bands	Range of values used for wetland proxy
NDVI =	$\frac{NIR - Red}{NIR + Red}$	$\frac{\text{Band 8} - \text{Band 4}}{\text{Band 8} + \text{Band 4}}$	0.4–0.9
NDWI =	$\frac{NIR - MIR}{NIR + MIR}$	$\frac{\text{Band 8} - \text{Band 12}}{\text{Band 8} + \text{Band 12}}$	0.2–0.5

Table 4: Sentinel-2 bands with central wavelength and resolution (from KAPLAN & AVDAN 2017a).

Sentinel-2 bands	Central wavelength (μm)	Resolution (m)
Band 1 – Coastal aerosol	0.443	60
Band 2 – Blue	0.490	10
Band 3 – Green	0.560	10
Band 4 – Red	0.665	10
Band 5 – Vegetation red edge	0.705	20
Band 6 – Vegetation red edge	0.740	20
Band 7 – Vegetation red edge	0.783	20
Band 8 – NIR	0.842	10
Band 8A – Vegetation red edge	0.865	20
Band 9 – Water vapour	0.945	60
Band 10 – SWIR – Cirrius	1.375	60
Band 11 – SWIR	1.610	20
Band 12 – SWIR	2.190	20

All work was executed in QGIS. The layers were prepared using the 'Semi-Automatic Classification' plugin; preprocessing included atmospheric correction and layer stacking. The scenes were then merged and clipped to match the extent of each study region. With the raster calculator, NDWI and NDVI were calculated (see above) for the mountain study regions. The lowland study region was excluded because the potential peatlands are restricted to selected features, such as oxbows and meanders (cf. 2.3.7 & ch. 2.4.4). Additionally, these indices would have been unsuitable for the lowlands, since they would have been unable to distinguish between potential peatlands and certain agricultural activities, such as rice paddies.

Based on the raster value range of NDVI for the mountain study regions (Table 3), the raster layer was reclassified to create a new binary raster with the NDVI raster values ranging from *0.4–0.9.* were set '1' and values outside of that range '0', respectively. Accordingly, the NDWI raster value range from *0.2–0.5* was set '1', and values outside of that range were set '0'. Both rasters were then aggregated using the raster calculator. This delivered a matrix of values ranging from 0 (no indications for NDWI or NDVI), 1 (only one of the indices matching), and 2 (both indices matching). The raster was then vectorized and areas of misclassification, caused by mountain shadow or glaciation, manually corrected.

The resulting combination of the NDVI and NDWI indices and its visualization helped to visually delimit potential peatland areas. It furthermore assisted in removing false positives during the manual mapping while using the high and very high resolution satellite imagery (Figure 5).

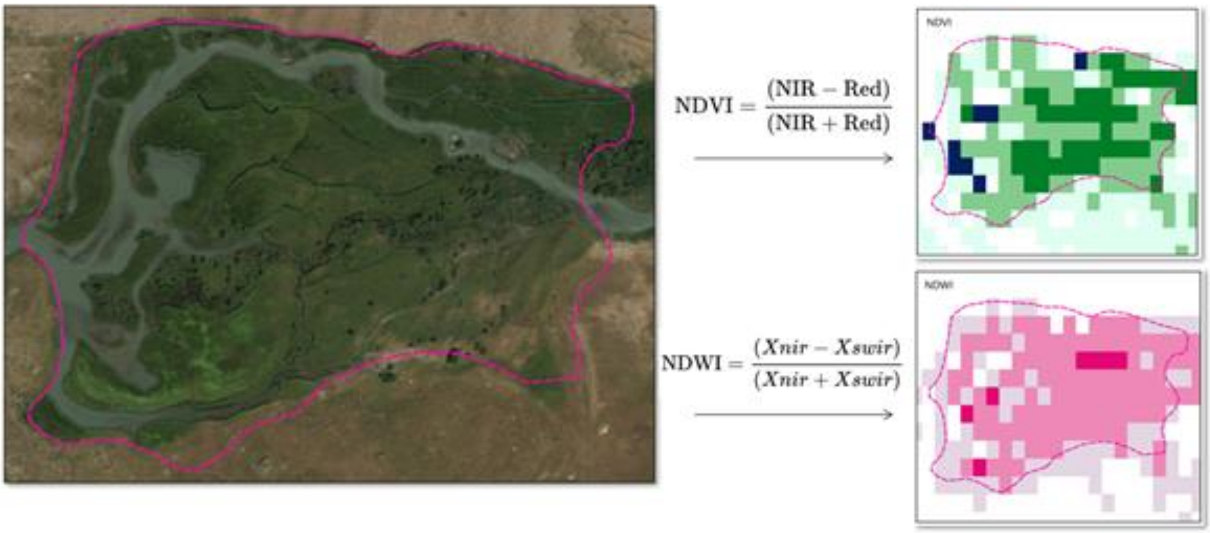

Figure 5: Visualization of the selected values of NDVI *(0.4–0.9)* and NDWI *(0.2–0.5)* used for indicating potential peatlands, exemplary at a probable peatland ID 11 (cf.Annex 5) in the Pskem Valley.

2.4.3 Raster DEM analysis

Topographic settings, such as *altitude*, slope *steepness*, slope *exposition*, and general *elevation* influence the occurrence of spring water (GHIMRE et al. 2019), which may act as potential sources for peatlands, because it provides steady water supply. Gentle slopes, low relative relief, north- and east-facing slopes, altitudes between 1,500–2,500 m, high vegetation density and forest demonstrated a higher likelihood of spring occurrence (GHIMRE et al. 2019). Thus, a raster analysis of a digital elevation model (ALOS JAXA, 30 m global DSM) was conducted in QGIS, to calculate slope gradient, slope aspect, and to visualize the surface elevation (m a.s.l.). Furthermore, the position of peatlands is often bound to rivers, either located directly along the water body, where the flow rates are decreased by a blockage and meanders, or assembled in a fan-shaped formation at the headwater of mountainous streams. These settings were highlighted by a hillshade overlay, extracted from the DEM (see above).

2.4.4 Delineating probable peatlands

The probable peatland locations were manually digitized in QGIS, as vector polygons. The mapping was done in the UTM projection. Being an equal-area projection, it conserves extents and, thus, it allows for the further calculation of the object's area (WEGMANN & LEUTNER 2016).

Figure 6: Burning field, leaving behind dark soils, as visible from space.

The high and very high-resolution optical imagery from the different sources (Google, Bing, Esri) was interpreted visually for the key features (cf. above; Figure 7), that point to probable peatlands. In mountainous regions, these were often characterized by a noticeably green vegetation, demarcated sharply from the surrounding steppes. In some places, more open vegetation cover made it possible to recognize the color of the underlying soil, which generally becomes darker with increasing levels of organic matter content. Other factors that lead to a darker hue must be carefully considered in the respective context of the feature, e.g. the soil might be dark from burning activities, as witnessed in the Syr Darya region (Figure 6). Regarding the surface characteristics, boulders, 'sprinkled' across the landscape, can often be detected in remote sensing imagery and indicate a high sediment load. This was interpreted as a hindering factor for peatland formation. The supplementary information on wetness, vegetation density or the setting of sites in the terrain gained from the index based classification (cf. ch. 2.4.2) and the terrain analysis of the DEM (cf. ch. 2.4.3) was used to support the delineation of probable peatlands. Figure 7 shows interpreted features from a mountainous potential peatland in the Angren Plateau.

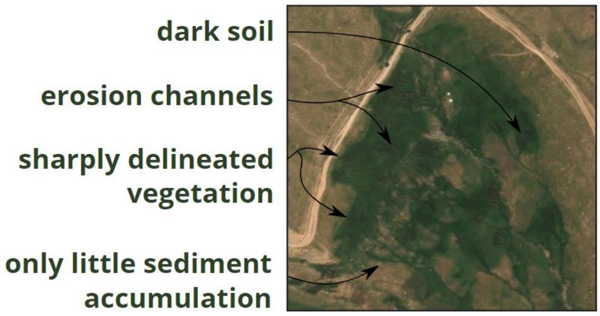

Figure 7: Example of a potential peatland location (I-2 Angren Plateau, Annex 6). Key features which are useful for identification are pointed out.

To assess the occurrence of probable lowland peatlands in the **Syr Darya basin** (Study region II-1, Annex 11), the methods for peatland delineation had to be adapted compared to the mountainous regions. This study region is dominated by the Syr Darya river floodplain. Vegetation here is generally denser than in the highlands and intensive production of mainly rice and cotton is common. Based on the findings of the field research (cf. ch. 3.3.2.4 & 4.1.2), mapping of probable peatland locations focused mostly on the transitional areas between land and water, along the meandering oxbow lakes. Here, the vegetation often forms non-submerged reeds and wet meadows. The false-color composites of Sentinel-2 imagery, like the band combination 8-4-3 (corresponding to NIR-Red-Green), was used for differentiating between vegetation types and to detect open water, in combination with the VHR and HR Google Earth and Bing imagery (Figure 8). The areas considered as potential peatlands were manually digitized as polygons. Those areas that have been changed due to land reclamation were digitized with the status of "lost potential peatland".

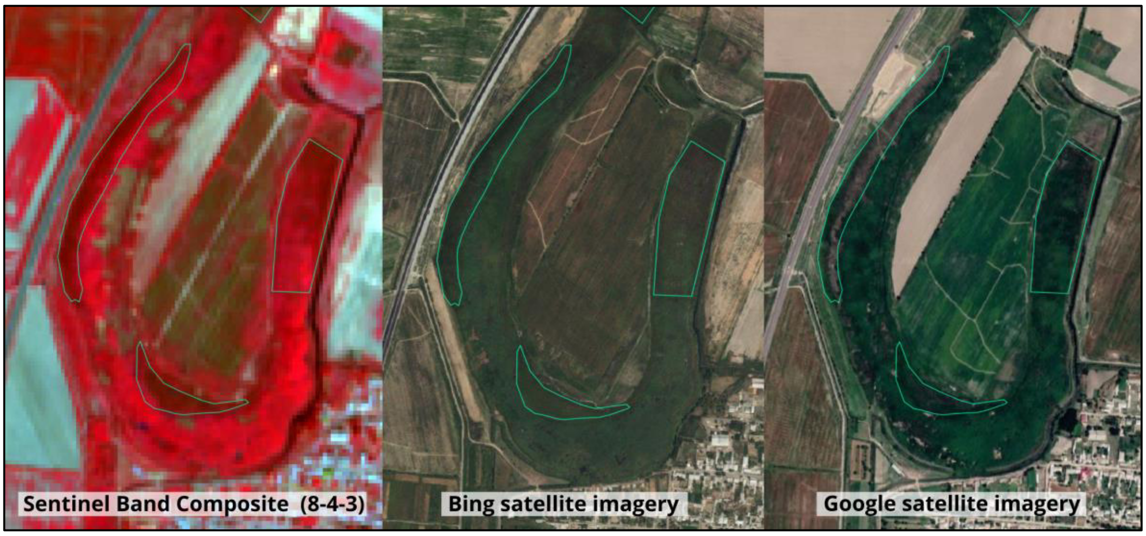

Figure 8: Comparison of different imagery used for probable peatlands mapping. Potential peatlands are located along transition zones between land and water.

2.5 Field study

Field data was collected between 10th – 24th of July 2019 in eastern Uzbekistan at 30 sample sites (Figure 9, next page & Annex 12). Logistics, administrative and scientific support from many persons enabled the field visits to Nuratau, the Chimgan Mountains, the Angren Plateau, the Zerafshan Biosphere Reserve, the Zerafshan mountains, and the Syr Darya floodplain.

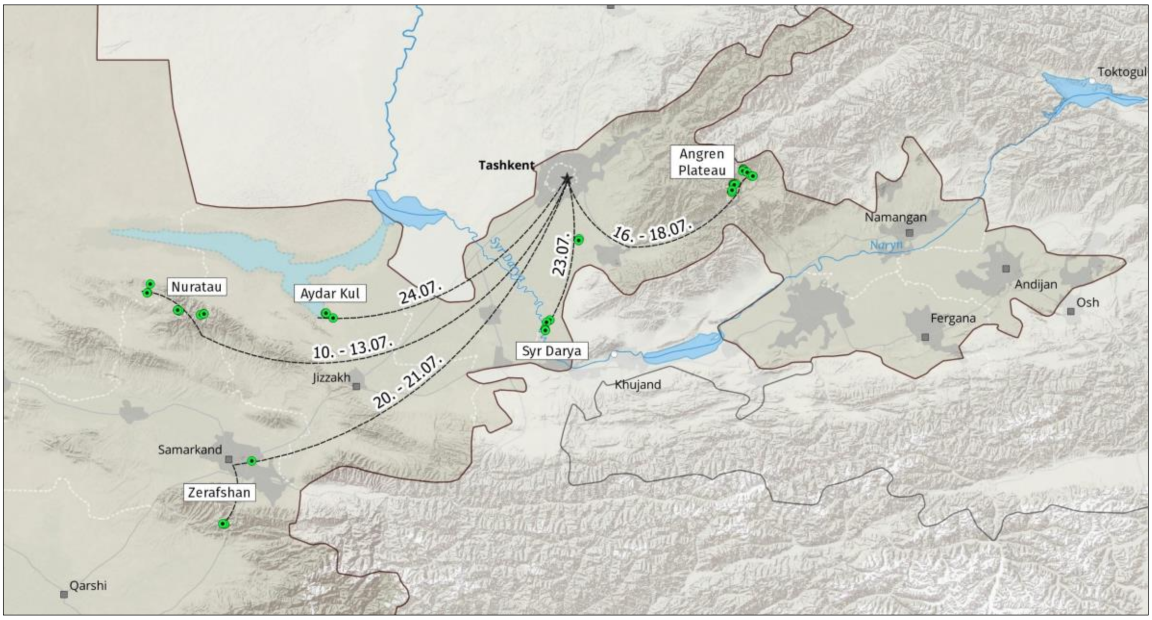

Figure 9: Field excursions and tested sites.

Sampling was conducted by Cristina Malpica-Piñeros and me, and in regards to vegetation mapping, supported by Natalya Beshko, who also handled the logistics of the field trips and helped us overcome administrative hurdles. For the trip to Nuratau we accompanied a group of botanists from the Botanical Institute of the Academy of Sciences, Tashkent. K.Sh. Tojibaev (Director of the Botanical Institute) and N. Beshko joined for the field trip to the Chimgan Mountains, on the Angren Plateau. For the trip to the Samarkand region, including Zerafshan Biosphere Reserve and the Zerafshan mountains, we had the support of A. Akhmedov. Lake Aydar Kul was visited by C. Malpica, together with N. Beshko. The day trip to the Syr Darya was accompanied by N. Beshko, and supported by local fishermen who provided us with a boat to reach our sample sites. Thanks to our driver and a Lada Niva 4x4, we were able to reach remote destinations.

A separate field trip to the Syr Darya was conducted in September from staff of the Michael Succow Foundation (S. Rilke), Greifswald University (P. König) and Tashkent University (B. Khabibullaev) and provided additional information on the river vegetation for an automated classification. Since I unfortunately could not participate myself, I prepared a guide and defined points along different vegetation gradients to be sampled for dominant vegetation cover and soil properties. Due to the seasonally high-water levels, the wetland locations were not accessible, thus, preventing the group from reaching promising peatland locations.

In preparation of the field survey, maps in A2 format were prepared in QGIS for each study region. They highlighted potential peatland locations to be visited, backdrop satellite and topographical information, and served as orientation during the excursions. Additionally, the coordinates of the determined points for the field survey were transferred to a hand-held GPS (Garmin GPSmap 60CSx), to help navigating to the selected probable peatland sites. However, the actual sampling sites in the field had to be chosen on-site, e.g. where vegetation cover was still present in the heat of July, indicating steady water supply, and by their accessibility. The chosen sites were tested for their characteristics and the information filled in a prepared form (see below & Annex 13)

GPS coordinates (UTM), elevation (m a.s.l.), slope, degrees of surface exposition were determined with the handheld GPS device and additional documented. The surface exposition (if sloped) was measured with a compass (SUUNTO MC-2). Wetness of the site was estimated using a self-developed scale, from: *dry* (dry soil and surface), *medium wet* (wet soil, but wetness barely detectable on the surface), *wet* (wet soil and wet surface) to v*ery wet* (water saturated soil and water excessively present on surface, either standing or overflowing), or s*ubmerged sites* (submerged completely under water, creating permanently anoxic conditions). Land use and signs of degradation (disturbed vegetation cover, landslides, water erosion gullies, pollution, etc.) were estimated visually. Remarkable or important site characteristics, such as special relief forms, wetland characteristics, special land use types were documented in the form of written text and sketches leading to schemes of peatland types (cf. ch. 4.1).

Soil assessment

Soil cores were extracted at each site using a hand drill (chamber 1 m length and Ø 22 mm). The UTM coordinates of each core location were recorded with the GPS device. The cores were photographed (Olympus E-PL5 & Canon EOS Digital Rebel XTi; raw format) next to a label, showing the individual core ID, and a metric scale for reference. In very wet locations and at sites with high concentration of mineral components (mostly located along the Syr Darya and the shore of Aydar Kul), the extraction with the hand drill was not possible, because the soil substrate did not stick to the coring chamber. In this case we extracted material with the help of a spade or by digging manually.

The assessed soil characteristics were soil color, substrate (sandy, silty, loamy, skeletal rich) and type (gley soil, organic soil, etc.). If present, the peat layer depth was measured and the degree of decomposition assessed. The first interpretation of the soil was done *in-situ* by me and C. Malpica. With some experience, peat or organic soils can be differentiated from mineral wetland soils by analyzing typical features, namely texture, color and weight (Barthelmes & Joosten 2018). This method of *in-situ* assessment of wetland soils turned out to be very reliable. To evaluate the quality of the *in-situ* peat classification and to specify the amount of OM, soil samples were extracted for laboratory analysis (cf. ch. 2.5). For each sample, ca. 5 cm slices were taken from the chamber of the hand drill. The depth of the sample was documented, along with the core and sample ID.

Vegetation

Research on the vascular vegetation was carried out by comparing the phytodiversity of the different regions. The identification of plant species was executed by N. Beshko, senior researcher of the Institute of Botany (Tashkent). This ensured a high quality of plant determination. Sampling took place within each mountainous region, covering representative wetland types.

Adjusting to the limited time foreseen for the field survey, a combined vegetation assessment for three sub-regions was conducted, without differentiating between single sample sites (1–30):

- wetlands around Lake Arashan on 2,700–2,800 m (*sites 10, 12, 13*)
- wetlands in alpine valley on 2,300–2,450m (*sites 15, 16*),
- wetlands around Lake Fazilman/Sentob Valley (*sites 4, 5, 6*)

With this approach we were able to cover a larger area while still delivering meaningful results to differentiate between the different montane zones. We chose this method, because the sample sites of each sub-region were often small and grouped in a close perimeter, thus being syntaxonomically similar. The well-established method of BRAUN-BLANQUET (1964) was chosen and adapted to document plant species and their coverage, with a scale representing the following classes (Table 5):

Table 5: Adapted Braun-Blanquet scale for the vegetation assessment at sites 4, 5, 5, 10, 12, 13, 15 and 16 (see above).

Key:	**r**	**+**	**1**	**2**	**3**	**4**	**5**
Abundance:	very few individuals	few individuals	numerous individuals	any number of individuals	any number of individuals	any number of individuals	any number of individuals
Cover:	**<1%**	**<1%**	**1–5%**	**6–25%**	**26–50%**	**51–75%**	**75–100%**

The species were later grouped into four categories, based on their habitat preferences: xerophytes, mesophytes, hydrophytes and aquatic species (Annex 16: Vegetation).

Plant samples from the peatlands and mires were collected, pressed and added to the collection of the National Herbarium of Uzbekistan (TASH) in Tashkent. The collection of herbarium samples is currently being digitized, to be made publicly available in the Digital Flora of Uzbekistan project. For 28 of the documented, representative wetland species (mostly *Juncaceae* and *Cyperaceae*), the botanical description for this online database was created as part of this thesis.

2.6 Laboratory analyses of soil samples

During the field survey, 29 volumetric soil samples were taken, packed in transparent sealed plastic bags, labeled with the site ID and core ID, and transported to Germany, for further processing. For the export of the samples from Uzbekistan, a phytosanitary certificate was issued by the State Plant Quarantine Inspection (Tashkent). A Letter of Authority was required by the German authorities, for the import of the soil samples. It was issued by the Landesamt für Landwirtschaft, Lebensmittelsicherheit und Fischerei M-V. Some samples (7) had to be discarded because the packages or the labels were damaged during transport.

In the laboratory, 22 samples were analyzed for **loss-on-ignition (LOI)**. The general procedure of sample pre-treatment was conducted according to DIN EN 16179:2012-11 (E) (*Sludge, treated biowaste and soil – Guidance for sample pre-treatment*; 2012), including drying samples at a low temperature (about 30°C) prior to further treatment. The average weight of the dried samples was 1.84 g (min: 0.78 g, max: 3.42 g). LOI was determined according to DIN EN 15935:2012-11 (E) (*Sludge, treated biowaste, soil and waste – Determination of loss on ignition*; 2012). The pre-dried samples were heated in ceramic crucibles at 550°C for 9 h using a *Kendro M 104* muffle furnace at the analytical laboratory of the Institute for Botany and Landscape Ecology at Greifswald University. The samples and crucibles were weighed with a *Sartorius M Power* analytical scale, returning values were documented with the accuracy of 4 decimal places. To prevent imprecise results caused by static charge, the ashed samples were treated with a *Zerostat Milty 3* anti-static instrument prior to weighing. The ash left after the procedure was kept for potential analysis of remaining elements as oxides. The percent weight loss during the ignition step returns the soil OM content (in percent %), with a method detection limit of 0.05% (NELSON & SOMMERS 1996). Based on the OM content, the samples were grouped into *mineral* (<10% OM), *half-peat* (>10–30% OM) or *peat* (>30% OM) (cf. ch. 1.3).

3 Results

The results are structured into three main parts, starting with the results of the desk study, including the proxy map and the literature research. The second part describes the results of our field study, with the presentation of the visited wetlands and their vegetation. Lastly, the chapter concludes with an overview over the probable peatland locations for the 7 study regions, selected with the remote sensing methods. Complementary content in the form of maps and data are available in the appendix (Annex 5 – Annex 16).

3.1 Proxy map

The compilation of proxy map data (cf. ch. 2.1) allows a first overview of areas with the potential presence of organic soils or peatlands (Figure 10). Resulting regions are promising as a first orientation, because they indicate higher water levels, wetland related vegetation and hydromorphic soils, rich in organic matter.

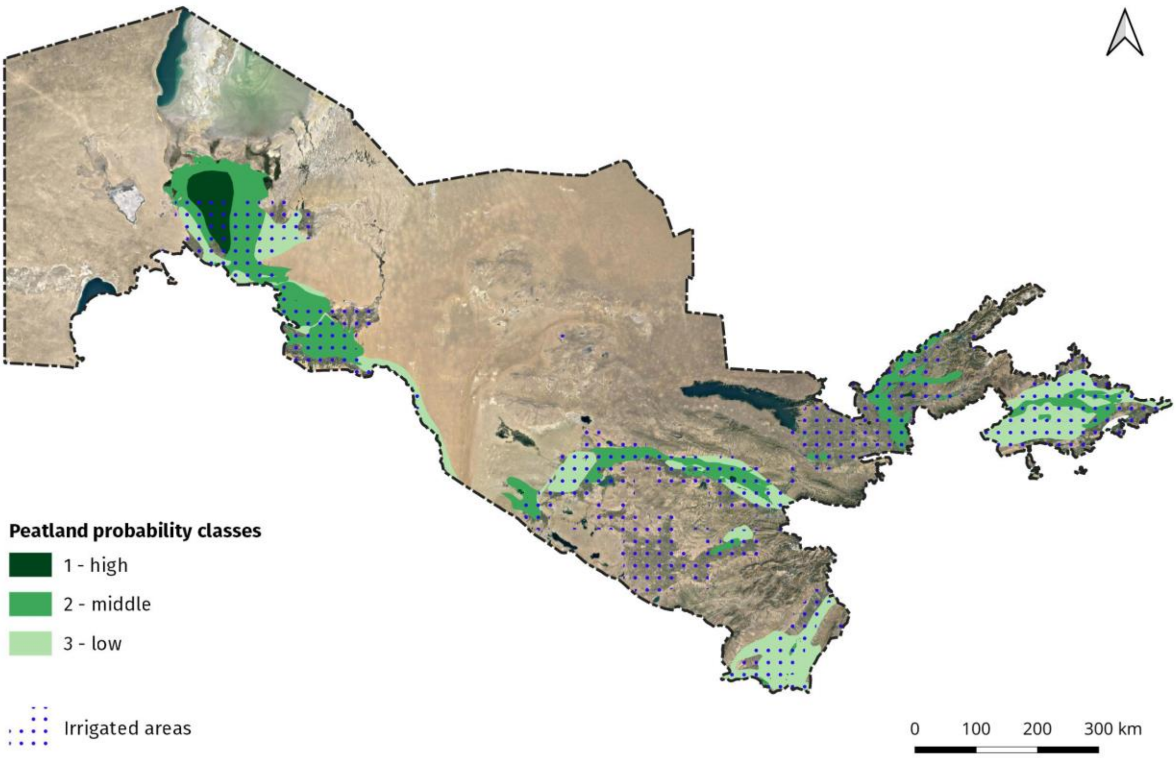

Figure 10: Proxy map – probability of peatland occurrence and irrigated areas.

In the east, the most prominent landscape feature highlighted as class 1 (*high probability of peat occurrence*, cf. Figure 10) is the Amu Darya delta region. It is located at the former coast of the Aral Sea, covering extensive reed stands, wet meadows and irrigated land (UNEP et al. 2011). The potential wetlands stretch down further to the south, along the lower Amu Darya river. In the southern parts of Uzbekistan, the Zeravshan river region is highlighted with intermediate probability of peat occurrence, while small isolated patches are indicated with the highest probability areas. Other regions identified as potentially peat supporting in eastern Uzbekistan are the Syr Darya river basin and the fertile Ferghana valley (Figure 10).

Common for the majority of these high probability regions is high land use pressure. An indicator of how strongly these wetlands are impacted by human activity are the irrigated areas (RAKHMATULLAEV et al. 2013). As shown in Figure 10, these overlay most of the probable peatland areas. Given the age and the coarse resolution of most maps used as proxies (cf. ch. 2.2), the results need to be carefully evaluated, with consideration of recent land cover and land use, and finally substantiated through field surveys.

3.2 Literature study

The literature study provided some first insights on peat formation (or its absence) in parts of Uzbekistan. Since the literature often stems from the former USSR, they tend to refer to bigger geographic units in Central Asia, covering also neighboring countries of Uzbekistan. Information like this is still considered useful to identify potential peatland types that might occur under comparable conditions in Uzbekistan.

The botanical monograph '*Flora and vegetation of Central Asian Water Bodies and their Use in the National Economy' (original Title: 'Флора и Растительность Водоемов Средней Азии и их использование в народном хозяйстве')* by TAUBAEV (1970) features information on species distribution for several types of wetlands. Directly mentioned are swamps or peatlands (referred to as *болоты* – 'boloty'), explicitly described as being covered with peat layers, for the Tien Shan and Pamir. These mountains cover a large territory in Central Asia, with their western parts reaching into Uzbekistan (cf. Annex 1). Peatlands with a special formation of water filled hollows and grassy peat hummocks are mentioned for the Trans-Ili Alatau, the natural border between Kazakhstan and Kyrgyzstan. Since these regions are biogeographically related to the Uzbek eastern mountain ranges (DJAMALI et al. 2012), the described main peat building plants according to TAUBAEV (1970) can be used as indication for the high mountains in Uzbekistan, too. They include: *Carex orbicularis, C. melanantha* and mosses such as *Aulacomnium palustre, Bryum ventricosum, Drepanocladus intermedius, D. fluitans* and *Calliergon turgescens.* These mountainous peatlands are further described as dominated by grass-sedge communities, with the dominating species being: *Polygonum viviparum, Deschampsia* *koelerioides, Pedicularis rhiananthoides, Saxifraga hirculus,* and *Gentiana algida.* Another type of peatland in the Trans-Ili Alatau are more adapted to drier conditions (TAUBAEV 1970). Often located on permafrost, the species *Tortula ruralis, Polytrichum juniperinum, Tortella fragilis* and *Carex melanantha* are typical here. When the permafrost layers disappear, these swamps are reported to form thick mats of *Kobresia bellardii* or *Polygonum viviparum* (TAUBAEV 1970).

Also mentioned by TAUBAEV (1970) are peatlands along the upper reaches of streams and rivers, again in the mountainous regions of Kazakhstan, located east of Uzbekistan. They can exhibit peat layers of 60–80 cm depth. *Aulacomnium palustre, Bryum ventricosum, Polytrichum juniperinum, Drepanocladus intermedius, D. fluitans, Carex orbicularis,* and *C. melanantha* are described as typical species, related to these wetlands. Along the river Ili (Kazakhstan), grassy peatlands form in the valleys (TAUBAEV 1970). These are considered the climax stadium of peatland development here, lacking deep layers of peat, and are used as meadows or pastures (TAUBAEV 1970).

The most detailed information on the characteristics of alpine grass swamps and peatlands are presented by KOROVIN (1961) in *'The Vegetation of Central Asia and Southern Kazakhstan'* (original title: *Растительность Средней Азии и Южного Казахстана*). These alpine peat swamps are called 'saz' *(сазы)* by the local communities (KOROVIN 1961) and are often dominated by sedges and grasses. Often, a peat layer of 50–80 cm develops on underlying permafrost. They are widely present in the Tien Shan and Pamir, and also reported to exist sporadically e. g. on the Kuhistan-, Turkestanski- and the Gissar-ridge and the Zerafshan mountains (cf. ch. 2.3; Figure 3) in Uzbekistan (KOROVIN 1961). Here, they are located along river terraces under waterlogged conditions, but mostly in the upper catchment areas of alpine streams, at 3,000 m a.s.l. and above. Clay-rich moraines from glacial activities benefit the formation of these alpine peatlands, but these landscape features appear more often in the central parts of the Tien Shan (e.g. Kyrgyzstan). While emphasizing the diverse characteristics and different plant societies of these mountainous wetlands, Korovin identifies *Carex pseudofoetida, C. melanantha* and *C. orbicularis* as typical species, often accompanied by dense stands of *Kobresia spec.*

Some of the peatlands form a hummock-hollow structure (Figure 11), with the hollows being filled with water. The structures develop with age and the hummocks can grow up to 50 cm high. According to KOROVIN (1961), the wet conditions benefit sedge species, who grow in bulks. This process leads to a self-supporting hummock formation, hosting an adapted community of up to 30 different plant species. If a disturbance happens (e.g. a drop of the water table), these systems will quickly deteriorate and the sedges are then replaced by other plant species (KOROVIN 1961).

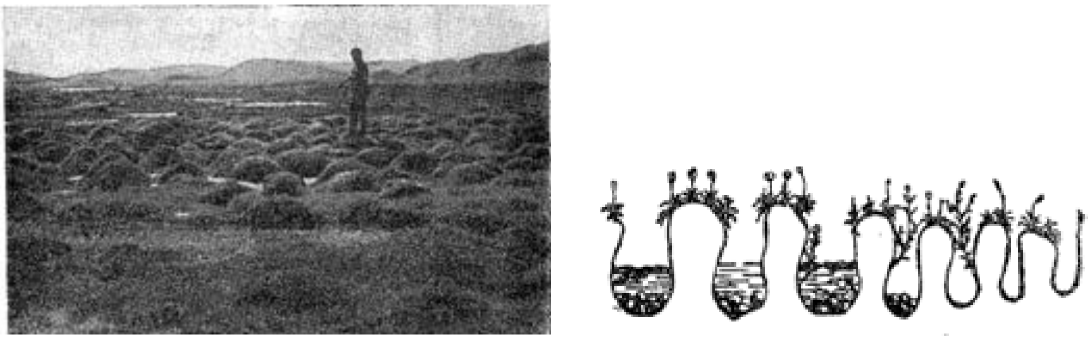

Figure 11: Sedge peatland in Akbalyk (Pamir) forming hummocky structures (from Korovin 1961: 215).

The *'Hydrogeography of the USSR'* (original title: *Гидрография СССР*) by Sokolov (1952) provides a more general view on wetland occurrence in the different geographic regions of the former Soviet Union. Here, peatlands or swamps (referred to as 'boloty', *болоты*) are mentioned to occur in steppes, but are limited to the alluvial plains of rivers. For semi-deserts, special types of mineral swamps are described, that are not covered by peat and are seasonally flooded. A salty mud formation, referred to as 'chakki' (*хакки*) is present in these swamps.

Where the rivers Syr Darya and Amu Darya (and the river Ili for Kazakhstan) cross the desert, swamps (again, referred to as '*болоты')* are mentioned to be present in their floodplains, covered by dense reed stands of 4–6 m height (Sokolov 1952). Peat presence is not explicitly described for these wetlands, but peat formation might be possible, at least locally. However, no literature could be located that supports this.

Lastly, Sokolov (1952) mentions a type of grassy peatland or swamp in the foothills of Central Asian mountains, to which he, like Korovin (1961), refers to as 'sazy' *(сазы).* This implies the presence of these grass swamps, also for the alpine territory of Uzbekistan.

"*Sheer endless reed stands" in the Amu Darya Delta* are also reported by Rogov (1957) in '*The hydrology of the Amu Darya Delta' (original title: Гидрология дельты Аму-Дарьи: Географо-гидрологическая характеристика*), as well as swamps and shallow lakes, scattered between the channels. Yet, when comparing the attached maps to the present hydrographical situation, these reports are most likely outdated, since most of the wetlands in the Amu Darya delta region degraded since the 1960s (cf. ch. 4.2.2). This also applies to the *'Materials of productivity Uzbekistan'* (Rogov1961*),* where wet meadows for hay production and reed pastures are described for the Amu Darya delta region.

3.3 Field study results

3.3.1 Vegetation

For all studied mountainous regions and their respective peatlands, a total of 67 plant species have been recorded during the field study. The full documentation is available in Annex 16. For 28 of the documented, representative wetland species (mostly *Juncaceae* and *Cyperaceae*) I created a botanical description for the online database of the Flora Uzbekistan project. (cf. Digital Annex: *'Wetland species entries for the Flora UZ database'*.)

Figure 12: Shares of families and genera of documented vegetation on wetlands.

Two of the species found are bound to very wet site characteristics, potentially growing under waterlogged conditions (*Veronica beccabunga, Phragmites australis*). 26 species are typical wetland plants. The majority (37) are mesophytic plants, adapted to a wider habitat range. Two of the documented plant species are usually found in drier site conditions.

(Figure 12) presents an overview over the families and classes of the plant species. More than ⅓ of all species are part of the Monocotyledonae, of which all representatives are grass-like species, belonging to the families of Cyperaceae, Poaceae and Juncaceae). Among these, Cyperaceae and Juncaceae are typically associated with wetlands.

Of the Dicotyledonae, especially species of the Asteraceae and Rosaceae families are represented. Meadow species are commonly found among the documented plants, with species like *Plantago lanceolata, Medicago lupulina, Cerastium cerastoides* and *Trifolium repens.* Together with the Poaceae, they serve as fodder plants, highlighting the importance of these ecosystems for grazing (KHUJANAZAROV & ISLOMOV 2020). Every site studied was intensely grazed by horses, cattle and sheep. This form of land use acts as a selective force, influencing the species composition (HERRERO-JÁUREGUI & OESTERHELD 2018).

An azonal distribution is especially common for wetland and aquatic species. With wetness working as a main driving factor for their presence, they can be found in lowlands and highlands alike, with distribution areas covering the Eurasian continent or even the globe (eg. *Phragmites australis*). A large altitudinal range of species can be observed also for the species of the mountainous peatlands. Nuratau is the lowest in elevation and the most arid of the three studied mountainous regions. 24

plant species were found here, in the mires around the Sentob valley (Study sites 3–6), at 1,650 m a.s.l. The biggest share among these are mesophytic species (Figure 13). *Carex duriuscula, Trifolium repens, Juncus articularis* and *Digitaria sanguinali* are the most dominant species, when ranked after BRAUN-BLANQUET (1974).

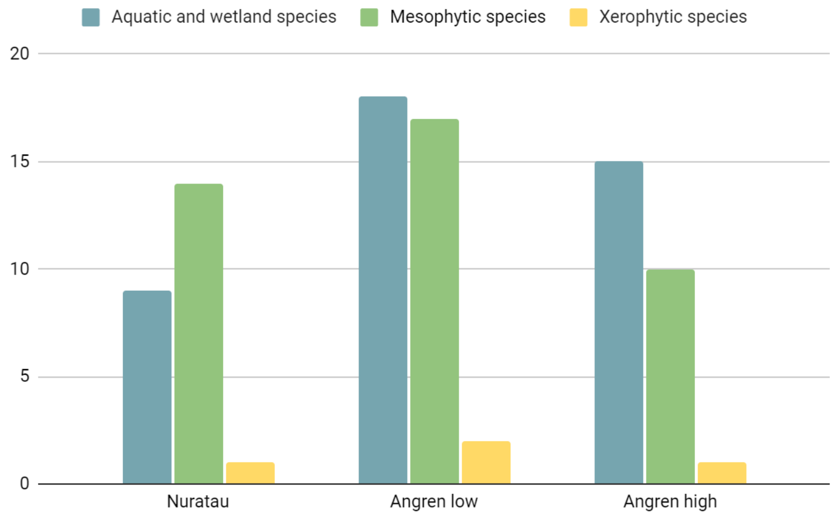

Figure 13: Habitat preferences of the documented plant species, sorted by region.

The highest plant diversity was documented for the middle ranges of the Angren Plateau at 2,300–2,450 m, along the peatland complex of an intensely grazed alpine slope (site 16). Species well-adapted to wet conditions represent the majority of the documented species, followed directly by mesophytes. Dominating species here are *Trifolium repens* and *Carex pseudofoetida*.

In the highest study locations of the Angren Plateau, at 2,700–2,800 m (study sites 8–13), 26 plant species were documented of which a majority (15) is well adapted to typical wetland conditions. *Ligula alpigena, Trifolium repens, Carex enervis* and *Carex pseudofoetida* are frequent species on those sites. Some wetlands are dominated by *Kobresia stenocarpa*. This phenomenon only appears in the higher mountain regions where Kobresia forms almost closed vegetation stands with a density of up to 75% plant cover.

Matching the reports of KOROVIN (1961) and TAUBAEV (1970) (cf. ch. 3.2), the species *Carex pseudofoetida, Carex melanantha and Carex orbicularis* are good indicator plants for alpine peatlands (locally called ‘sazy’). The formation of dense mats of *Kobresia spec*., as mentioned by KOROVIN (1961), could be found on the highest sites.

3.3.2 Description of sample sites

During the field study in 2019, we visited locations in the study regions *Angren Plateau (*Annex 6*), Nuratau (*Annex 9*), Ugurt mountains/Zeravshan (*Annex 10*)* and the *Syr Darya lowlands (*Annex 11*)*. Additionally, we took samples outside of our main study regions during the travel, at the coast of the Aydar Kul lake, near Lake Tashkent (close to a water reservoir) and in the Tugai Forest Biosphere Reserve near the Zeravshan river (close to Samarkand). Altogether, 30 sites were studied in detail.

The documentation of the results is available in Annex 14: *Field survey results - Study sites 1-30 (Excerpt)* and the geodata of the studied locations is accessible as geopackage in the Digital Annex. The map in (Annex 12) provides a quick overview of all visited sites, whereas in the following chapters I want to present a selection of the most important sites in more detail. These sites were chosen for further description, because they provide a high concentration of peatlands or organic soils of varying characteristics, featuring also different landscapes, altitudes and geographical regions.

3.3.2.1 ANGREN PLATEAU – LAKE ARASHAN

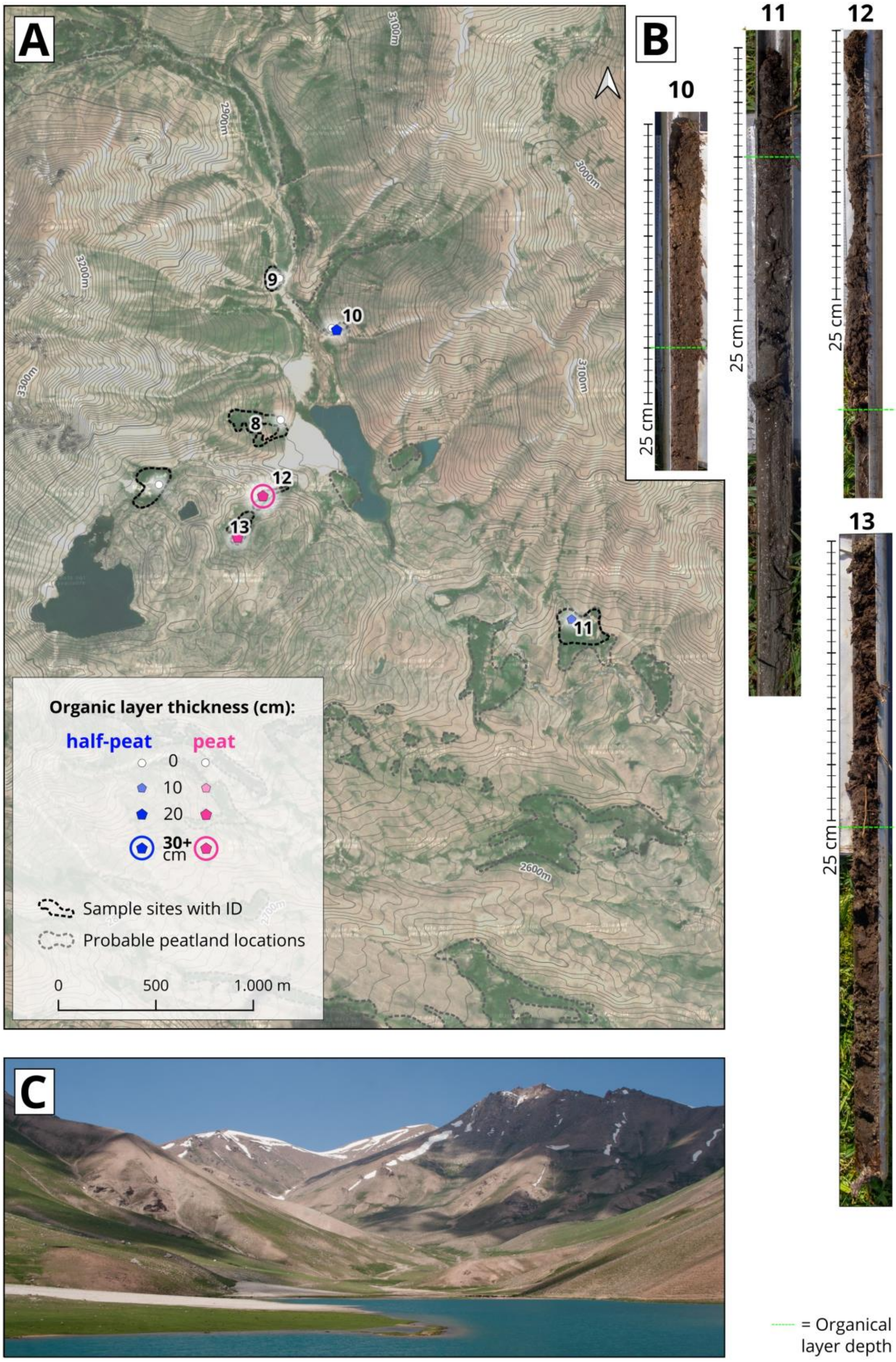

Figure 14: Sample sites Angren Plateau – Lake Arashan.
A: Map; B: Cores; C: View over lake Arashan (from south-east)

Lake Arashan (Figure 14, C) is situated on the Angren Plateau, embedded in the surrounding Arashan mountain chain. It is part of a series of glacial lakes, rivers and springs. One of the surrounding springs is used as a religious pilgrimage destination by locals, which is why the remote area is accessible by car over a rudimentary route. The whole area is used as range land by local shepherds with herds of cows and sheep. Among all areas studied, this was the one at the highest altitude, with elevations reaching almost 3,000 m. 6 sites (ID 8–13) were documented here, 7 corings were conducted and 5 soil samples taken.

Site **8** (Figure 14, A) was situated in a steep slope, facing east, at 2,755 m a.s.l. Despite the wet conditions, no pronounced organic layers were found here. The organic matter (5.1% Organic Matter; further addressed as 'OM'; Annex 15) of the light-brown soil was heavily mixed with sediments (clay, sand and stones). Site **9** was only slightly sloped, and located at 2,725 m, next to the stream which served as tributary to the lake (Figure 14, A). The soil was highly water-saturated and the ground was swinging when we walked on it. The heavy, grey, hydromorphic soil had an OM content of 9.2% (Annex 15) and the organic material was mixed with clay. Both sites had a grassy, grazed vegetation cover.

Figure 15: Site Site 10 with erosion channels and uneven surface relief.

Sites number **10** and **11**, both include layers of half peat (Figure 14, B) and were covered by grassy, sharply grazed vegetation. Site 10 (Figure 14, A) was placed in a strongly eroded slope, at 2,773 m, exposed towards the south-west. Two cores were taken only a few meters apart from each other at Site 10, but exhibit quite different levels of peat development. One did not provide any significant organic layers while at the other sample point, 20 cm of half peat (18,3% OM, Annex 15) were found. The heterogeneity can be explained with the high erosion activity along the slope, which was shaped by water-filled erosion channels and smaller landslides, leaking water at the edges (Figure 15). The soil substrate consisted of large amounts of stones and sand. Due to the skeletal character of the soil, the organic soil components accumulated in the voluminous pores.

Site **11** (Figure 16) was located a bit further towards the southwest of Lake Arashan (Figure 14, A), in a broad valley of alpine meadows at ~2,670 m above sea level. We only found thin layers of half peat, barely reaching depths of 10 cm. The wet, dark-grey gley soil was rich in clay and sand.

Figure 16: View over site 11.

At sites **12** and **13** (Figure 14, A) peat layers were found with up to 62.5% OM in 15 cm depth on site **12** (Annex 15). Here, the layer of dark brown peat stretched to 30 cm depth (Figure 14, B), allowing this site to be classified as a **peatland.** The peat showed only small rates of decomposition, with many roots and plant fibers being still intact. At 35 cm depth, the OM reduced to 27% and the soil properties changed towards a stonier sediment rich skeletal substrate. Site 12 (Figure 17) was located at a steep slope, facing east, at 2,822 m. The hydrological surface conditions were medium wet; the surface showed only little signs of erosion, despite intense grazing of the vegetation (Figure 18). At site **13**, at 2,848 m a.s.l., the slopes descended more gently with an exposition towards the north-east (Figure 14, A). The conditions were more heterogeneous, showing disturbances from past rockslides and little streams and ponds intersecting the area. The vegetation changed in some parts from the typical sedge swamps towards a more moss dominated vegetation, marking the only spot of our studies where relevant moss covers could be found (50–70%). Along the slopes, the peat reached depths of 19 cm (Figure 14, B).

Figure 17: Photo of site 12, lower part with view towards lake Arashan. Water is partly overflowing degraded peat.

Figure 18: Photo of site 12, showing relief and vegetation. (Photo by C. Malpica)

3.3.2.2 ALPINE VALLEY SAMPLE SITES

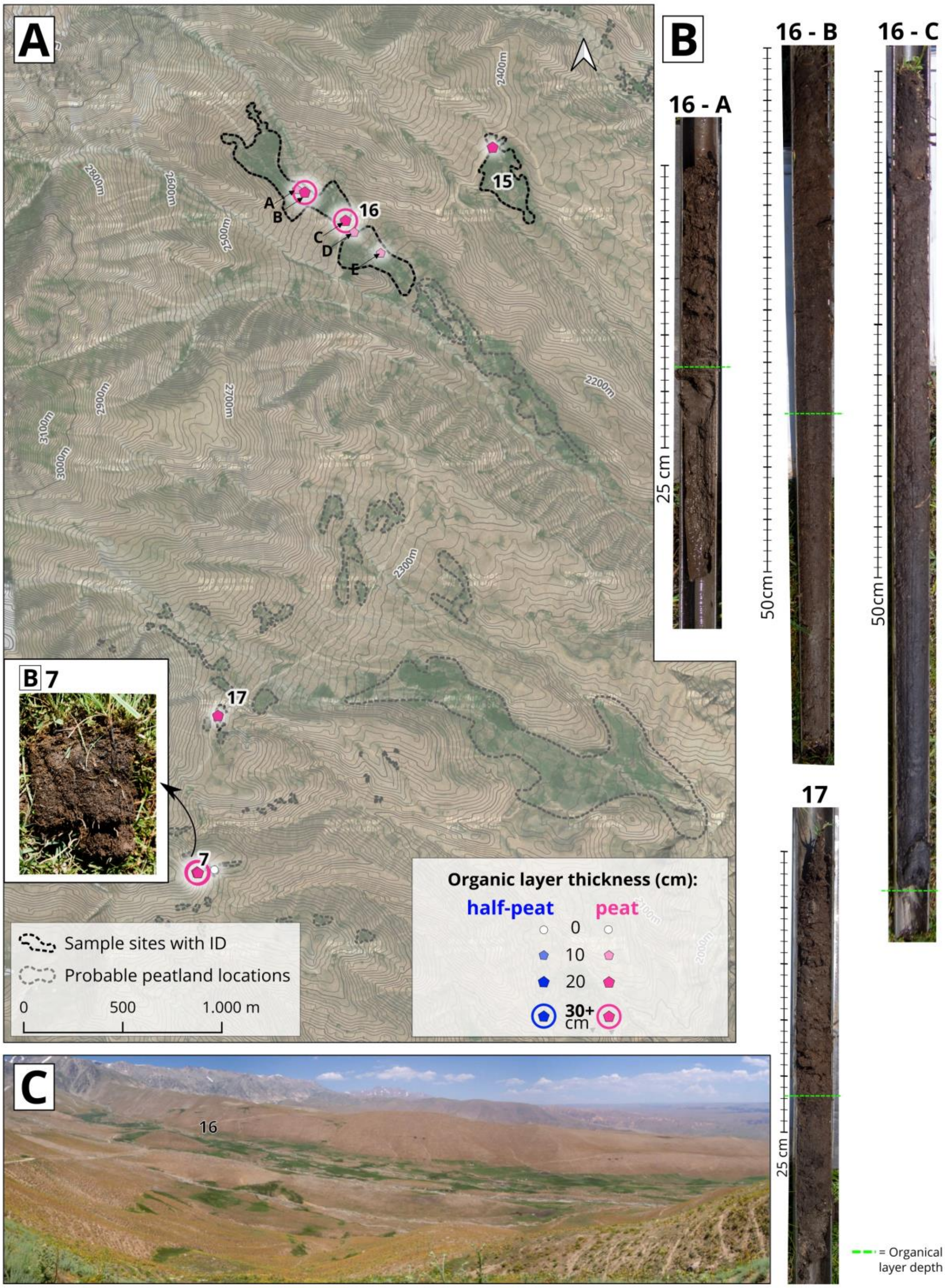

Figure 19: Sample sites Angren Plateau – Alpine valley.
A: Map; B: Cores; C: Panoramic view over valley with peatland complex (site 16).

The sites visited in this area (numbers 7, 15–17) are located around a gently sloped valley (site 16, Figure 19, C), covering altitudes around 2,400 m above sea level (Figure 19, A).

Site **7** (Figure 20) was located directly below a road (2,405 m a.s.l) and was interpreted as a sloping fen, on a spring mire. The site had a pronounced domed structure, consisting of interchanging layers of mineral deposits and peat. The wetness increased in a gradient towards the center of the dome. Sedges and Kobresia dominated the heavily grazed vegetation. The peat in the uppermost part (7 A in Figure 19) had an OM content of 38% (Annex 15) and in the lower part (core 7 B in Figure 19, B) the OM content increased to 64.6%. Signs of degradation were visible in the organic layers, where parts of the peat from the upper reaches was transported downhill, where they were deposited as organic layers mixed with non-organic sediments (Core 7 C, Figure 19, B at 2,380 m).

Figure 20: Sampling at site 7, at the edge of the doming peat body (l: C. Malpica a. r: L. Hebermehl). Photo by N. Beshko

Figure 21: Site 15 with camp in background.

On site **15** (Figure 19, A) a highly degraded peat layer of 19 cm (38.6% OM, Annex 15) was located at a slight slope at 2,383 m above sea level, facing south-east. The site was situated in a valley, with a nomadic shepherds' camp set up at the edge and was used as pasture (Figure 21). A dense net of rivers spread throughout the wetland, which, in combination with swampy surface conditions, was making it difficult for us to access the central parts. The soil was dark brown, with an organic layer sitting on a base of fine sediments.

Site **16** (Figure 19, A) was the largest peatland complex documented, stretching over a gently sloped valley and opening towards the south-east at 2,400 m a.s.l. The alpine meadows in this valley were used as pasture by local shepherds and, thus, subjected to intense grazing. Across the entire valley, a heterogeneous surface shaped the landscape (Figure 19, C). Little streams dug their way through the topsoil, forming a web of runoff water and flowing around domes which were covered by intensely grazed *Carex spec., Kobresia spec*. and other meadow plants (cf. ch. 3.3.1). The domes consisted mostly of highly organic peat, showing different states of decomposition and organic matter proportions. A variety of different hydrological conditions of the peat domes added to the overall heterogeneity, from only moderately wet to swampy and barely walkable sections (Figure 23). Rock and sediment slides from the upper reaches covered some parts of the valley. The intense grazing contributed to a high level of erosion, visible as disturbed plant cover, which again led to the formation of deep erosion channels. We also recognized signs of eutrophication of the soil and the surface runoff, presumably caused by the high amounts of manure from the local cattle, horse and sheep herds.

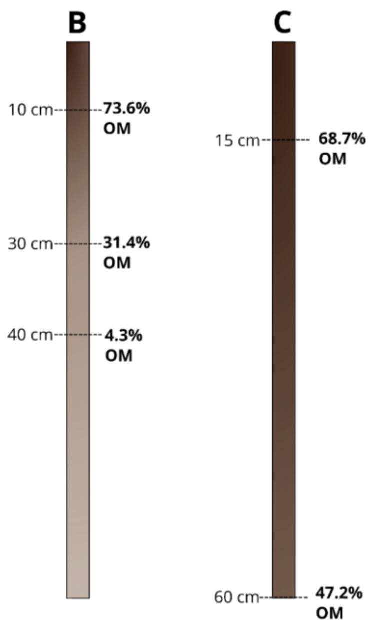

Figure 22: Decreasing Organic Matter (OM) content of Cores B and C (Site 16) with increasing depth

At the core of the highest checked point (core 16 A in Figure 19), we measured a peat layer of only 15 cm depth and with an OM content of 40% (Annex 15). The peat layers increased in thickness at the following downwards coring points, with peat depths of 35 cm at core B and more than 75 cm at point C (restrictions in our equipment did not allow a deeper drilling at that point). The OM content decreased rapidly with depth at point B, with OM proportions as high as 73.6% at 10 cm, decreasing to 31.4% at 30 cm and finally to 4.3% at 40 cm (Figure 22). At core C, the measured OM content started at 68.7% at 15 cm and remained relatively high with 47.2% OM at 60 cm depth. The peat at site 16 was generally highly decomposed and compacted and of a very dark color (Figure 19, B).

Figure 23: View over the dissected peaty hills at Site 16.

Another finding which highlights the high soil movement in this mountain region is site **17 (**Figure 19, A), exhibiting an open soil profile, showing interchanging layers of mineral sediments and peat (Figure 24). The site was located at a slight slope, exposed towards the north-east. At the small wetland we discovered peat layers of up to 22 cm depths. The surface showed only medium wet conditions for the largest parts, with runoff water flowing through erosion gullies and small streams. The uneven relief, with little hills and open soil profiles, overgrazed and partly missing vegetation, as well as the visible sediment flow from uphill, all indicated a high level of disturbance.

Figure 24: Site 17; A) view over the dissected peaty hills; B) initial peat layers (dark brown) interrupted by rock and sediment deposition.

3.3.2.3 NURATAU/AKTAU

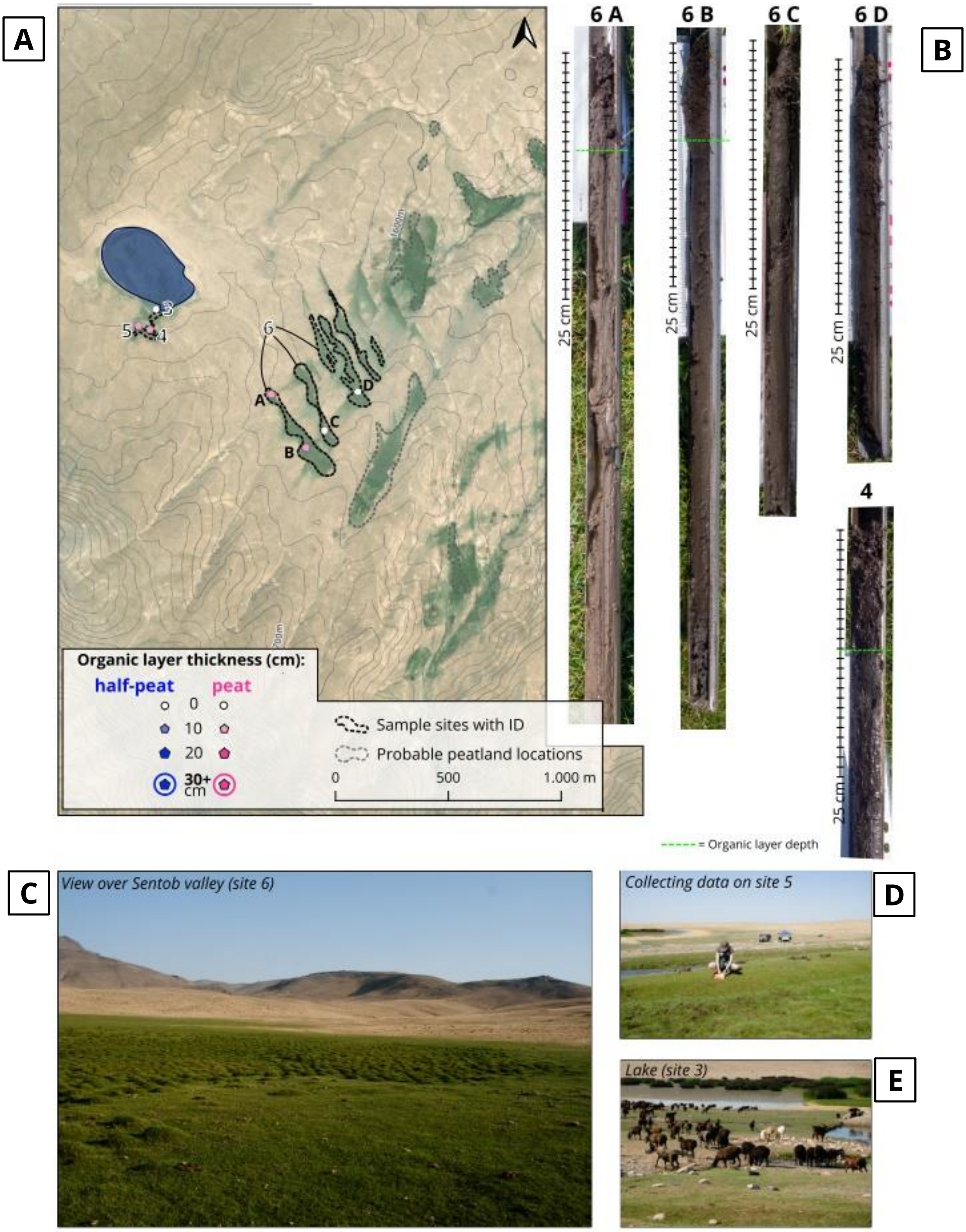

Figure 25: Sample sites Nuratau – Lake Fazilman & Sentob valley
A: Map; B: Cores (site 6, A–D; site 4); C: View over Sentob valley; D: Collecting Data at site 5; E: Lake (site 3).

In this region we will focus on Lake Fazilman (Figure 26) and the valley uphill from the mountain village Sentob (Figure 25, A). The isolated lake lies in the Nuratau mountains on 1,650 m above sea level. Located in the middle of a vast steppe land, the lake and the clean spring water attracts shepherds seeking to water their herds, as well as local villagers and tourists who come to the place for recreational purposes (SALIMOV 2019, EGAMBERDIYEVA 2019).

We started the sampling at site **3**, located directly at the shore of the lake (Figure 25, A&E). Here, no organic layers were developed. The wet and muddy ground was subjected to trampling and vegetation developed only partly under the ongoing disturbances by animals (Figure 26).

Figure 26: Lake Fazilman with horses.

Sites **4** and **5** (Figure 25, A&D) were both located several hundred meters uphill from the lake on a slight slope. They were dissected by a ditch and thus treated as separate sites. However, they resembled each other in terms of vegetation, hydrological conditions and peat development. The soil was very water saturated and the surface “wobbly” at both sites. Despite the intensive grazing, the vegetation cover was mostly intact. The peat layer did not exceed 10 cm in thickness and had an OM content of 39.2% at site 4 (Annex 15). Beneath the thin peat layer, mineral soil developed on a hydromorphic layer of clay rich gley with a grey color. Noticeable was the hummocky surface relief across the peat covered areas, that we also found at site 6 (Figure 25, C) and which was a unique feature among all our documented peatlands.

As site **6** we identified a complex of natural terraces, stretching over the valley north of Sentob village (Figure 25, A). Each ‘terrace step’ ended with a wet part, where groundwater exited the surface over a large part at the edges and supported a dense vegetation of meadow and wetland plants (Figure

27). These wet parts also changed in regards to the soil properties, with organic soils developing sharply delimited from their dry surroundings. We defined the organic layer of the uppermost step as peat, with OM contents reaching up to 53.7% (Annex 15). Even though the geomorphological features of the top terraces continued towards the downhill areas, we hesitated to classify the organic layers there as peat or half-peat, since mineralization processes and decomposition were quite advanced. They are still mentionable as pronounced organic soils in quite a typical (half-steppe) setting. Like at site 3 and 4, the pronounced hummocky surface was also present at site 6 (Figure 27). The soil was extremely water saturated. Water filled the hollows between the hummocks and the soil swung and bounced when walking or jumping on it in some parts. Well visible in the pictures of the cores from site 6 are the light-grey, clay-rich gley soils beneath the organic layers (Figure 25, B).

The site was intensely grazed, presumably being an important pasture among the ages-old settlement history of the valley (BESHKO 2016, SALIMOV 2019). During our stay we witnessed several herds of horses, cattle and sheep moving over the meadows. The grassy vegetation was kept short from the grazing and consisted of many plants typical for pastures (cf. ch. 3.3.1).

Figure 27: Wetlands with terrace structure in Sentob valley, Nuratau, (partly with peat and organic soils). Right: Detail of partly submerged and water-saturated surface and vegetation.

3.3.2.4 SYR DARYA

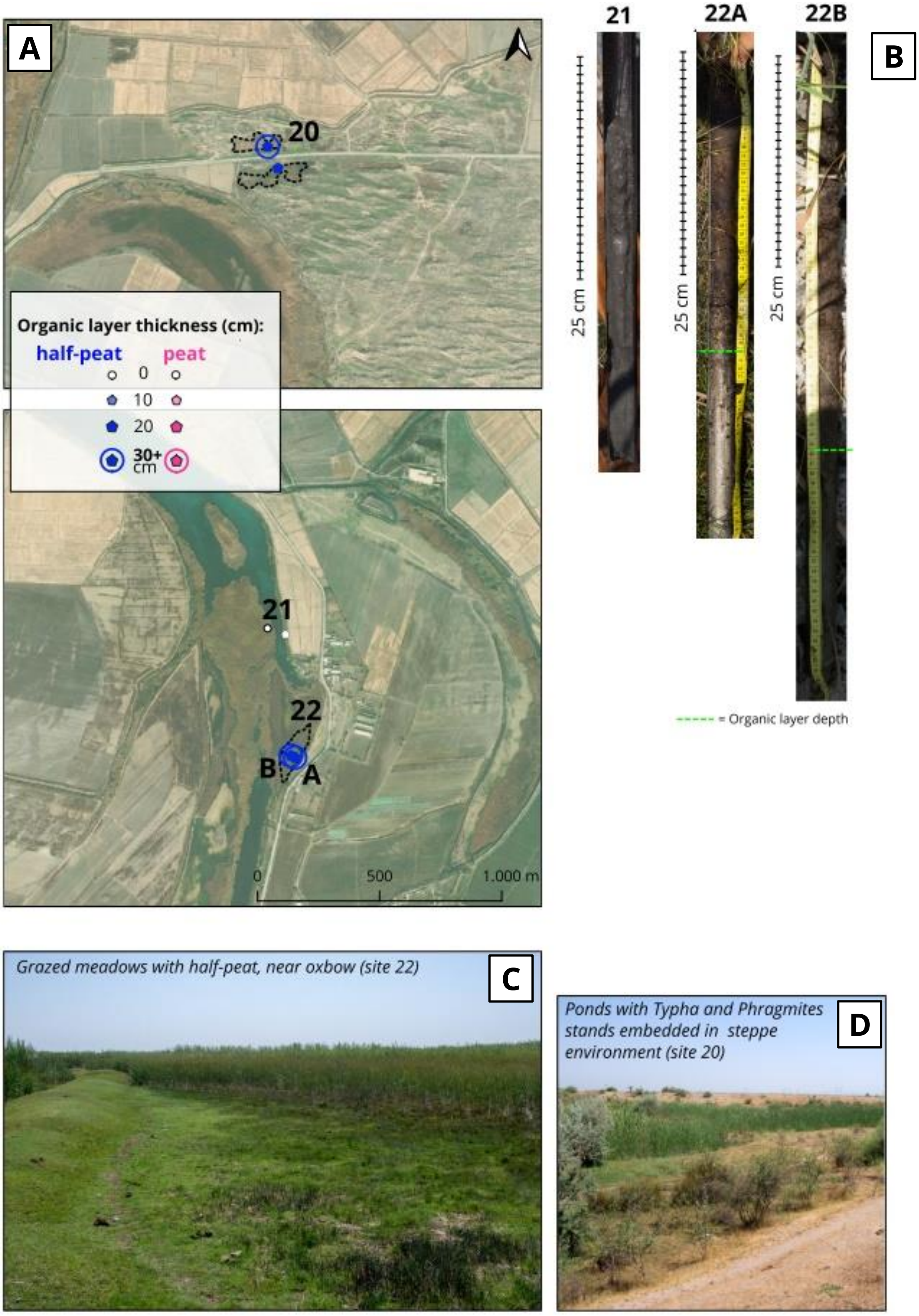

Figure 28: Sample sites Syr Darya. A: Map; B: Cores; C: Photo of site 22 D: Photo of site 20.

The study of the Syr Darya meanders allowed us to complement our research of mostly highland locations with those of the lowland (Figure 28, A).

Site 20 lies in the Dalversin Steppe (BESHKO et al. 2016), located close to the Syr Darya, where depressions of a hilly landscape were filled with small ponds. The site includes two water filled depressions (Figure 28, D), overgrown with dense stands of cat tail (*Typha spec.*) and reed (*Phragmites australis*). The coring of the site in both ponds presented a layer of 35 cm of half peat, with an OM content of 11% (Annex 15). The fibric half-peat contained well preserved pieces of rhizomes and leaves. Beneath the black organic layer, a hydromorphic soil was situated, consisting of a grey mineral soil layer with sandy substrates and fine sediments. At the time of sampling the soil was submerged under 50 cm of water.

Figure 29: Dense reed vegetation, oxbow lakes are shaping the landscape along the Syr Darya. Left: Detail on black soil – alluvial sediments intermixed with organic material.

The sampling at site **21**, on both shores of an oxbow lake (Figure 28, A, Figure 29), revealed a layer of detritus (Figure 28, B), consisting of fine sediments, intermixed with organic material. The black substrate emitted the typical sulphuric odor, created by anoxic decomposition processes. Analysis of the soil samples showed an OM content of 6% (Annex 15). The vegetation was made up completely by *Phragmites australis* (Figure 29).

Site **22** was located at the banks of an oxbow lake (Figure 28, A), which was bordered by an artificial dyke-ditch structure in the east, and to the west by dense reed stands. The wet meadows were grazed by cattle (Figure 28, C & Figure 30, Figure 31). Following the increasing wetness gradient, the vegetation changed, from dry meadow vegetation, towards a higher dominance of *Juncus* spec., which then was replaced by *Typha* spec. and finally transitioned into dense stands of *Phragmites australis,* where the surface was completely waterlogged. An organic layer (35 cm, core 22A in Figure 28, B) started to develop under the *Juncus* vegetation and increased along the gradient towards the wetter parts (45 cm, Core 22B in Figure 28, B). The characteristics of the organic layer led to a first classification on site as hemic peat - with typical features like low bulk density, black color, visible plant fibers and a loose structure. The analysis of soil samples in the laboratory led to a correction of this classification from peat to half-peat, with an OM value of only 16.2% (Annex 15).

Figure 30: View down and over site 22.

Figure 31: Grazed meadow at site 22.

3.3.2.5 OTHER SITES

Sites **1** and **2** (Map in Annex 9), visited in the Nuratau region in the proximity of the 'Walnut tree reserve' (BESHKO 2016), were shallow wetlands without peat layers occur. Site **1** was located in a wet meadow, in the middle of a village, site **2** at the banks of a little stream.

Site **19** (UTM coordinates: *531458, 4533900)* was another sampled lowland location, lying close to the so-called *Tashkent Lake*, a water reservoir providing the water supply of Uzbekistan's capital city. Stands of cattail and reed were scattered over a heterogenous area, with apparent human disturbance with channels, ditches, landfills and open water. At a very wet place with 4–5 m high cattail and reed 25 cm of peat were found (OM content 59.7%; Annex 15), thus being the only lowland site of our sample sites with *Phragmites* that also matches the criteria to be classified as peat. The soil was of a dark-grey color, with underlying sandy sediments.

Sites **22–26** were all located at the shoreline of the Aydar Kul lake at 375–378 m above sea level (Annex 9). Despite being in some parts densely vegetated by reeds and cattails and provided a high water level (Figure 33), the cores at all sites all presented a beige, clay rich mineral soil without a pronounced organic layer. The site conditions indicated a high sediment load from the river water.

In the Zerafshan mountains, we sampled one wetland (site **28**), where groundwater exited to the surface along small spots on an otherwise dry meadow at 1,650 m above sea level (Figure 34). Here, a typical wetland vegetation was found, but the cores returned no organic layers. In addition to the Zerafshan mountains, we were able to visit the Biosphere Reserve at the Zerafshan river, close to Samarkand. The region is known for the tugay forests, which are a typical form of Central Asian riparian woodland (KHOLBUTAYEVA et al. 2020). No signs of peat formation or organic soils could be found here. The few wet patches at site **29** were covered only by sparse vegetation that probably did not provide the biomass necessary for accumulation and formation of organic soils (Figure 34).

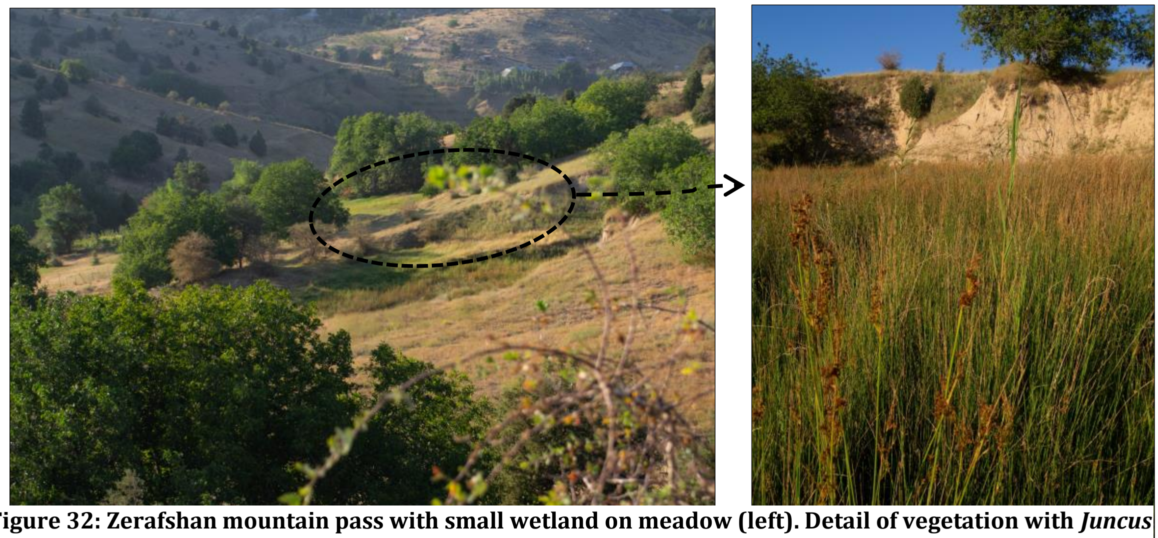

Figure 32: Zerafshan mountain pass with small wetland on meadow (left). Detail of vegetation with *Juncus* and other wetland plants (right). No organic layers were found on these sites.

Figure 34: Zerafshan Tugai Biosphere Reserve – Shallow water in a depression, on mineral soil.

Figure 33: Landscape at Aydar Kul with shrub-vegetation (*Tamarix spec.*) and flooded areas.

3.4 Mapping of probable peatlands

This chapter presents the results of the GIS study of probable peatlands locations (cf. ch. 2.4), from the study regions in both the lowland and the highland areas of Uzbekistan (cf. ch. 2.3). A map for every study region shows the location of the probable peatlands in the landscape and the related sites of the field survey (Annex 5–Annex 11).

3.4.1 Quantitative analysis of all highland probable peatlands

In the 7 mountainous study regions (maps: Annex 5–Annex 10), **512** sites were documented and digitized as probable peatland locations (geodata available as digital annex). Some of these features include groups of probable peatlands in a "peatland complex", that share a proximity and the same watershed. If these sub-parts of peatland complexes are considered as independent entities, this mapping covered **733** single sites. Altogether, the mapped probable peatlands cover an area of **2,205.46** ha (22 km^2) in these mountainous study regions. This number is meant as an orientation since the mapping was mainly done remotely (with only few field validation points) and is far from an exhaustive spatial covering. The positioning of the mapped potential peatland locations on a digital elevation model (DEM) allows the interpretation of their relation to the surface and their general distribution in the relief, which is especially relevant for the mires of very heterogeneous montane environments.

Altitudes of the mapped probable peatland sites range from 721–3,592 m a.s.l. (Figure 35). The peak in the distribution at 3,200 m a.s.l. is caused by the plateau character of the study region 'Angren Plateau' (Annex 6) at this particular elevation, combined with the high concentration of probable peatlands in this region. The small peak at 1,400–2,000 m a.s.l. can be explained by study regions 'Nuratau/Aktau' and 'Zerafshan mountains' (Annex 9 & Annex 10). Both are relic mountains and mountain ridges, located at a lower altitude compared to the other study regions, that are located in the higher western Tien Shan and Pamir mountains.

Since altitudes are varying for each study region, a differentiated analysis of the elevation offers a more precise view of the distribution of peatlands (Figure 36). The whisker plot demonstrates how the range is different for the respective regions, with a broad elevation distribution in regions I-1, I-2, and I-4 and only small variations for region I-3 and the considerably lower foothill regions I-5/6 and I-7.

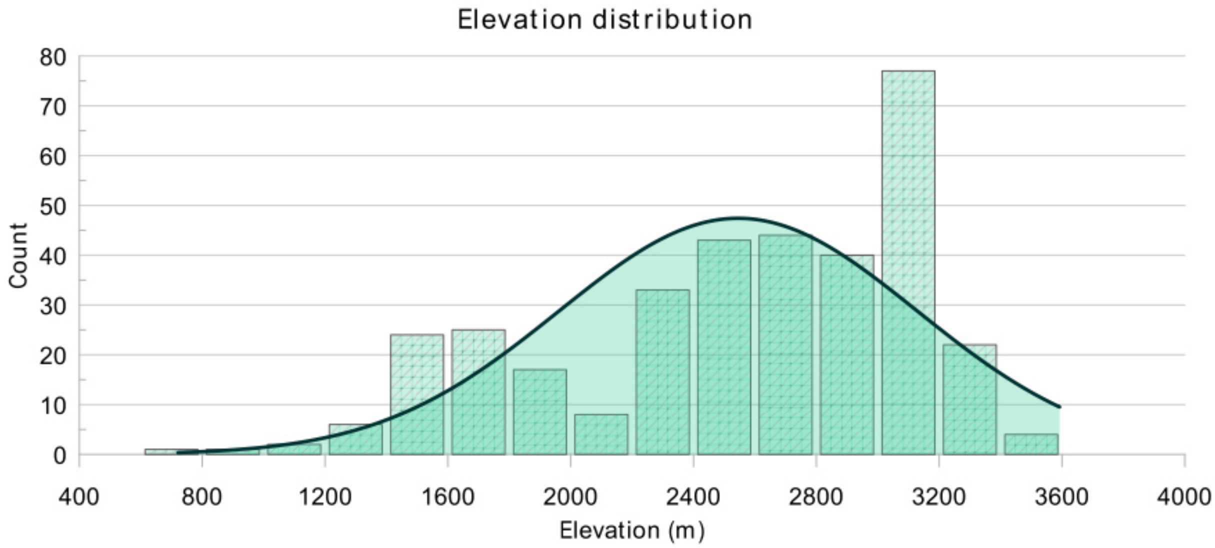

Figure 35: Elevation distribution of highland probable peatlands (total numbers).

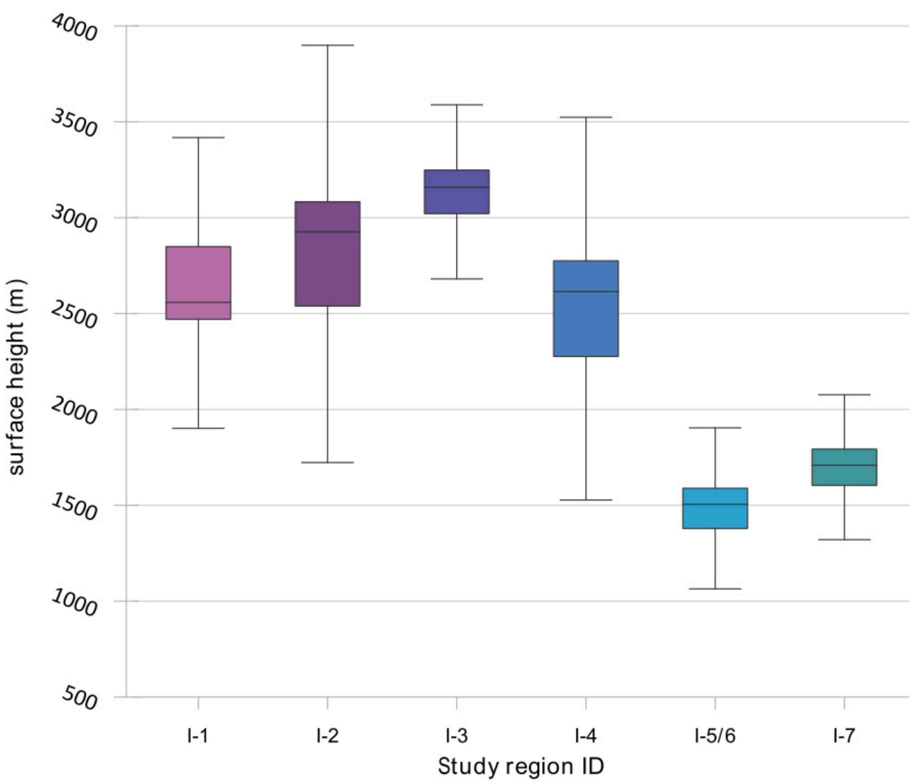

Figure 36: Boxplot of elevation distribution of probable peatlands per study region.

The sites are mostly located along slight slopes, ranging from 0–22° (Figure 37). Slopes between 2–12° appear to be particularly suitable, since most of the probable peatlands are located within that range, while at steeper slopes the number quickly decreases.

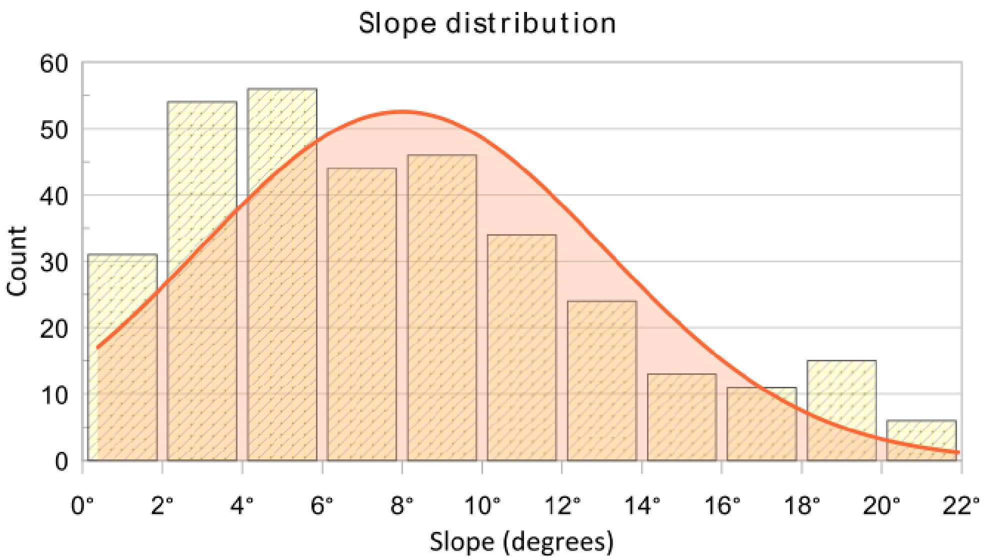

Figure 37: Distribution of probable peatlands in relation to surface inclination.

Another information that can be extracted by analyzing the digital elevation model is the surface exposition of the sites, i.e. the compass direction the peatlands are facing. As shown in Figure 38 (next page), probable peatlands were located at surfaces facing all directions, but sites facing north or west are more common, while those facing south were the fewest. When located on slopes, the surface aspect influences the strength of solar radiation, evaporation, and precipitation a peatland is exposed to. The western parts of mountains are located windward and have higher precipitation than the leeward eastern slopes. Southern exposed slopes are exposed to stronger solar radiation than their north-facing counterparts, making the climate on the latter more suitable for wetlands.

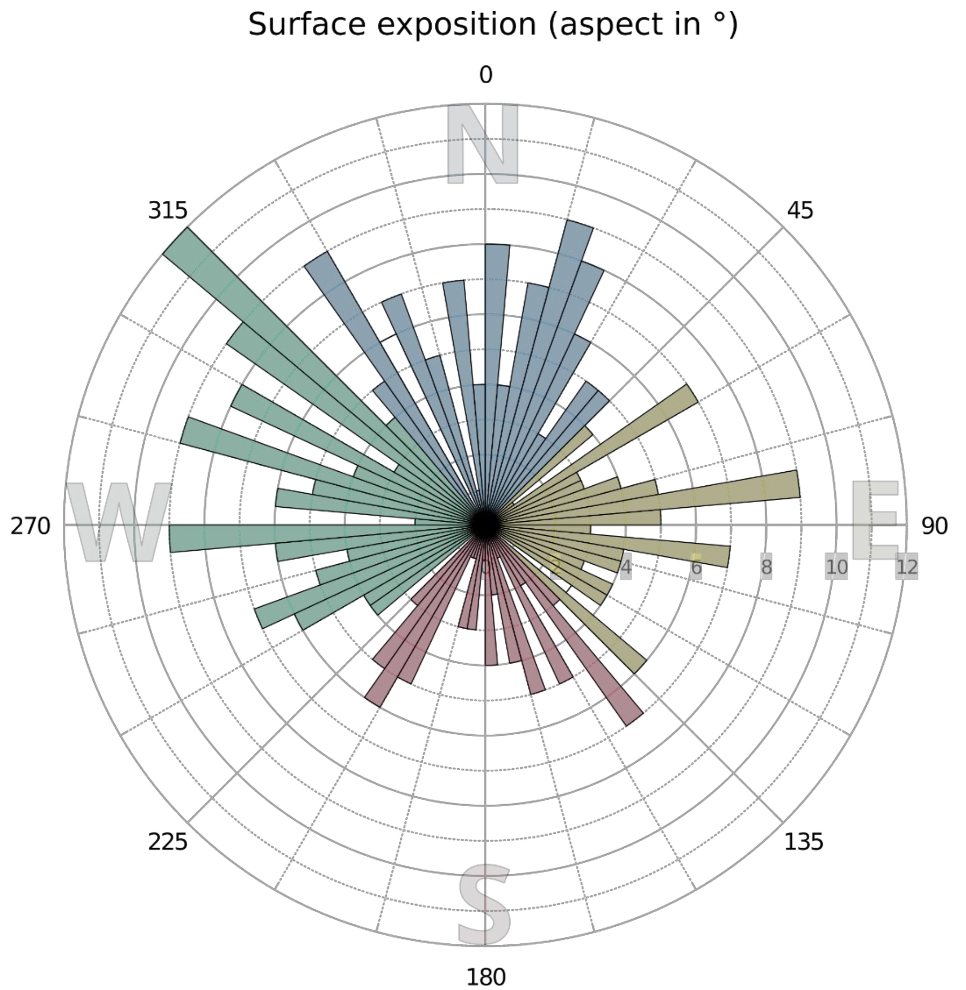

Figure 38: Distribution of probable peatlands in relation to the surface aspect (compass direction in degrees). Length of bars represents the total number of recorded probable peatland locations.

3.4.2 Probable peatlands by respective study region

PSKEM VALLEY (I-1) Map: Annex 5

Table 6: Calculated areas of potential peatlands in the Pskem valley.

	area (m²)	area (ha)
total area of all sites	**2,607,534**	**260.75**
average size of single site	**86,918**	**8.69**
min size of single site	**5,260**	**0.52**
max size of single site	**606,875**	**60.69**

The total area of the considered study region in the Pskem valley (Annex 5) is 1.409 km^2 (Table 6), with a total of 30 probable peatland sites that were mapped. Together, they cover an area of 260 ha. The sites in Pskem region are the largest, compared to the other regions, averaging at 8.69 ha. The tallest site is located at the *Shovurkul dolina* (ID 2; UTM coordinates *677545, 4679515*), a lake that was created by a rock slide in the upper catchment area of the river Oygaying (*Ойгаинг*) (KOLDAJEV et al. 2015). Even though relatively young, peat formation may have already started, because of the continuous water supply and a dense vegetation cover visible in satellite images.

Other, distinctively smaller sites are hugging the slopes at springs, where they form small wetlands complexes. The mountains are steep and glacial activities are high in this region, especially at the higher altitudes in its western part (SEMAKOVA et al. 2015). For this reason, most of the probable peatlands are located in proximity to the deep river valley and its tributaries, where the climate conditions are less harsh and the slopes gentler. Heights of probable peatland sites ranged from 2,159–3,333 m a.s.l. In the Pskem valley, grazing activities are reported to be relatively high (ALIKHANOV 2018; Figure 41). Photos of wetlands in this region were provided by M. Murzakhanov (Michael Succow Foundation), depicting the different locations of potential wetlands – either in the hills (Figure 40), or in the steep river valley of the Oygaying (Figure 39).

Figure 39: Wetland in the Oygajing river valley. Peat formation has not yet been confirmed. (Photo by R. Murzakhanov).

Figure 40: Wetland, potentially classifying as peatland, in the hills of Pskem region (Photo by R. Murzakhanov).

Figure 41: Potential spring mires. Well visible is the sharp contrast between wetland vegetation and surrounding mountain steppe. Herd of sheep (middle of the picture) for scale. (Photo by R. Murzakhanov).

ANGREN PLATEAU (I-2) Map: Annex 6

Table 7: Calculated areas of potential peatlands in the Angren Plateau.

	area (m²)	area (ha)
total area of all sites	**13,739,277**	**1,373.93**
average size of single site	**42,935**	**4.29**
min size of single site	**240**	**0.02**
max size of single site	**1,052,234**	**105.22**

By counting 320 sites on a study area of 1,409 km², this region (Annex 6) offers by far the highest number of potential peatlands of all considered mountainous study regions. Moreover, these sites include peatland complexes that themselves are made up out of several small patches. The mapped probable peatlands are covering a total of 1,374 ha (Table 7) and are summing up 1% of the total study area (1.409 km²). This number does not include the potentially high amount of miniscule but ubiquitous peatlands that could not be mapped because of their small size (Figure 42). The region is very rich in springs, originating along aquifers of the mountain slopes (MUSTAFAYEVA et al. 2018). The potential peatlands are often located at these spots and very likely classify as sloping spring fens (JOOSTEN & CLARKE 2002), a hypothesis supported by the field survey results (cf. ch. 3.3.2.1 & 4.1.1). The altitudes of probable peatland locations range from 2,000 m to 3,367 m a.s.l. The largest probable peatlands are those located in valleys, like the one studied during our field survey (site 16; probable peatland ID 153, cf. ch. 3.3.2.2), where the deepest peat layers were found (75+ cm; mineral ground not reached). In these valleys the probable peatlands cover areas of up to 105 ha (Table 7).

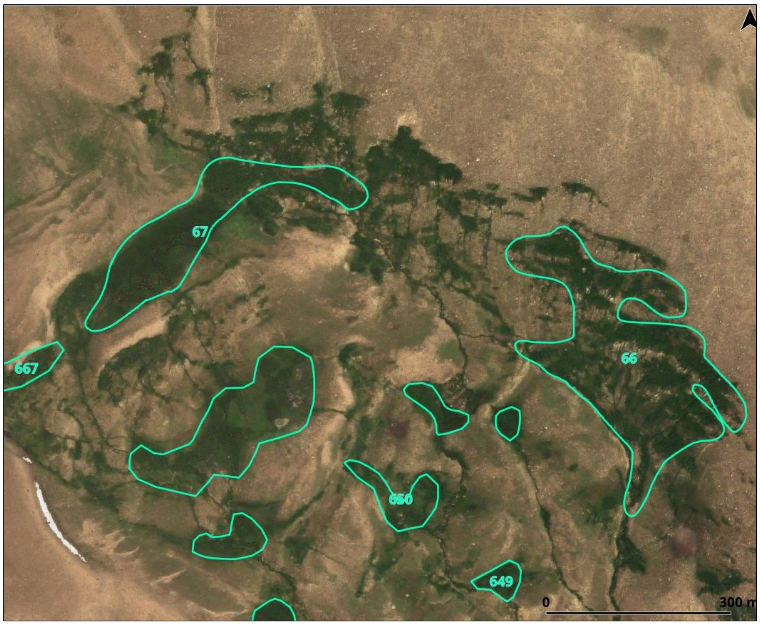

Figure 42: Potential spring fens situated at slopes and forming peatland complexes. Because of their small size and sheer amount, not all of them (in this image visible as green spots in the north) were mapped.

GISSAR MOUNTAINS (I-3) Map: Annex 7

Table 8: Calculated areas of potential peatlands in the Gissar mountains

	area (m²)	area (ha)
total area of all sites	**2,522,989**	**252.30**
average size of single site	**68,189**	**6.82**
min size of single site	**2,432**	**0.24**
max size of single site	**746,416**	**74.64**

In the Gissar mountains, **252 ha** of probable peatlands were mapped at **37** locations across a total study area of 2,818 km^2 (Table 8; Annex 7). The potential peatlands in these remote mountain regions are almost all located around the highest catchment areas of mountainous streams (Figure 44), where they are placed on what likely classifies as sloping springs (SUCCOW & JOOSTEN 2002). Few are also found in the river valleys (Figure 43). The biggest site measures 74.64 ha; the smallest one only 0.24 ha. As one of the highest study regions, the elevation ranges between 2,500–3,600 m a.s.l.

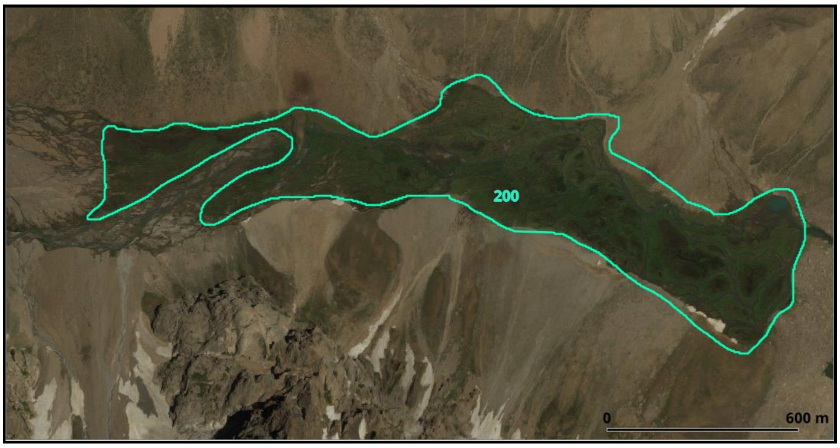

Figure 43: The biggest potential peatland site in the Gissar mountains (74.6 ha, Table 8), located in a meandering river valley. Dark brown soil patches potentially indicating organic top soil.

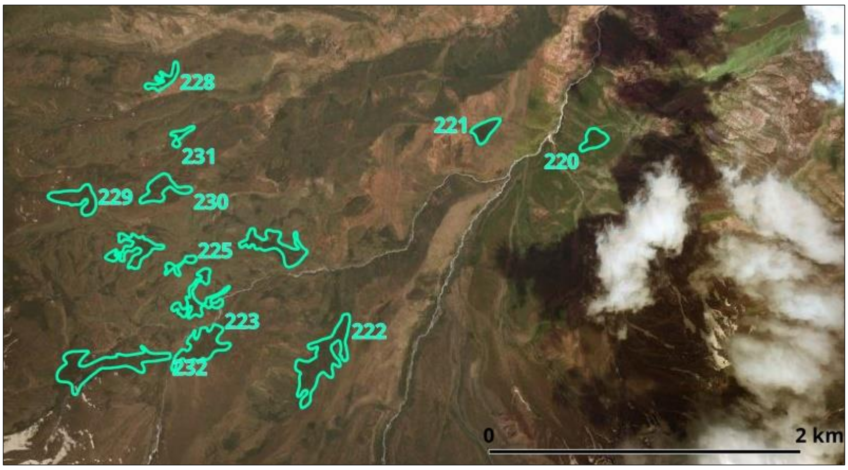

Figure 44: Ensemble of potential peatlands in the upper catchment area of a river.

NORTH-TURKESTAN (I-4) Map: Annex 8

Table 9: Calculated areas of potential peatlands in North-Turkestan

	area (m²)	area (ha)
total area of all sites	**1,819,206**	**181.92**
average size of single site	**46,646**	**4.66**
min size of single site	**1,098**	**0.11**
max size of single site	**910,966**	**91.10**

39 probable peatland locations were mapped for the North-Turkestan study region (2,818 km^2; Annex 8), adding up to **181.92 ha.** The sites were mostly very small (averaging 4.66 ha; Table 9), while the smallest one measuring only 0.11 ha, and the largest one (a complex of peatlands in a catchment area) reached 91.1 ha. Elevation ranges from 1,824–3,030 m a.s.l. The probable peatland sites were located at the transition zone of the tree line, where mountain steppes started to include sparse *Juniperus* forests (Figure 45). Compared to the higher altitude mountain regions (I-1 to I-3), the potential peatlands in this region are less pronounced and distributed more scarcely. The probable peatlands and the surrounding steppes are heavily shaped by grazing activities, as visible in the aerial images (e.g. Figure 45).

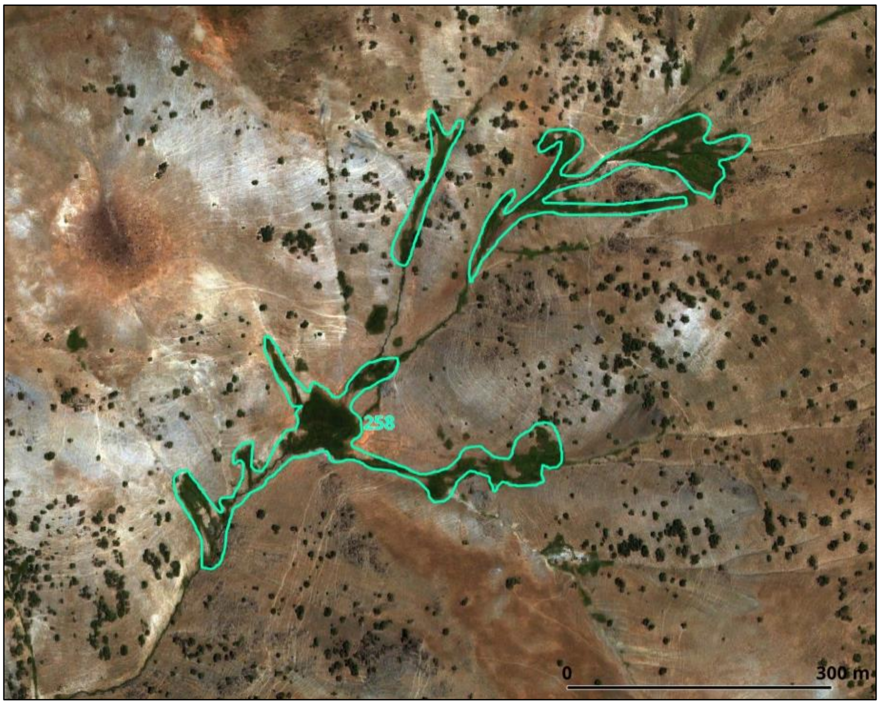

Figure 45: A mapped potential peatland complex along a small stream in a landscape setting, typical for Northern Turkestan: Juniperus forests with heavily grazed mountain steppe. The orange-brown spot (upper-left corner) shows a big herd of livestock and their droppings.

NURATAU-AKTAU (I-5/6) Map: Annex 9

Table 10: Calculated areas of potential peatlands in the Nuratau/Aktau mountains

	area (m^2)	area (ha)
total area of all sites	**887,794**	**88.78**
average size of single site	**22,764**	**2.28**
min size of single site	**1,369**	**0.14**
max size of single site	**131.548**	**13.16**

For Nuratau and Aktau, with 8,310 km^2 the biggest of the study regions (Annex 9), 39 potential peatlands were mapped, covering together **88.78 ha** (Table 10). Due to the arid climate, combined with sparse overall water availability and the relatively low elevation of this isolated mountain chain (BESHKO et al. 2016), it is not surprising that the density of wetlands and thus, probably peatlands is very low. For all the supporting visual material, wetlands could hardly be differentiated visually from their surrounding: medium resolution satellite images of Sentinel-2, higher resolution satellite images of Google Earth and Bing, wetness and vegetation indices. Wetlands with highly organic soils that were documented during the field survey (sites 4, 5, 6: 3.3.2.3, Figure 25) were barely detectable on satellite. Probable peatlands were found despite the geographical conditions, with the biggest one measuring 13.16 ha (Table 10). They were often located in valleys, along rivers and springs (Figure 46).

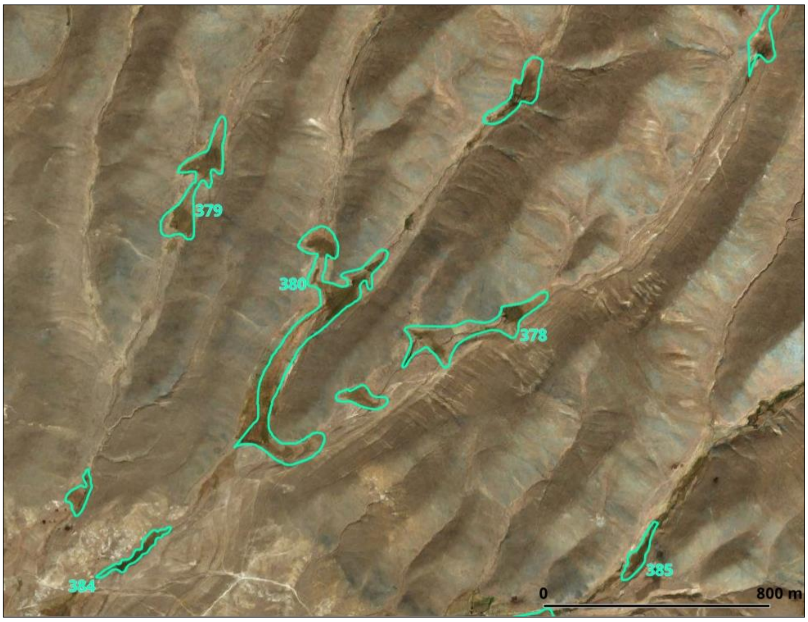

Figure 46: Examples of probable peatlands in the Nuratau foothills that are rare and have often been barely recognizable on the satellite images.

URGUT (1-7) Map: Annex 10

Table 11: Calculated areas of potential peatlands in Urgut (Zerafshan mountains)

	area (m^2)	area (ha)
total area of all sites	**477,848**	**47.78**
average size of single site	**10,167**	**1.02**
min size of single site	**1,023**	**0.10**
max size of single site	**36,507**	**3.65**

47 potential peatland sites were located, mapping covered the 2,816 km^2 big study region (Annex 10). The average size of the individual sites was the smallest in comparison to the other regions, with only 1 ha (Table 11) Wetland features visible in the satellite imagery were only weakly pronounced (Figure 47). For the region, many land-use and settlement activities can be observed and are more common than in the other mountainous regions that were studied.

Figure 47: Example of Probable peatlands in the foothills of the Urgut region (near Zeravshan mountain pass). Forests, orchards and settlements (right) indicate a milder climate compared to the higher mountain regions.

SYR DARYA (II-1) Map: Annex 11

Table 12: Calculated areas of potential peatlands in Syr Darya lowlands.

	area (m^2)	area (ha)
total area of all sites	**10,527,824**	**1,052.78**
average size of single site	**69,262**	**6.93**
min size of single site	**1,095**	**0.11**
max size of single site	**712,457**	**71.25**

The only lowland study region is located in the Syr Darya basin (Annex 11), where a total of 154 probable peatlands, amounting to 1,052 ha, were mapped, averaging 6.92 ha, and the biggest probable peatland measuring 71.25 ha (Table 12). The probable peatlands are located along the meanders and at terrestializing oxbow lakes of the Syr Darya. Predominantly, the mires are located at what was interpreted as predominantly reeds (*Phragites australis, Typha spec.*) and wet meadows. Moreover, single sites were mapped along the western tributaries of the Syr Darya, nested in the valleys of branching side-arms of smaller streams and rivers. The distinction between natural wetland vegetation and the adjacent crops was very clear, since man-made structures (dykes, terraces, dams, channels) and artificial shapes that characterized the cultivated land, were clearly visible in the satellite images.

Table 13: Potential loss of probable peatlands, over 2014–2019 timespan.

	area (m^2)	area (ha)
total area of all sites	**3,749,509**	**374.95**
average size of single site	**117,172**	**11.72**
min size of single site	**9,087**	**0.91**
max size of single site	**503,408**	**50.34**

The assessment of satellite imagery, taken in different years (2014, 2019) revealed that large areas of former existing potential peatlands had disappeared (cf. ch. 4.2.2). Based on this observation, the losses of potential peatlands were quantified, by comparing the different imageries and by mapping the "lost probable peatlands" as an extra category. The total area of lost potential peatland sites, over the time span of 2014–2019 in the study region 'II-1 Syr Darya', amounts to 375 ha (Table 13), which is **26%** of total potential peatlands mapped for that region.

4 Discussion

4.1 Distribution and characteristics of peatlands in Uzbekistan

Evaluation and integration of the results of the desk study (e.g. peatland probability map based on proxies, cf. ch. 3.1 and probable peatland mapping, cf. ch. 3.4), the field survey (cf. ch. 3.3) and the soil sample analysis in the laboratory (Annex 15) allows the identification of regions in Uzbekistan that harbor peatlands and mires, and regions with the potential to do so (Figure 48).

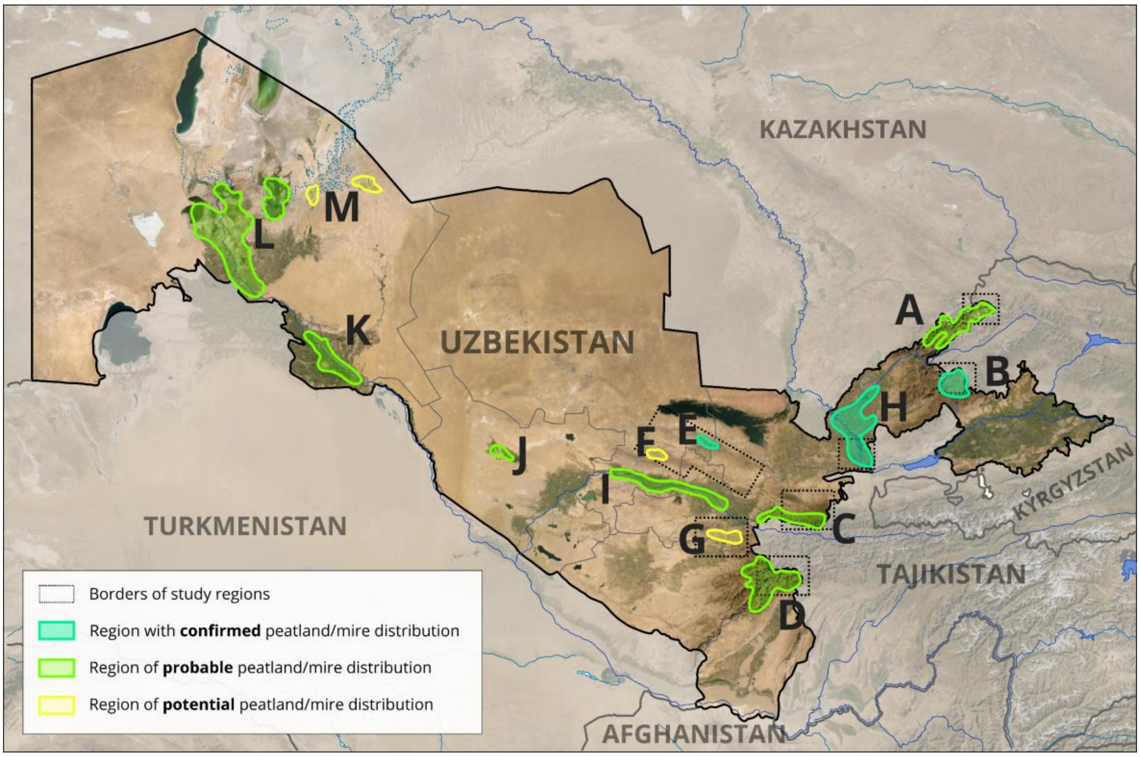

Figure 48: Regions in Uzbekistan with confirmed, probable, and potential occurrence of peatlands/mires.

HIGHLANDS: A: Chatkal – Pskem Valley; B: Chatkal – Angren Plateau; C: Northern Turkestan ridge; D: Gissar mountains; E: Nuratau relic mountains; F: Aktau relic mountains; G: Zerafshan mountains, Urgut;

LOWLANDS: H: Syr Darya floodplains and wetlands of the Tashkent region; I: Zerafshan river floodplain; J: Peshku district wetlands; K: Lower Amu Darya floodplain; L: Upper Amu Darya floodplains and delta; M: Upper Akcha Darya lakes

Peatlands could be **confirmed** during the field survey in the highland regions of the *Angren Plateau* (B) and the *Nuratau relic mountains* (E). Peatlands were found in the lowlands at a water reservoir in the *Tashkent* district, and at oxbows in the *Syr Darya* floodplain (H).

In at least seven regions in Uzbekistan the presence of peatlands can be expected, but they still need to be confirmed by (sufficient) ground truth data. As such, they are classified as **probable** peatland regions. These include the *Pskem valley* (A in Figure 48), the *Turkestan mountain* ranges (C) and the *Gissar mountains* (D). All of them were study regions for the remote-mapping of probable peatland locations (3.4, Annex 5, Annex 7, Annex 8). Furthermore, **probable** peatlands are very likely present in the lowland regions of the *Zerafshan river* floodplain (I), the irrigated wetlands north of Bukhara (*Peshku district*) (J), the *lower Amu Darya* floodplain (K) and the upper reaches and *delta region of the Amu Darya*, including the deltaic lakes (L).

Potential peatlands in regions with e.g. less favorable overall climatic or hydrological conditions (cf. ch. 1.2.1) might be present at three areas, namely the *Aktau relic mountains* and foothills (F), the *Zerafshan mountains* (G) and in the small, scattered wetland depressions along the historical *Akcha Darya* delta in the Kyzyl Kum (M). For these areas is further field work essential to confirm or refute the presence of peatlands.

Based on the limited field survey that could be conducted in the framework of this thesis, and tentative peatland types and their characteristics have been deduced. However, more detailed investigations of ecohydrological variables, physical and chemical characteristics and their associated vegetation, are necessary to gain a deeper understanding of the peatland types of Uzbekistan.

4.1.1 Highland peatland characteristics

In the Uzbek highlands, peatlands mostly occur as **sloping mires** (fed by ground-/surface water) and **spring mires** (fed by artesian springs). Both occur in places, where water supply is almost constant and exceeding the high rates of evapotranspiration and lateral run-off (SUCCOW & JOOSTEN 2001). These places are commonly found at artesian springs, often in combination with higher altitudes and thus, limited evapotranspiration rates (JOOSTEN & CLARKE 2002). Located at slopes or at hillfoots, these peatlands are either supported by the spring water of small aquifers, or are located in the perimeter of glaciers and fed by their meltwater, which carries high sediment loads. Thus, these peatlands are strongly connected to the chemical properties of the bedrock (ALJES et al. 2016). The sloping and spring mires predominantly belong to the class of **surface flow peatlands**, with lateral water flows also appearing on top of the peat layer. This phenomenon is caused by temporal water deficits in these mires, resulting in a stronger decomposition and compaction of the peat layer. Subsequently, the hydraulic conductivity of the peat decreases, forcing the water to overflow the mire surface (JOOSTEN et al. 2017). By oxidation of the peatland, a series of feedback loops is set in motion, including peat degradation, increased surface flow and a lowering of the water table, that quickly leads to a worsening of the situation (SUCCOW & JOOSTEN 2001).

We observed this phenomenon, for example along the sloping mires located in the alpine valleys (site 15 and 16; cf. ch. 3.3.2.2, Figure 19). When the water was not able to flow through the strongly decomposed and compacted peat bodies, it collected in channels on the peatland's surface, setting off water erosion processes. These processes were also witnessed at the much smaller spring mires (e.g. site 12 & 13).

The following sketches present the schematic stratigraphy (not to scale) of sites in Angren (Figure 49, Figure 50, Figure 51) and Nuratau (Figure 52), based on the first observations from the field-survey.

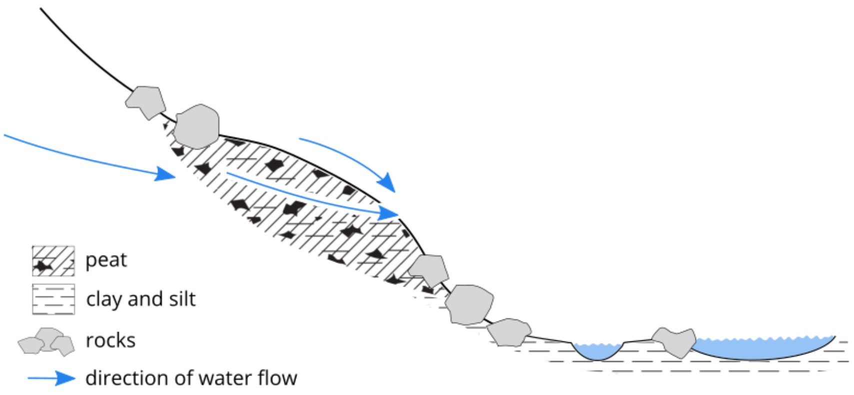

Figure 49: Schematic stratigraphy of a sloping spring mires, as documented at site 12 & 13 (not to scale). The spatial extension is limited by the restricted water availability and erosion activities. Surface flow is partly occurring, especially on decomposed peat, causing erosion channels. For site description, cf. ch. 3.3.2.1.

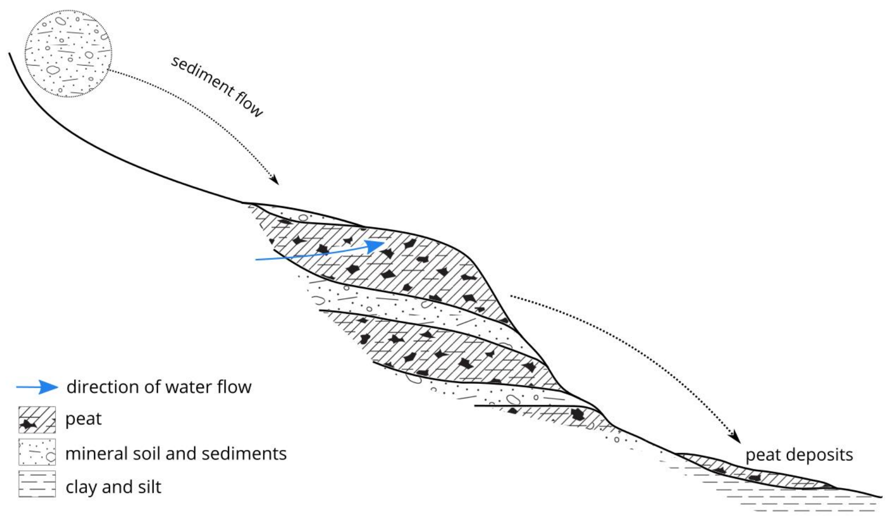

Figure 50: Schematic stratigraphy of a sloping spring mire at site 7 (not to scale). Layering of peats and mineral soils (also witnessed at site 17) is likely caused by sediment flow from the upper reaches. Parts of the peat eroded and were deposited further downhill. For site description, cf. ch. 3.3.2.2.

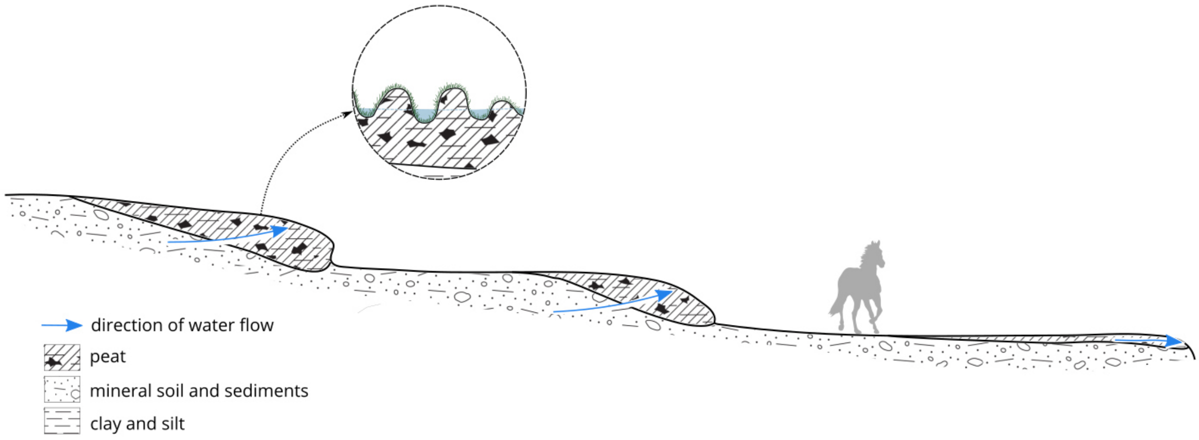

Figure 51: The spring mires at site 6 (Nuratau, cf. 3.3.2.3), with accumulating peat and organic soils on the edges of the "terrace steps", where water is exiting to the surface. Noticeable is the hummocky mico-relief of the wet parts. These mire-terraces are intensely grazed. For site description, cf. ch. 3.3.2.3.

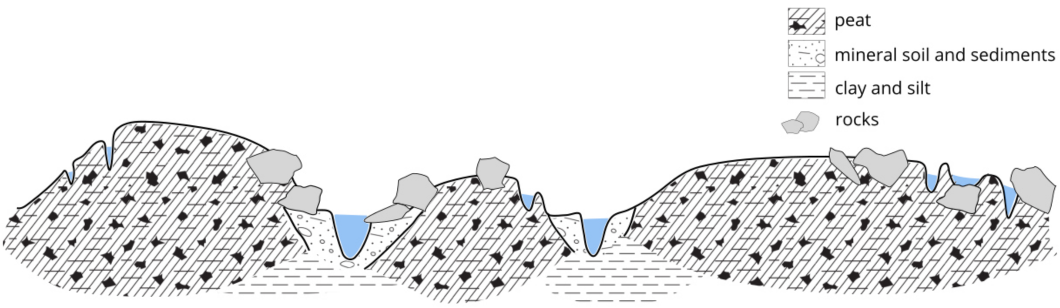

Figure 52: Schematic cross section (perpendicular to direction of water flow) of Site 16, depicting the peat hills, eroded by intersecting water channels. For site description, cf. ch. 3.3.2.2.

Based on the characteristic vegetation for a higher availability of minerals and nutrients, the surveyed mires mostly classified as **mesotrophic sedge fens** (cf. ch. 3.3.2.1 & 3.3.2.2). The vegetation mapping in alpine mires in several regions (Nuratau at 1,650 m, Angren at 2,300–2,450 m and Angren Plateau at 2,700–2,800 m a.s.l.), indicated differences in species composition regarding altitude, climate and geographical region (ch. 3.3.1). Further research on the syntaxonomy of mires in Uzbekistan is important, to better understand the main environmental gradients in the mires, which shape the species composition. Comparable studies on mountain mire vegetation have recently been conducted for other Central Asian regions, like in the mountains of Kyrgyzstan by NOWAK et al. (2016), and on a larger scale for the trans-boundary Irano-Turanian region (Iran, Tajikistan, Kyrgyzstan) by NAQINEZHAD et al. (in review). The ongoing botanical studies demonstrate the increasing attention of the research community towards Central Asian mires and peatlands and associated vegetation communities (cf. ch. 1.1).

Although it was assessed in the field survey, whether the soil of the sites fulfilled the standards to classify as peatlands..., many sedge fens provide quite shallow peat deposits of only a few centimeters, or half peat, with OM levels below 30% (Annex 15). This is a typical trait for the peatlands of Central Asian mountains (ÖZTÜRK et al. 2015). It should be considered to adapt an extended, more inclusive concept of peatland classification for arid highland zones, as many mires still function like "proper peatlands", including peat accumulation and the associated ecosystem services (MINAYEVA et al. 2016).

4.1.2 Lowland peatland characteristics

The field survey confirmed peat formation in the lowlands. Peatlands found here were located along the alluvial plains of the Syr Darya, located at an oxbow and in small relief depressions (sites 19–22, 3.3.2.4). Based on their situation and characteristics, they were classified as floodplain mires (sometimes also called *'flood mire'*; SUCCOW & JOOSTEN 2001). These riverine ecosystems are shaped by natural fluvial dynamics (STERZYŃSKA 2015), and the associated deposition of silicate rich fine sediments (loam and clay) mixed with organical parts (SUCCOW & JOOSTEN 2001). According to SUCCOW & JOOSTEN (2001), well adapted, dominating vegetation forms are reeds composed of e.g. *Phragmites australis*, *Typha* spec., sedge species and a few other wetland species. These plants have also been found in the Syr Darya floodplain mires rooted firmly in the soil and building organic layers "from the ground up". Due to the strong seasonal changes in water levels developing peat layers are often highly decomposed and enriched by mineral components from the sediment load from flooding events (SUCCOW & JOOSTEN 2001). This matches the characteristics from our soil corings (cf. ch. 3.3.2.4 – Figure 28, B), that were extracted during the surveys in the Syr Darya meanders (Sites 20–22). The typical alluvial organic soils that are strongly shaped by the sediment load and the high decomposition rates, are also classified as *'Mudden'* (Ger.), in other words, a highly organic mud with high amounts of fine mineral sediments, as opposed to pure peat or half-peat (SUCCOW & JOOSTEN 2001).

Altogether, the soil characteristics of the surveyed sites in the floodplains and adjacent areas were quite heterogeneous (cf. ch. 3.3.2.4). Most of the sites were very wet or submerged under water and vegetated by reed stands (sites 19, 20, 21, partly site 22). Some soil substrates were high in fine sediments, with low amounts of OM and the characteristic sulphuric smell (site 21), classifying them as silty peats (*Mudden)*. At other sites, hemic half-peats (site 22) or hardly decomposed (fibric) *Phragmites* peats with OM levels reaching 60% (site 19) were found.

An interesting discovery was made at the transition zone between a wet pasture and a marshy reedland, at the border of an oxbow lake (site 22, Figure 53). Here, the organical layers were considerably closer to the characteristics of "typical" peat, with a dark colour, low bulk densities and more pronounced depths (45+ cm; cf. ch. 3.3.2.4). Based on these characteristics, the organic layer was classified as full peat in the field, but this *in-situ* assessment was later corrected by the laboratory analysis, where OM levels were tested to be at 16,2% (= half peat; Annex 15). These remarkably pronounced peaty layers occurred in an area with ongoing grazing activities. Thus, anthropogenic influence may have contributed to the formation of this half-peat.

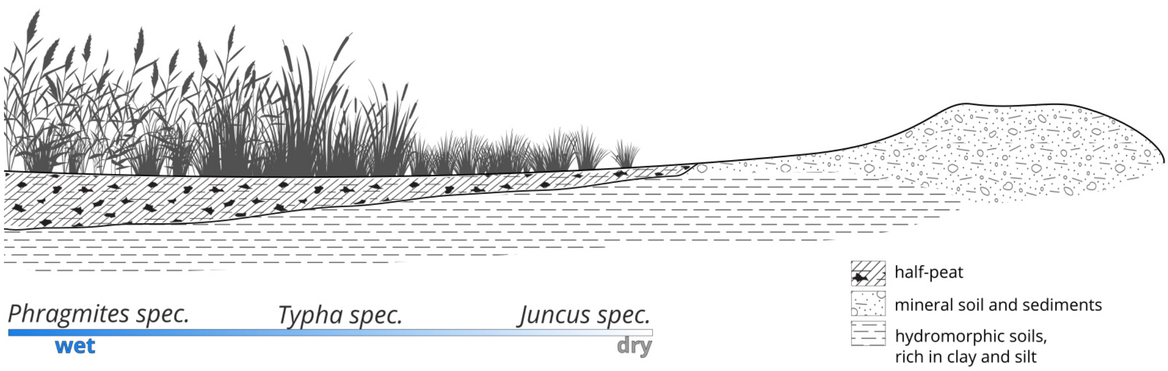

Figure 53: Schematic view (not to scale), depicting the peat development on site 22, on a grazed meadow/reed stand near an oxbow. Vegetation and peat developmet follow a wetness gradient.

The process of mire genesis under anthropogenic activities has been described for the coastal floodland mires (salt marshes). This peatland type is primarily located in the wet marshes of the temperate sea coasts, as along the Baltic Sea. JESCHKE (1987) describes the origin of these wetland types as '*anthro-zoogenetic*', because they only developed under human use. By continuously stepping on vegetation and ground with their hooves, the grazing cattle compacts the soil and incorporates organic material into the topsoil layer. The soil becomes less permeable for oxygen; hence decomposition rates are reduced and the accumulation of peat is initiated. Thus, grazing becomes an important factor for the peat formation, the vegetation and the stability of the mire (JESCHKE 1987). The survival of these ecosystems depends on regular human intervention (VAN DIGGELEN et al. 2006). Palynological evidence from Europe shows that most of the coastal fens have a history of land use. They were slightly drained and used for hay production (WASSEN & JOOSTEN 1996), and only after the traditional land use forms were given up, the former natural fen vegetation transformed towards halophytes and shrub vegetation (KOTOWSKI et al. 2006).

The special role of wet meadows as described above was considered during the mapping potential peatland locations in the Syr Darya basin (cf. ch. 2.4), by focusing on these anthro-zoogenetic transitional zones between land and water.

This anthro-zoogenic mire development comparable to the Baltic Sea marshes might be transferable to the meandering river floodplains of the Syr Darya. Even though the climatic conditions are less favorable, it might be valid for the floodplain and the delta region of the Amu Darya river. too. Further research would be necessary to shed a light on this.

4.2 Ecosystem services, status and threats of peatlands

Both highland and lowland peatlands provide important, but partly different ecosystem services and face partly different pressures from human land use. Moreover, the amount and thematic focus of research on them differs greatly. For these reasons, the highland and lowland peatlands are discussed separately in the following sub-chapters while emphasizing different aspects on ecosystem services, threats and conservation status.

4.2.1 Highland peatlands

Mountainous peatlands are especially important in dry climates. They provide important habitats, supporting biodiversity for wetland species and other species alike, which are otherwise not found in arid regions. They regulate hydrological systems in the headwater areas of streams, influencing the availability of water further downstream throughout the year. Since the lowlands of Uzbekistan depend on freshwater from the mountains, peatlands contribute to its regular availability by slowing the waterflow (MARTIN-ORTEGA et al. 2014, MINAYEVA 2012). Mountain peatlands also provide resources like fodder in the form of pastures (KHUJANAZAROV & ISLOMOV 2020, ALJES et al. 2014, MINAYEVA 2012). Further, they regulate the micro-climate and function as carbon sinks (ALJES et al. 2016).

However, the mountain peatlands are sensitive to disturbances, e.g. by drainage, intensive grazing, or the drop of the water supply. These disturbances can cause oxidation processes in the peat layer: the organic material decomposes and the mineralization processes in the organic soil layer increase. This leads to the compression of the peat and sagging of the soil, due to the increasing soil density and loss of updraft by the lacking support of water. This compression leads to a loss of the soil's hydraulic properties, like water retention potential or water conductivity (STEGMANN & ZEITZ, 2001). Such peats often lost their protective vegetation cover, and are now highly susceptible to erosion processes, like wind and water erosion. This process could be witnessed in the mountainous spring fens included in this study, where we found indicators of peatland degradation, like destroyed vegetation cover, erosion channels and signs of peat decomposition and compaction on almost all sites (Figure 54).

Figure 54: Water erosion on a degraded peatland (site 16).

IMPACTS OF CLIMATE CHANGE

Montane ecosystems are especially fragile and vulnerable towards the impacts of climate change (HOCK et al. 2019) with alpine wetlands among the most vulnerable to warming climates and precipitation changes. Even small changes in climate conditions cause an upward shift of vegetation belts (WILSON & NILSSON 2009), altering the sensitive montane ecosystems. For example, already a change of 1°C or the decrease in precipitation by 20% leads to the altitudinal rise of the fir line by approx. 120–140 m (GLAZIRIN et al. 2002).

XENARIOS et al. (2019) did a review of the impacts of climate change in the Central Asian mountain massifs (Tien Shan and Pamir), which are measurable in increased warming, variable shifts in precipitation patterns, as well as the changing trends in runoff-peak patterns of streams, towards earlier annual dates. The shrinkage of glaciers is visible in all Central Asia, but especially pronounced in the western outer reaches of the Tien Shan, including study areas like the Pskem region (NARAMA et al. 2009, SAVOSKUL & SMAKHTIN 2013), that were identified as potential peatland hot spots during our study.

As evident during the field work, mountainous peatlands and mires of the Uzbek highlands serve as pastures. Being dependent on a steady water supply and susceptible to degradation, they are threatened by the impacts of climate change. A study of mountain regions in Bolivia documented the decreasing availability of water for mountainous peatland pastures, which was linked to changes in the cryosphere, driven by climate change (YAGER et al. 2019). With changing climate trends, pastoral communities are increasingly concerned about the decline of alpine and sub-alpine pastures, that provide the resources necessary to maintain their livelihoods (XENARIOS et al. 2019). The climate change-driven desertification of highland peatlands was also reported by MINAYEVA (2012) for Mongolian highlands, indicating the overall desertification trends in Central Asia. Human activities, such as over-pasturing, strongly increase climate-driven desertification by damaging the vegetation cover. This leads to degradation of the top soil, drying up of the peatlands, and, consequently, sometimes even causing peat fires (MINAYEVA 2012). The temperature increase leads to enhanced decomposition rates of the soil organic matter, declining the ability of peatlands to function as carbon sinks. The drying soils furthermore limit the plant C-uptake (LU et al. 2009).

Though adaptation programs exist, the general lack of scientific information and knowledge gaps, and the existing data constraints in the field of mountain peatland research are problematic, decreasing the effectiveness of the programs (XENARIOS et al. 2019). Additionally, threatening the long-term success are the hierarchical governmental structures, and the ongoing international tensions (including conflicts over water resources) impeding transboundary cooperation (XENARIOS et al. 2019).

HEADWATER FUNCTION

The runoff of meltwater in the high mountains of the western Tien Shan plays a key role in the provision of water for the downstream regions, including irrigation channels, hydropower generation, and general water consumption along the Syr Darya and Amu Darya. Thus, these regions are especially reliant on meltwater sources during the summer, when the dry season coincides with the highest demand (ARMSTRONG et al. 2019). Though the role of headwater peatlands in the hydrological systems is still an under-researched subject, several studies strongly suggest that mountain peatlands provide important water regulation services (e.g. BALEK 2006, KRECEK & HAIGH 2006, VALOIS et al. 2020). Mountain peatlands are playing a role in the regulation of groundwater discharge and water runoff, by providing a retention potential in the landscape (BALEK & PERRY 1973, KOCUM et al. 2018). The degradation of peatlands can affect these functions (JOOSTEN & CLARKE 2002), and therefore impact the hydrological conditions of river systems, especially in the river source regions (ZHANG et al. 2011). MITSCH & GOSSELINK (2000) propose that 3–7% of watersheds should be in wetlands, to assure sufficient control of water quality and water supply. A hypothesis that can likely be transferred to the headwater peatlands of the Central Asian massifs. On the other hand, peatlands lose significant amounts of water to evapotranspiration, a phenomenon that can be negatively correlated to the water table, creating a feedback loop (VALOIS et al. 2020): if the water table is lowered by drainage or a decreasing water supply, evapotranspiration increases, further reducing the water table.

A report on the implementation of the UN Millennium Development Goals on the conservation of inland water bodies (GORLEKIN et al. 2006) highlights the importance of and threats to the ecosystems of upper watershed areas of rivers, including the Pamir-Alai and Tien-Shan. According to the report, the degradation of mountain pastures, erosion processes, and pollution are increasing, resulting in the loss of their regulatory functions and increasing the risks of flooding events and other natural disasters (GORLEKIN et al. 2006).

The further investigation of the water flow regulating functions of mountain peatlands, and how they are functionally and geographically embedded in the hierarchy of hydrological systems is especially crucial for Central Asia. Because here, the lowlands predominately depend on the ongoing water supply from the highlands. The results of this thesis underpin the need for a better understanding.

4.2.2 Lowland peatlands

Lowland peatlands in Uzbekistan have been found in the Syr Darya floodplain and some depressions (cf. ch. 3.3.2.4). They may be located in other river floodplains, at inland water bodies, and potentially in the delta region of the Amu Darya, too. Of Uzbekistan's fragile arid ecosystems, intrazonal wetlands and associated floodplain vegetation are the most affected by environmental change, resulting in irreversible alterations to these systems (TRESHKIN 2001). However, research on floodplains in Central Asia is scarce, and moreover, existing research on floodplains rarely takes the occurrence of peat into consideration. Available information from peat-forming, undisturbed floodplain wetlands mainly relates to the effects of water and nutrients on vegetation composition (WASSEN et al. 2002), hydraulic properties of peat soils (GNATOWSKI et al. 2010) or groundwater-surface water interactions (ANIBAS et al. 2012) (STERZYŃSKA 2015). Given the ecological significance and their scarcity, in combination with the growing reclamation pressures, floodplain peatlands of Uzbekistan need to receive more attention in research, conservation, and policy-making. Some of these aspects are discussed below while highlighting ecosystem services, the impact of land-use changes, and examples of sustainable use of floodplain peatlands, are presented.

ECOSYSTEM SERVICES

Floodplains provide diverse ecosystem services, including flood prevention, provisioning services through fisheries and agriculture, support of biodiversity, acting as nutrients sinks, and recreational opportunities (POSTEL & CARPENTER 1997, MITSCH & GOSSELINK 2000, PALMER & RICHARDSON 2009). Yet, it is exactly their productivity putting them at risk from human use (OPPERMAN et al. 2017). Floodplain wetlands (incl. peatlands) have been used for flood management all over the world (cf. *Associated Programme on Flood Management* 2012). However, their restoration and the associated societal benefits have received increasing attention (e.g. GOUREVITCH et al. 2020). How much they reduce flood-risk depends on their location in the landscape, properties of the soil, vegetation characteristics, as well as their overall status and their management (PALMER & RICHARDSON 2009, ACREMAN & HOLDEN 2013).

Furthermore floodplains, including peatlands, support specific biodiversity by providing habitat to species relying on high water availability. Their role in the nutrient cycle has become more important with high nitrogen loads from fertilizers (PALMER & RICHARDSON 2009), but their function as carbon sinks is just turning out essential nowadays. Infiltration sustains groundwater levels, while fisheries sustain human livelihoods (PALMER & RICHARDSON 2009).

CHANGE OF HYDROLOGICAL SYSTEM AND LAND-USE CHANGES

The most important driver of wetland change in Central Asia are anthropogenic activities, which are closely connected to the land use and water allocation in the major river basins (for Uzbekistan: *Syr Darya, Zerafshan,* and *Amu Darya*; BAIBAGYSSOV et al. 2020). The diversion of the river water through irrigation channels benefits the intensification of land use and increases crop yields, while drastically altering water regimes (BAIBAGYSSOV et al. 2020). In combination with both, climatic drivers and hydropower for generating electricity in winter, the annual flood pattern of the Syr Darya has reversed. The spring-summer floods decreased and the winter floods increased. These changes have severe consequences for the floodplain ecosystems (KUZ'MINA et al. 2019), including peatlands.

Figure 55: Sections of the Karasu river floodplain (tributary of Syr Darya river) with recent land use change between 2014 and 2019.

The loss of floodplain ecosystems through direct conversion and exploitation is a key issue for Uzbekistan's biodiversity (DAVIESSON & FET 2001). These habitats are converted for arable agriculture and cotton production. The mapping of probable peatlands in the Syr Darya basin (cf. ch. 3.4.2) indicates high activities of land reclamation in floodplains, that ultimately cause the destruction of entire floodplain wetlands, including peatlands. An analysis of satellite images from 2014 and 2019 reveals that the area of land reclamation in natural floodplains in the Syr Darya study region (II-1) amounts to an estimated area of 375 ha during these 5 years. This amounts to **26%** of the total area of probable peatlands. Figure 55 shows examples of the recent transformation of natural floodplain vegetation to e.g. paddy fields in the Karasu river floodplain, a tributary river of the Syr Darya.

Through converting the floodplain wetlands for e.g. cotton and rice, the area available for livestock grazing has considerably reduced. Additionally, rich water meadows (and thus, potential peatlands), have increasingly been drained, resulting in drastic changes of reedbed habitats and the loss of species diversity, while also reducing the quality of pastures for grazing and hay production (DAVIESSON & FET 2001). In turn, herding concentrates on the remaining, fragile habitats (Figure 56), leading to further degradation. Since the livestock sector is more independent from the otherwise centralized arable farming sector, many people rely on livestock to improve their economic situation. For these reasons, the sector is growing, and adding further pressure on the sensitive wetland and peatland ecosystems (DAVIESSON & FET 2001).

Figure 56: Cow near an oxbow in the Syr Darya basin, munching on reed vegetation.

POTENTIAL MIRES OF THE AMU DARYA DELTA REGION

KUST & NOVIKOVA (2006) studied the desertification processes in the former "living delta" regions of the Aral Sea, at the Amu Darya (UZ) and Syr Darya (KAZ) estuaries. For the delta region, they describe former 'meadow-bogs' with constant wet, fine textured soils, composed of peat, intermixed with loams and clays. Based on their descriptions, at least some of the mentioned 'bogs' might have been peatlands as e.g. floodplain mires.

Irrigation and flow–regulation of the Amu Darya and Syr Darya river waters have been identified as key factors causing the salinization of ground- and delta waters and the drying of the deltaic lakes since the 1960s. After these estuary regions fell dry, a complex transformation leads to the development of 'salty bogs' of which the soils then classify as '*solonchaks'* (KUST & NOVIKOVA 2006). The peat layers mineralize during this process at a fast rate of 1 m in 20–30 years and may last for decades, even for hundreds of years, while affecting the complete former 'bog' area (KUST & NOVIKOVA 2006). The result is ultimately desertification, salinization of ecosystems, groundwater, and soils, and the change of former wetland plant communities towards xerophilic plant communities (KUST & NOVIKOVA 2006, NOVIKOVA et al. 1996).

Due to the lack of historical data on the wetlands (incl. peatlands) of the Aral Sea and at the estuaries of the Amu Darya and the Syr Darya, it is difficult to assess the full extent of (potential) peat degradation. If they have existed, large areas of these floodplain peatlands have already collapsed ecologically or are still acutely threatened. An attempt to quantify the loss of reeds and accompanied lakes and bogs has been conducted by GAPPAROV & LATCHININSKY (2000). They figured that the area covered by reeds in the delta region has shrunk by 70%, and more than 30,000 ha of 'bogs' and lakes have completely dried up. A land-cover classification of Landsat images was done by LATCHININSKY et al. (2007), depicting the remaining reed stands at that time, potentially indicating the locations of remaining 'bogs'. The extent, characteristics and status of the remaining deltaic wetlands (incl. peatlands), as well as their loss need to be assessed to comprehend the complete ecological disaster. This may help to develop restoration measures and to mitigate the loss of carbon stocks and habitats, and its socio-economic consequences.

WISE USE OF LOWLAND MIRES AND PEATLANDS – PALUDICULTURE

This work has touched upon the threats upon peatlands in Uzbekistan. To conserve them, protection and restoration of floodplains and associated floodplain mires and peatlands, need to be accompanied by measures creating alternative income sources for the local communities. The term 'Wise Use of Wetlands' aims at the sustainable use of wetland ecosystems (DAVIS 1993). While adapting this concept for peatlands (cf. JOOSTEN & CLARKE 2002), forms of wet agricultural practices have been developed or are under development ('*Paludicultures'*; cf. WICHTMANN et al. 2016, CRIS et al. 2014). In order to maintain a high water table and prevent the loss of carbon, paludiculture uses mainly peat-forming plants that grow under wet conditions, such as reed (*Phragmites australis*; KÖBBING et al. 2013). Paludiculture should focus on rewetted peatlands to prevent additional pressure on pristine peatlands.

From an economic perspective, highly productive wetland (incl. peatland) vegetation like reeds are interesting as energy biomass in the form of pellets and biofuels, but also show potential for innovative use to replace plastics (KÖBBING et al. 2013, BAIBAGYSSOV et al. 2020). *Phragmites australis, Cladium* and *Cyperus* are traditionally widely used as construction material (thatching and matting) and for making paper pulp (JOOSTEN & CLARKE 2002). Economical assessments on the use of reed stands in Kazakhstan (BAIBAGYSSOV et al. 2020) and in Mongolia (KÖBBING 2014) demonstrate that even in arid regions, the potential for sustainable use of wetlands exists, and is advised from an economic and ecological standpoint. Thus, regionally adapted wise use of wetlands and associated peatlands might offer alternatives to the currently destructive land use in Uzbekistan's lowlands. Future research may evaluate the socio-economic potential of these peatlands and contribute to the development of new, innovative land use approaches of adapted cultivation.

4.3 Methodological aspects

4.3.1 Preparation and constraints of the field survey

The combination of literature review, remote sensing analysis and field study proved useful to map and examine peatlands in Uzbekistan. The desk study delivered understanding of the existing knowledge and the study region's geography. However, the topic of arid peatlands is largely under-researched (MINAYEVA et al. 2016), especially for Uzbekistan. Direct information on peatlands was virtually not available, and English literature as well as the access to the Russian scientific literature (mostly from Soviet times) was limited. Thus, the peatland probability map based on proxies (cf. ch. 2.2) turned out to be largely outdated, because the rapid land use change in Uzbekistan rendered much of the existing information unusable for the assessment of current peatland distribution.

More helpful and up-to-date information actually stemmed from so-called 'grey literature' as photo documentation from prior trips of the Pskem mountains and other scientific excursions, online photo databases or travel blogs. The latter regularly contained descriptions and depictions of different landscapes, often including wetlands that could potentially classify as peatlands. For researchers with knowledge on landscape ecology and the interpretation of satellite images, these pictures can provide valuable information - at least to inform a targeted field survey. With the development and constantly improving GIS and remote sensing tools to simplify e.g. digitization and data integration, vast amounts of information from across the globe have become accessible. The exploitation of the available primary information sources from scholarly content, to historical records or reports can support scientific progress. At the same time, it is important to critically evaluate the information provided.

Following the selection of probable peatland sites (cf.c ch. 2.3), 7 different regions were covered during the field survey. This provided an overview on very different parts of eastern Uzbekistan and can serve as a baseline for further and more detailed research. The existence of peatlands has been proven, several actual locations confirmed (cf. ch. 3.3.2), and more in-depth information on environmental conditions developed (see above). Though covering several study regions added to a more comprehensive image of the peatlands present, the time and the diversity of approaches for on-site assessments was limited. Since Uzbekistan covers an extensive area, and includes remote regions, it cannot be recommended to conduct field surveys without experienced locals. The support of the scientists from the Tashkent Institute of Botany that made a field trip of this scope possible. The successful data collection on-site benefited greatly from the local expertise from N. Beshko.

The inaccessibility of many regions during certain seasons and administrative hurdles posed challenges to the field study. The research visa is limited to 4 weeks per stay and several border regions require official permits for research, which can be difficult to obtain. Particularly the mountainous regions, that were identified as hotspots for peatland formation are protected by regulations, which also restrict *in-situ* research (e.g. Angren Plateau, Gissar mountains, Pskem Valley). For example, the amount of soil samples brought to Germany was restricted. While UAVs would have provided additional information over larger areas in a very high spatial resolution, their use was impossible for most of the regions due to political tensions along the border and unclear regulations. Therefore, the applied methods had to match the restricted accessibility, time frames, and administrative regulations, such as focusing on the eastern part of Uzbekistan. Nevertheless, the western lowlands of the river Amu Darya, the isolated wetlands in the desert, or in the (former) delta regions of the Aral Basin should be included into further research to either confirm or disprove the presence of lowland peatlands.

We identified peat characteristics on site and used the soil Organic Matter (SOM) content to confirm our *in-situ* classification. The SOM content can be used for the assessment of soil organic carbon. It allowed us to differentiate 'organic' from 'mineral' layers, and to classify 'half-peat' from 'peat' in an efficient way (cf. ch. 2.5, Annex 15). One component of SOM is soil organic carbon (SOC), which would have enabled more precise peat classification, e.g. by considering the different soil substrates (KLINGENFUß et al. 2014). The ratio between SOM and SOC differs between different peat types (KLINGENFUß et al. 2014) and the conversion factors of SOM to SOC must be chosen accordingly. In order to assess the characteristics of peatlands and their soils in Uzbekistan more precisely, future studies should consider measuring SOC.

Further studies are also necessary for the other mountainous regions, at best delivering a more in-depth analysis of the present peatlands. A better understanding of the interaction between soil characteristics, hydrology, and vegetation would increase the accuracy of (semi-)automated remote sensing classification approaches. With the data of this first study, the link between the composition of wetlands vegetation and the properties of the underlying soil (soil organic matter and peat depth) cannot be fully understood. A sedge fen in the highlands or a reed swamp in the lowlands could or could not have developed peat deposits. This limits the accuracy of peatland mapping methods. While gathering more ground truth data, the spectral reflectance of arid peatlands and their location in the relief can be assessed more precisely and interpreted with the help of remote sensing techniques (cf. ch. 4.3.2).

Overall, the detection and successful mapping of peat formation remains a challenging task in the arid highlands of Central Asia, including Uzbekistan, and it demands data with high temporal and spatial resolution. Studies from the Arctic and Mongolia concluded that only a limited number of species in harsh climate conditions can indicate peat formation (MINAYEVA et al. 2019). In contrast, the variability of peat formation indicators (soil & vegetation) is very high under arid climates. This hampers the (semi-)automated recognition of peat formation (MINAYEVA et al. 2019) and methodology needs to adapt to these challenges accordingly.

4.3.2 Remote sensing and classification techniques

Remote sensing (RS) data of the earth's surface and the related tools offer promising and cost-efficient methods (OZESMI & BAUER 2002) to analyze very large or remote areas. RS already profoundly supports ecological research in ecosystems that are difficult to measure (BERND 2015). It has been especially beneficial in Uzbekistan, where peatlands are primarily located in the mountains (often with access restrictions), or in the swampy, hardly accessible reed stands of the lowlands. Today, data from earth observation satellites is freely available with up to 10 m spatial resolution (EUROPEAN COMMISSION 2018, KAPLAN & AVDAN 2017a). Aerial imagery, e.g. from Unpiloted Aerial Vehicles (UAV's), can also offer higher resolutions and acquisition on specific dates (RUWEIMANA et al. 2018, IIZUKA et al. 2018, KAPLAN & AVDAN 2018). While this imagery is not freely available, the costs can still be considerably lower than field studies, and the advantages of covering larger areas remain (BRYSON et al. 2014). Already relatively simple indices can provide ecologically meaningful results and monitor e.g. land use change (PETTORELLI 2013). Cloud computing and the increasing amount of earth observation data bear enormous potential for environmental research (cf. YAO et al. 2020). Through the continuous collection of imagery, seasonal dynamics can be monitored (MOSER et al. 2017, KAPLAN et al. 2019). This can be especially useful for wetlands that share a spectral similarity to other features and can be only differentiated by temporal patterns (HALABISKY, BABCOCK & MOSKAL 2018), or when using lower resolution imagery (SIVANPILLAI & LATCHININSKY 2006).

At the same time, challenges to the mapping and subsequent analysis of wetlands with remotely sensed data exist. Especially, the differentiation between the various sub-types of wetlands, including peatlands, is difficult (MAHDAVI et al. 2018). The RS methods, therefore, need to be chosen to fit the unique characteristics of the peatlands of interest, from small mountainous peatlands to the reed-dominated wetlands of the meandering rivers of the lowlands. KAPLAN & AVDAN (2017a) found medium (e.g. Landsat) or high (e.g. Sentinel-2) resolution optical satellite data in combination with pixel-based classification approaches to be rather limited for peatland mapping. Though, this might be different while using other data sources, different indices or classification approaches, or several points in time to detect seasonal changes. They recommend the combination of object-based and index-based classification for better results regarding wetland contents and wetland borders (KAPLAN & AVDAN 2017a). In their later work, they showed that combinations of 'VHR' (Very High Resolution) data obtained with a UAV and optical, thermal, and radar satellite imagery can map wetlands much more accurately (KAPLAN & AVDAN 2017b, KAPLAN et al. 2019). The application of a UAV also allowed them to differentiate types of wetlands (KAPLAN & AVDAN 2017b), though that depends on local characteristics and might not be possible in other locations.

A higher spatial resolution, which can be achieved e.g. with UAVs, is generally linked to increased classification accuracy (cf. CAMPBELL 2011). However, the classification accuracy depends on the ratio of resolution to the size of the features to be classified (LECHNER et al. 2009). A meta-study by YU et al. (2014), confirms that classification accuracy is not achieved solely by a higher spatial and spectral resolution, but rather depends on the complexity of the classification system used. Nevertheless, the resolution is especially relevant when analyzing small-scale structures like the mountainous peatlands in Uzbekistan. Many peatlands that we studied *in-situ* and areas that I mapped as potential peatlands were too small to cover one or several complete pixels of e.g. medium-resolution Landsat (30 m) or Sentinel-2 imagery (10–20 m). A coarse image resolution in combination with small features results in mixed pixels, where one pixel covers the spectral classes of different features, leading to the assignment of wrong classes (OZESMI & BAUER 2002).

Moreover, using optical satellite imagery in mountainous regions tends to give less accurate results due to mountain shadows and shading the actual surface (LI et al. 2018). Seasonal changes can be harder to detect due to shadows (LI et al. 2019), but also due to snow cover during winter. This underlines that remotely sensed data cannot substitute information collected on the ground completely. The accuracy of analyses depends on validation with *in-situ* data for ground-truthing (HORNING et al. 2016, MILITINO et al. 2018), particularly in areas with sparsely existing data and information – as in the mountains of Uzbekistan.

There are numerous data sources and approaches bearing further consideration for research on peatlands in Uzbekistan: radar imagery from satellites like Sentinel-1 provided promising results in first applications (KAPLAN & AVDAN 2017b, KAPLAN et al. 2019). Both light detection and ranging

(LiDAR) and hyperspectral data have been used successfully to map wetland species (ZHANG et al. 2018, ADAM et al. 2010). Highland wetlands, like *cobreisa* and *carex* swamps, were successfully classified with an object-based classification method (ZHANG et al. 2011). These wetlands share similar characteristics to the mountainous spring fens of Uzbekistan (cf.ch. 3.3.1) Accurate results were achieved by defining thresholds and extraction rules for a combination of data sources, such as DEMs and indices, derived from Landsat TM images, to account for the characteristics of different wetland types. Still, this method requires a comprehensive understanding of the wetland's environmental requirements, and sufficient amounts of accompanying ground-truth data from field surveys, such as soil samples, moisture and vegetation (ZHANG et al. 2011).

However, whether these approaches can be adapted to differentiate peatlands from other types of wetlands is uncleaar. Equally important are the refinement of existing and development of new methods to gain information from all these diverse data. One example that could be useful is improved measuring of soil organic carbon (ANGELOPOULOU et al. 2019), which might be adaptable to detect (likely) peat occurrence. Given the importance of peatland ecosystems for Uzbekistan, but also globally, I hope there will be further research in this direction.

This thesis shows the potential for mapping peatlands in mountainous and remote areas using satellite imagery, and how this can guide in-depth research in the field. Still, the differentiation between peatlands and other wetlands through remote sensing data proved difficult. Especially, if trying to cover large areas with small and patchy peatland pockets like in Uzbekistan. Due to the restricted time and topic for a MSc-thesis, only limited approaches could be tested. Yet, through this work I hope to contribute to the emerging field of peatland mapping and monitoring using earth observation technologies.

5 Conclusion

In this study, the occurrence of peatlands in Uzbekistan was investigated. By combining a desk study, spatial data analyses and a field study, it was possible to indicate study regions, delineate probable peatlands, and lastly, to confirm them during the field survey in 2019. The overall finding of this thesis is that peatlands ('peat': >30% of Soil Organic Matter and 'half-peat': 10–30% SOM, resp.) are covering wide altitudinal and climatic ranges in Uzbekistan, from the semi-deserts of the lowlands, to steppes in relic mountains, up to alpine regions. However, in many cases they are small and/or have a patchy distribution. Additionally, the restricted number of sampled sites requires caution when interpreting the results.

Based on the field study, different peatland types were postulated, mainly 'sloping mires' in the highlands and 'floodplain mires' in the river valleys of the lowlands. Because precipitation is low and high evapotranspiration rates further limit the availability of water, peatlands are exclusively fed by ground- and surface water and bound to locations of steady water supply, be it springs, rivers, or water bodies. Due to the arid conditions and intense land use, these peatlands show less pronounced features as compared to those of temperate zones, while similarly fulfilling important ecological functions. This suggests the need of adopting an inclusive classification approach for arid peatlands.

Due to the unfavorable arid climate in Uzbekistan, peatlands cover only a small part of the country's territory. The mapping of probable peatlands in all study regions revealed overall small patch sizes; summing up to 32,5 km^2. Trough preserving water resources and maintaining wet habitats, their natural value and ecosystem services are especially crucial in the arid environment. Headwater highland peatlands function as water storage, regulating water flow. As mountain pastures with vegetation rich in mesophytic plants of high nutritional value, these peatlands also provide for people's livelihoods. In the floodplains, peatlands mainly serve as nutrient sinks, for flood control and biomass production and harbor specific biodiversity.

Highland peatlands are among the most vulnerable ecosystems in the world. The field survey revealed their degradation in Uzbekistan, too, presumably caused by overgrazing and amplified by climate change. Among the sensitive intrazonal ecosystems of Uzbekistan, floodplains have been affected the most by human disturbances and large parts have been lost over the last decades. Floodplains, and the peatlands in oxbow lakes, are threatened by massive changes in the hydrological systems of rivers, resulting in changes of flooding regimes and water allocation, and finally their destruction. On the other hand, field work revealed that peat characteristics were especially pronounced under grazing land. This raises the question, if anthropogenic use may partly function as a driver for peat development.

The remote mapping carried out as manual delineation of peatlands, proved to be a promising method to inform field surveys in regions with scattered and small-sized peatlands patches. The identification of key features for the mapping of highland and lowland peatlands proved successful to improve recognition and delineation of features. However, remote sensing techniques bear much more potential for peatland classification and mapping – if methods are carefully chosen. And finally, the gathering of sufficient ground-truthing data and a keen understanding of the peatland characteristics is crucial. Thus, further field research is urgently needed, because targeted and successful conservation strategies can only be developed based on sound scientific findings. Approaches like the Man and the Biosphere Program (MAB) of the UNESCO aim to support both nature and local communities, by developing alternative, sustainable sources of income and promoting environmental education. One example of recent development in this direction is the recently nominated Lower Amu Darya Biosphere Reserve.

One major finding is that peatlands in Uzbekistan have so far been lacking recognition, from research and conservation communities. Also, this work opened up further questions, regarding vegetation, hydrology, peatland classification, and the ecosystem services of peatlands in Uzbekistan. Mapping peatlands in western Uzbekistan may also reveal additional insights to the current (and former) distribution of peatlands and its limits in these unfavorable climates.

I hope my work adds to the knowledge about arid peatlands, and that it underlines the need for further study and acknowledgment of these unique ecosystems in Uzbekistan.

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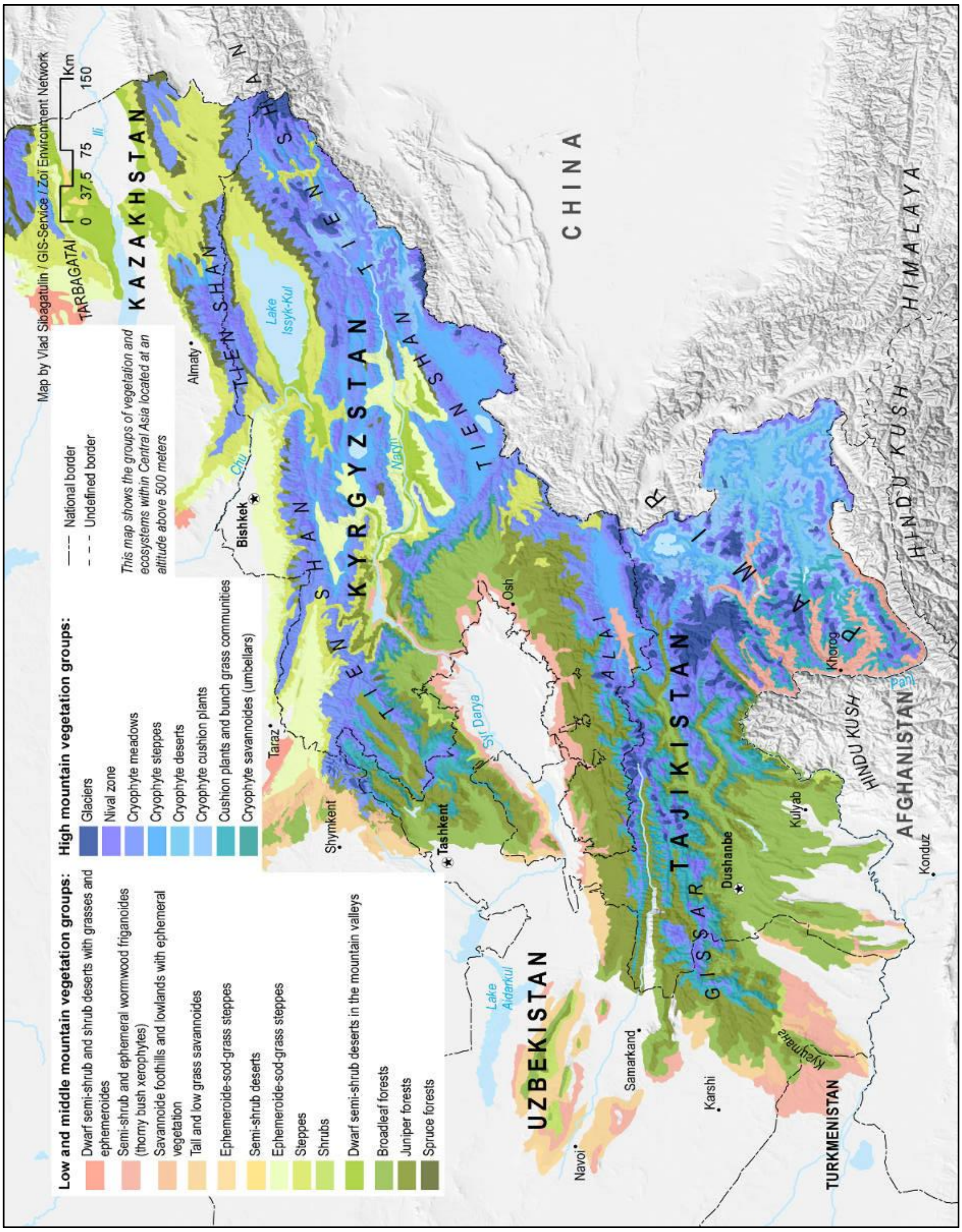
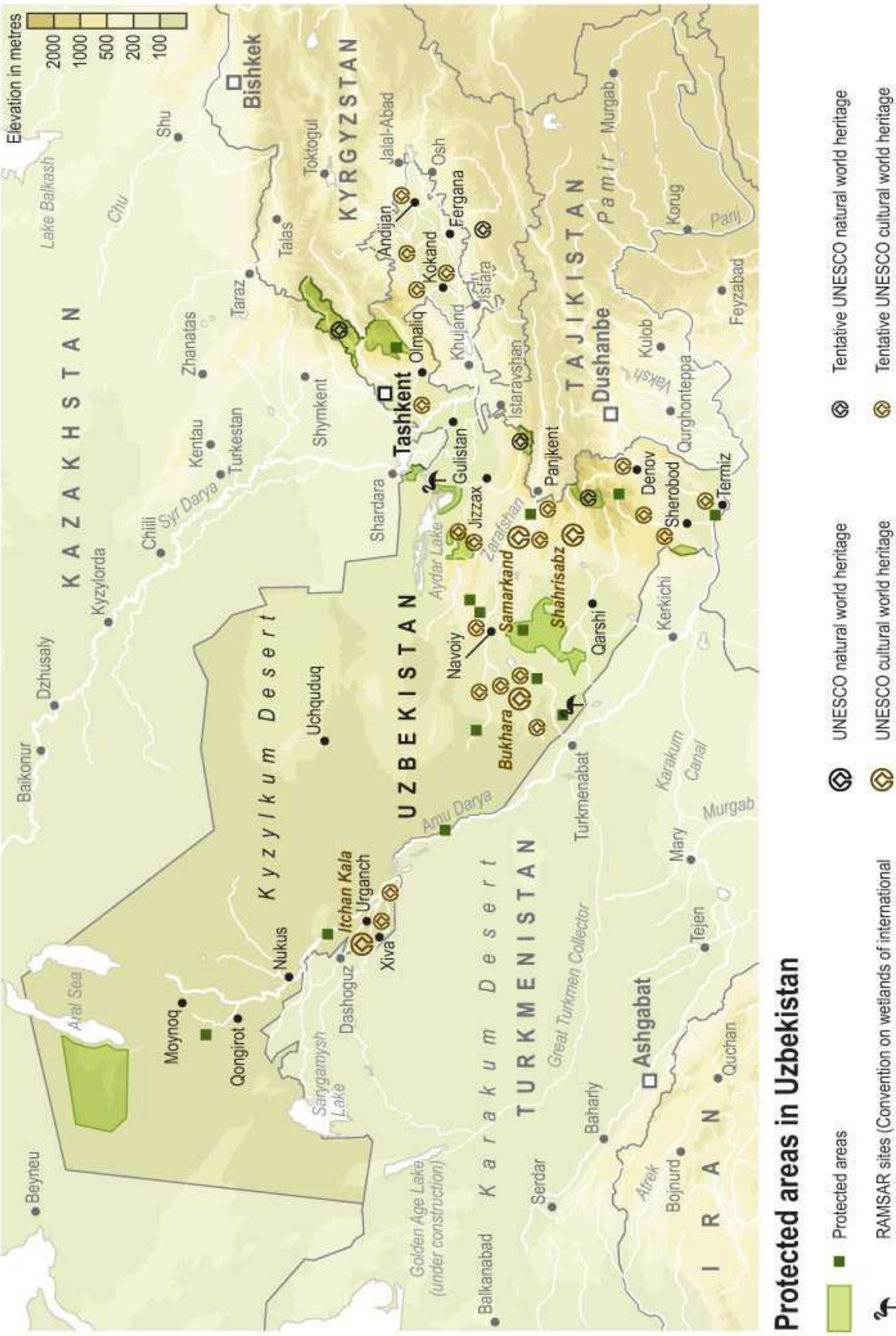
Greifswald, January 2021

Annex

Annex 1: The phytogeographical region of Central Asian mountains (Source: Zoi Environment Network 2015).



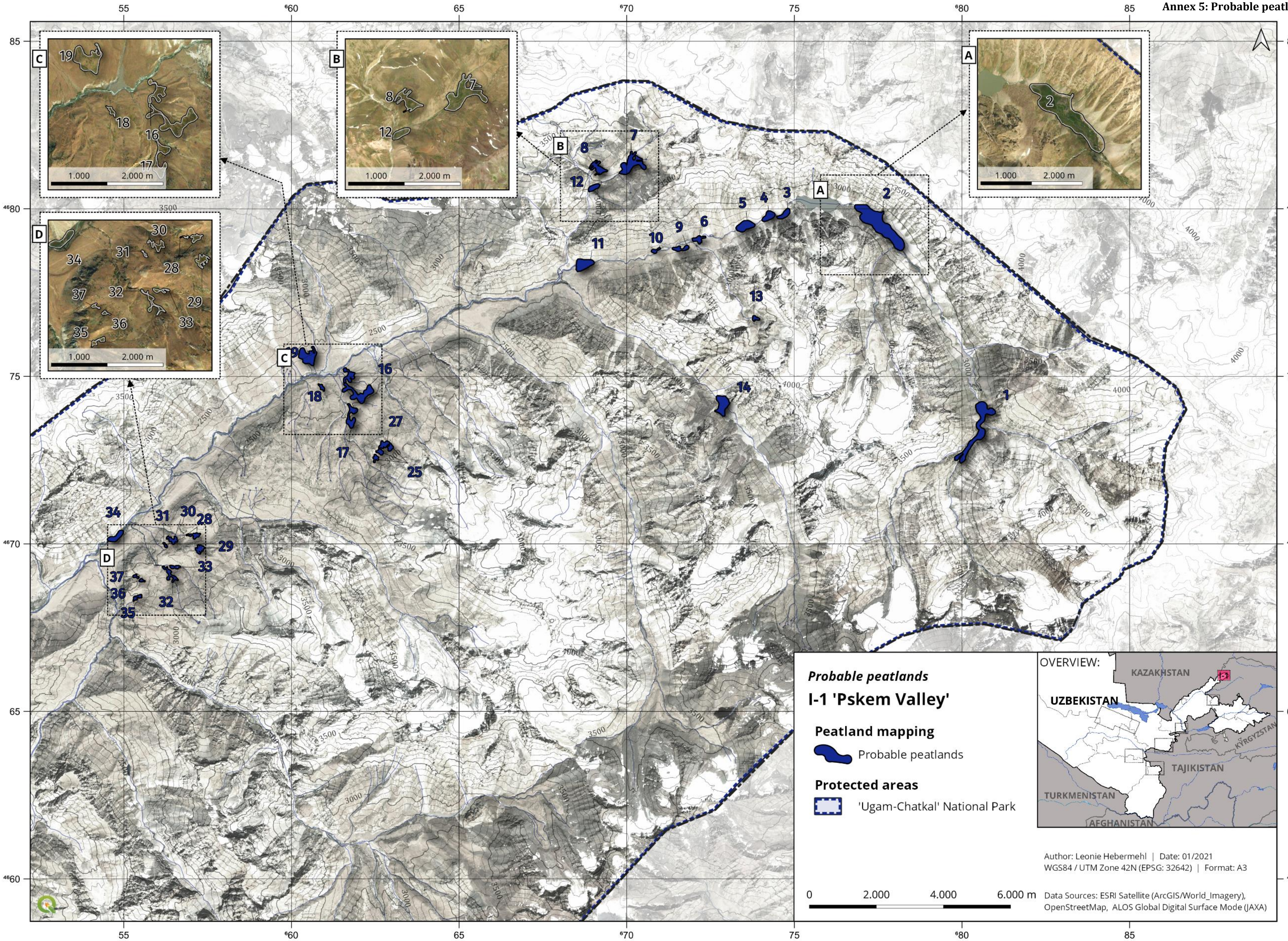
Annex 2: Protected areas of Uzbekistan (Source: ZOI ENVIRONMENT NETWORK 2012)



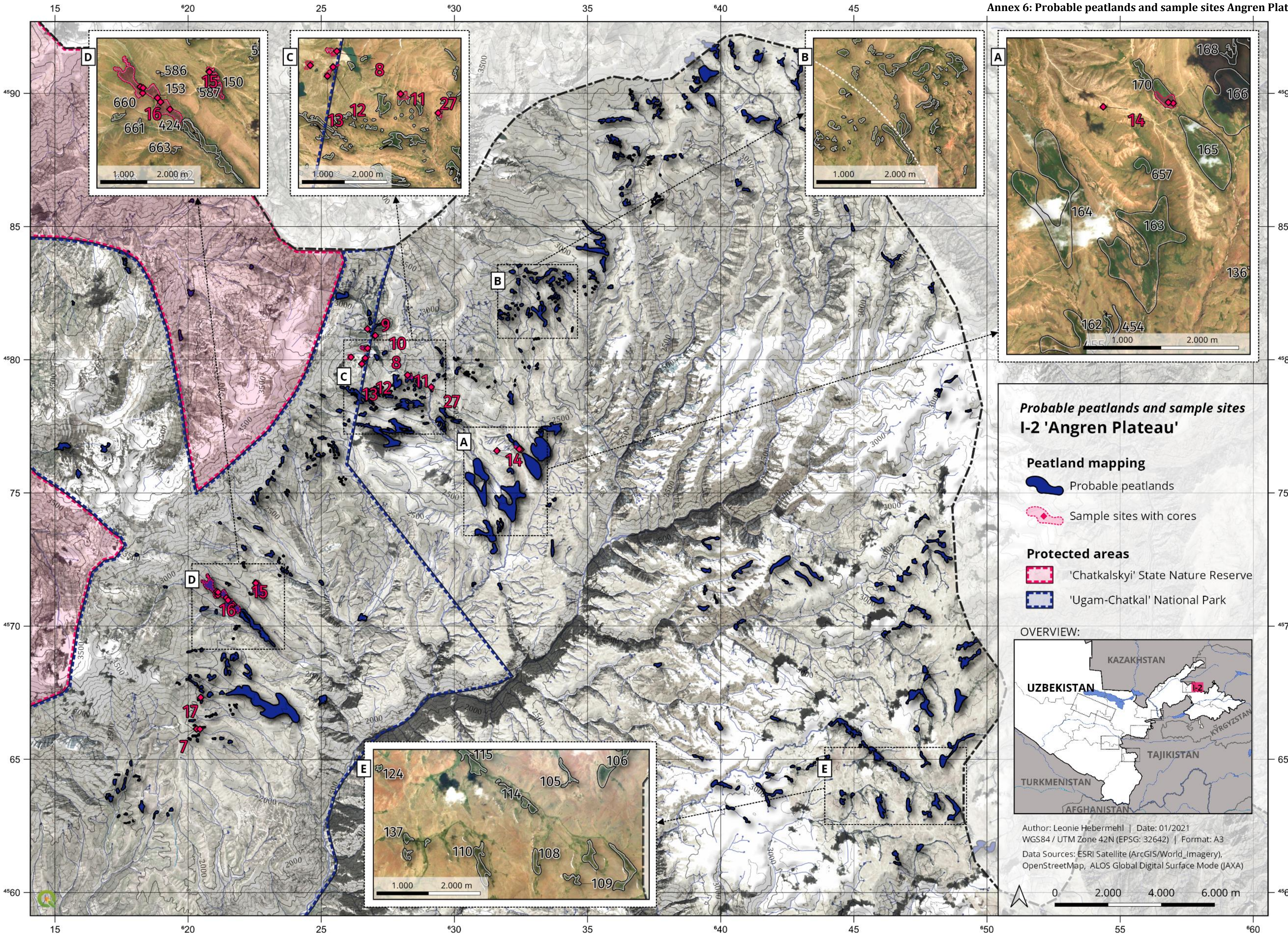
Annex 3: Soil map of USSR Uzbekistan (1960)

Annex 4: Soil Map of Soviet Central Asia (1970)

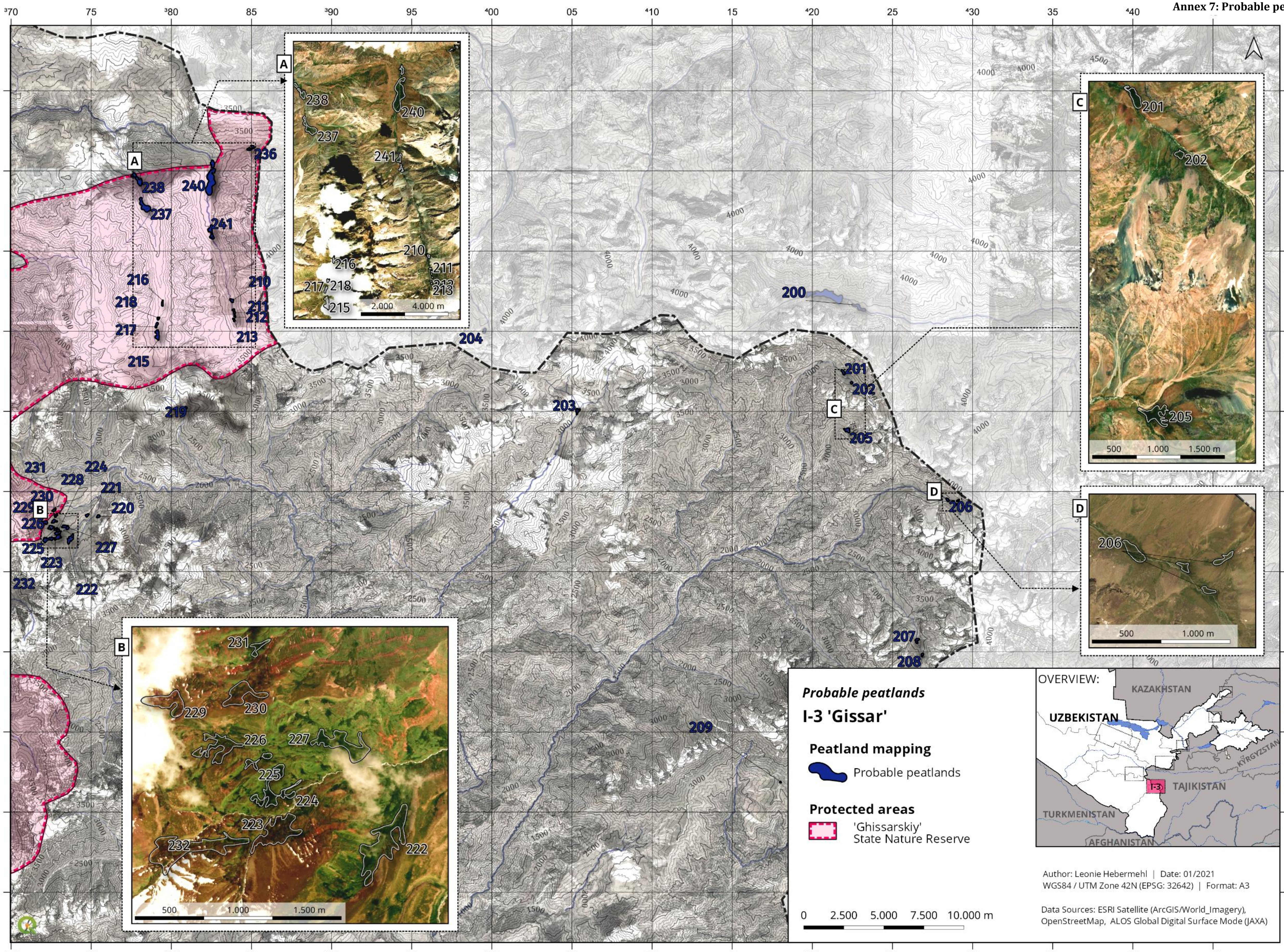
Annex 5: Probable peatlands Pskem Valley (I-1)



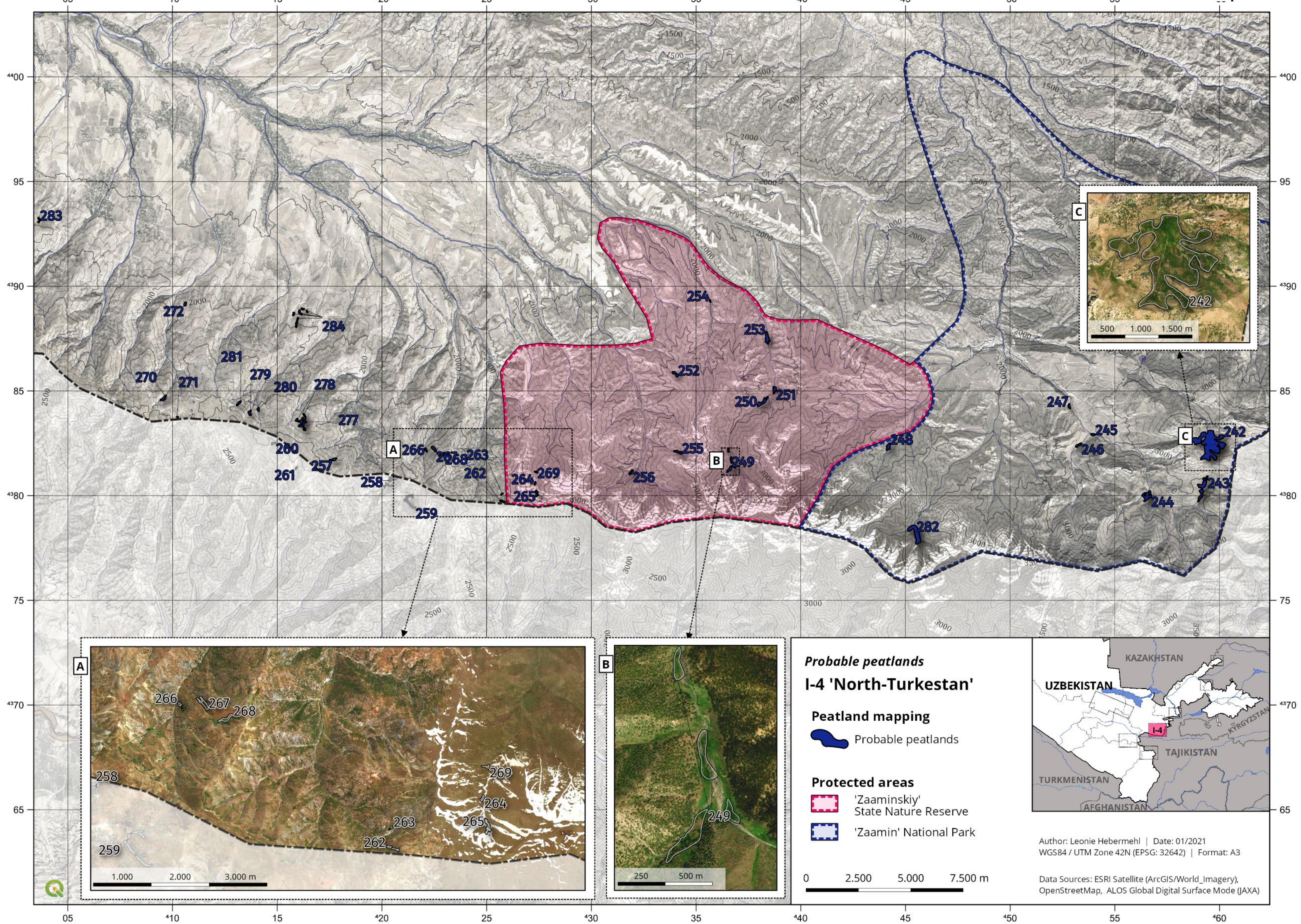
Annex 6: Probable peatlands and sample sites Angren Plateau (I-2)



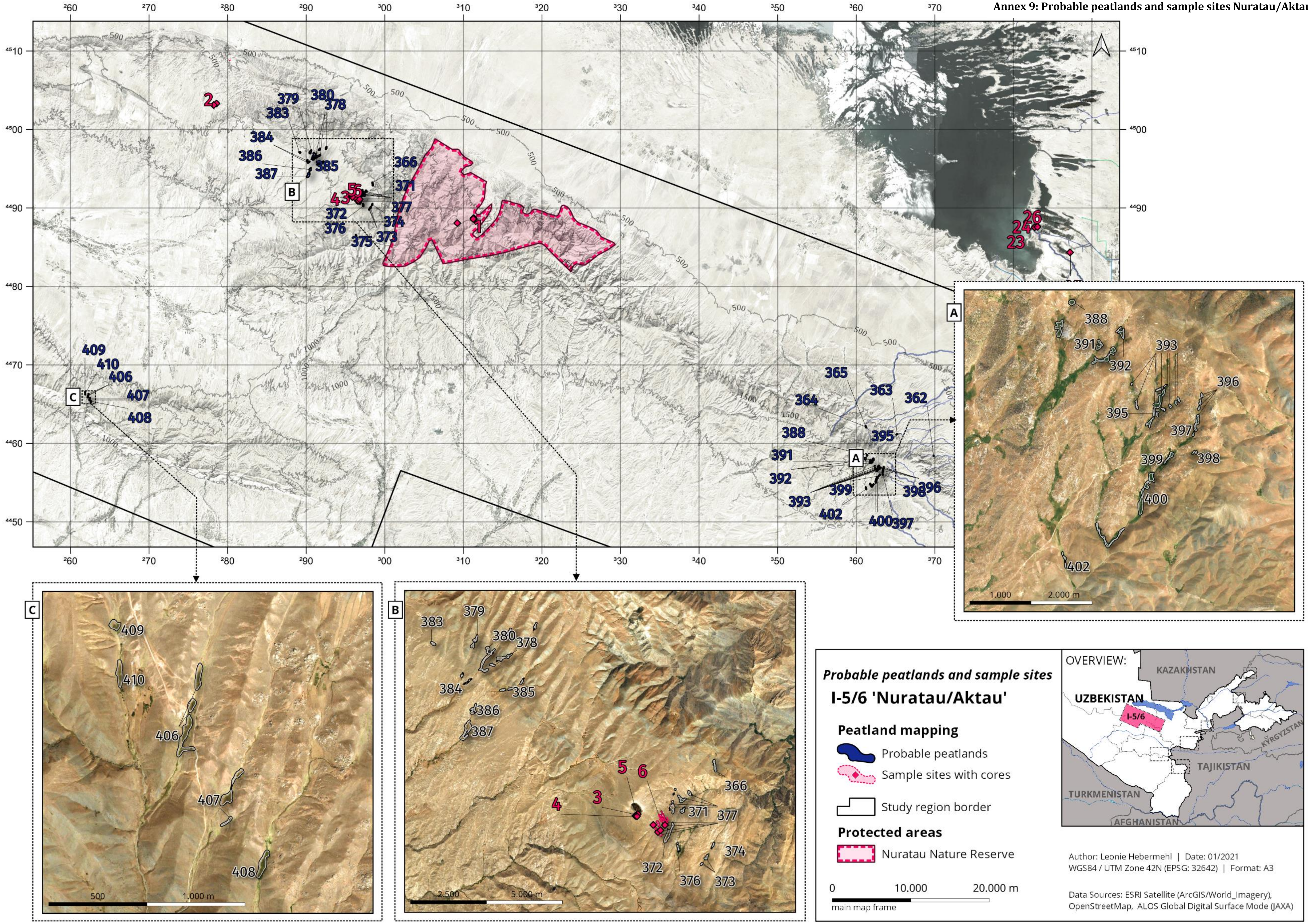
Annex 7: Probable peatlands Gissar (I-3)



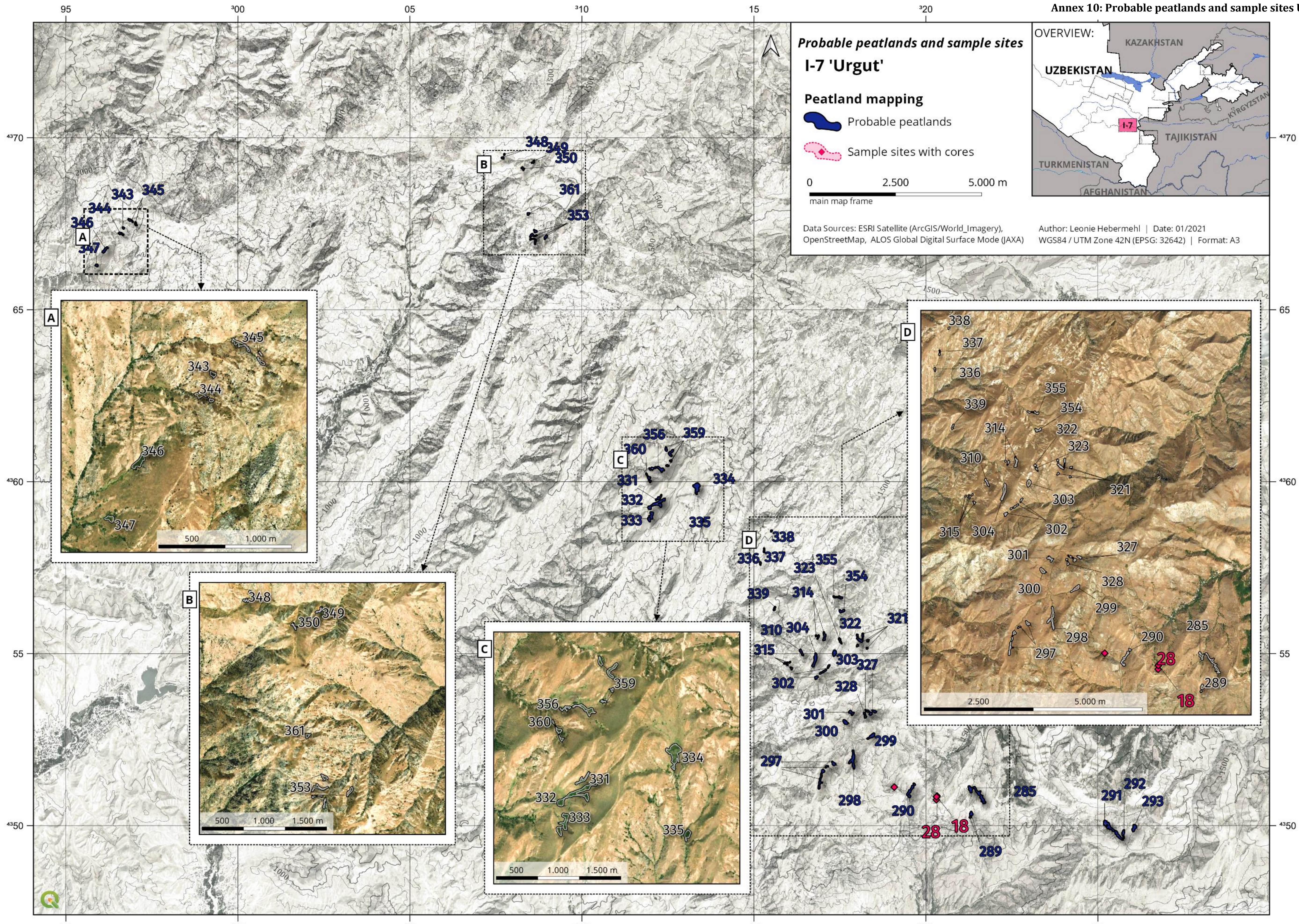
Annex 8: Probable peatlands North-Turkestan (I-4)



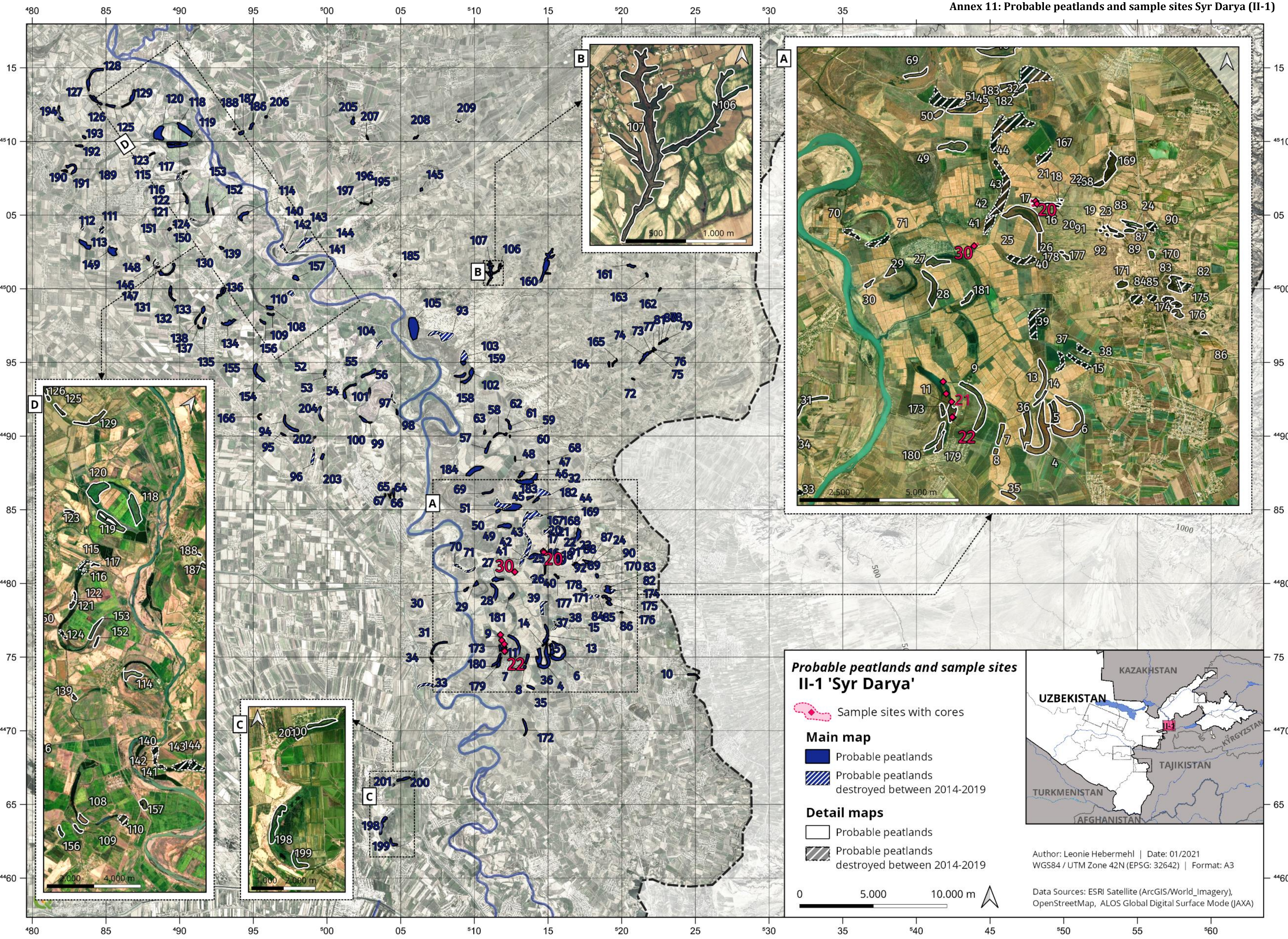
Annex 9: Probable peatlands and sample sites Nuratau/Aktau (I-5/6)



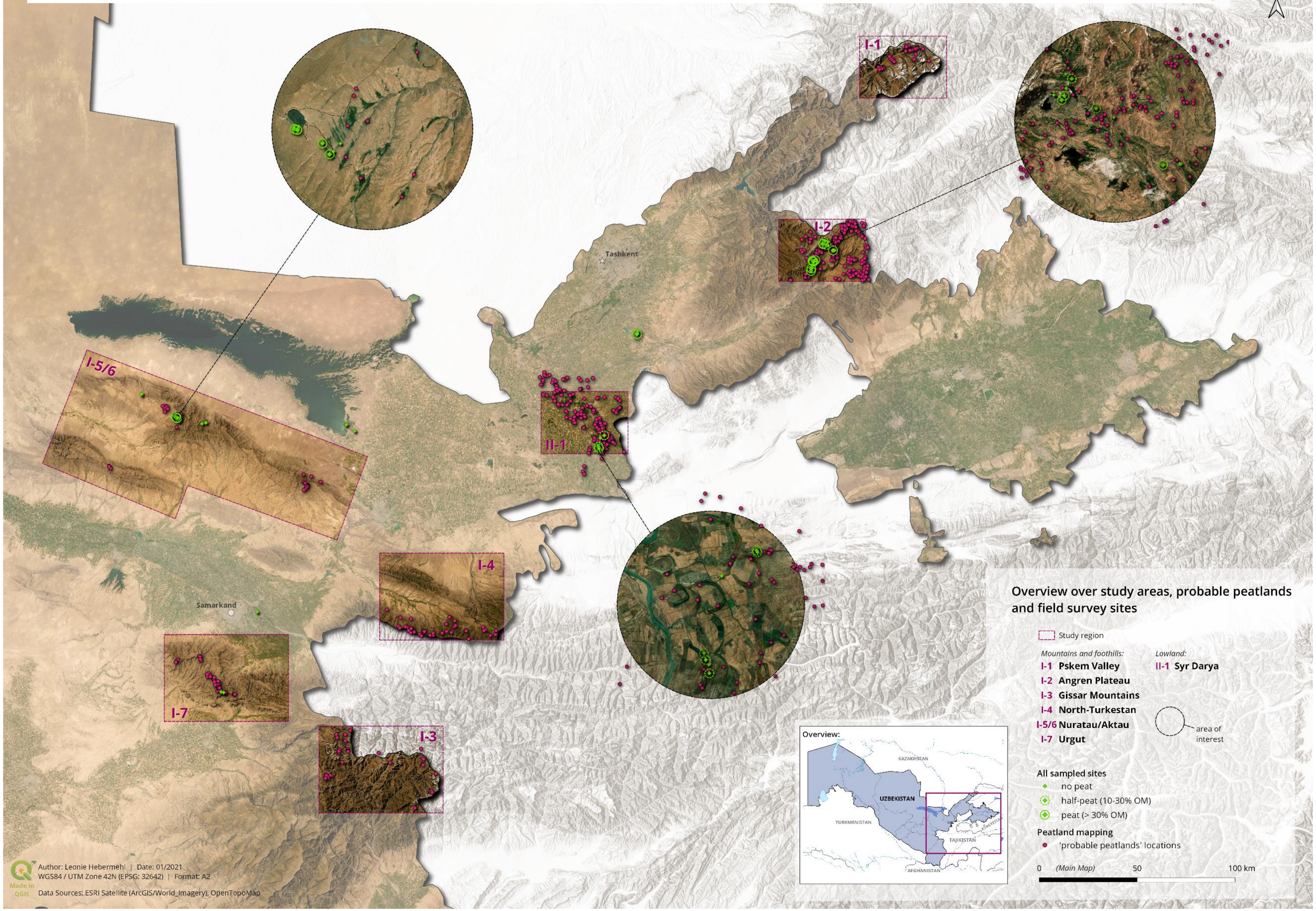
Annex 10: Probable peatlands and sample sites Urgut (I-7)



Annex 11: Probable peatlands and sample sites Syr Darya (II-1)



Annex 12: General overview over the locations of study regions, mapped probable peatlands and field study locations



Annex 13: Form for site assessment (relevé)

Cores: yes ☐ no ☐	Samples taken: yes ☐ no ☐	Wetness:	Level of degradation:
Soil colour:	Soil substrate (material, grain size):		Soil type:

Core №	GPS №	Peat depth:	Samples taken in depths (cm):		
			a:	b:	c:
			a:	b:	c:
			a:	b:	c:
			a:	b:	c:
			a:	b:	c:
			a:	b:	c:
			a:	b:	c:
			a:	b:	c:
			a:	b:	c:
			a:	b:	c:
			a:	b:	c:
			a:	b:	c:
			a:	b:	c:

Labeling core samples : [Relevé No.]-[Core No.]-[a-c]

Comments:

Relevé no.: ☐

Researcher:	Date:	GPS №:	Coordinates: WGS84 ☐ UTM ☐
Region:	Location (short descr.):		
Height (m):	Slope:	Expositon:	Comment:

Vegetation type:	Layer coverage (%):	Veg. height (cm):

Plant species list

BRAUN-BLANQUET-Scale

Symbol	r	+	1	2m	2a	2b	3	4	5
Cover %	-1	-1	-5	< 5	6-15	16-25	26-50	51-75	76-100
Individuals	1	2-5	6-50	> 50	any	any	any	any	any

A= Additional

Annex 14: Field survey results - Study sites 1-30 (Excerpt)

Field survey results						UTM coordonates:									
Study site ID	Region ID	Region	Date	Documentation	GPS No	X	Y	Area (sqm)	Elevation (m a.s. l.)	Slope	Exposition (°)	Cores taken	Soil Samples taken	Peat (y)/ half peat (h)	Peat depth
1	I-5/6	Nuratau/Aktau	Wed, 10.07.2019	LH, CM	307	*311309*	*4488724*	1,778	985	slight	0	2	0	no peat	0
2	I-5/6	Nuratau/Aktau	Thu, 11.07.2019	LH, CM	315	*278232*	*4503116*	759	805	flat	0	1	0	no peat	0
3	I-5/6	Nuratau/Aktau	Thu, 11.07.2019	LH, CM	316	*295923*	*4491461*	1,138	1,639	flat	0	1	0	no peat	0
4	I-5/6	Nuratau/Aktau	Thu, 11.07.2019	LH, CM	318	*295848*	*4491409*	2,790	1,651	slight	270	1	1	peat	10
5	I-5/6	Nuratau/Aktau	Thu, 11.07.2019	LH, CM	320	*295888*	*4491397*	1,140	1,649	slight	260	1	0	peat	10
6	I-5/6	Nuratau/Aktau	Fri, 12.07.2019	LH, CM	322	*296436*	*4491104*	77,908	1,651	medium	20	4	3	peat	10
7	I-2	Angren Plateau	Tue, 16.07.2019	LH, CM	327	*620315*	*4566142*	522	2,405	medium	110	4	2	peat	30
8	I-2	Angren Plateau	Wed, 17.07.2019	LH, CM	331	*626744*	*4580430*	25,463	2,755	steep	110	1	1	no peat	0
9	I-2	Angren Plateau	Wed, 17.07.2019	LH, CM	334	*626738*	*4581157*	8,730	2,725	slight	120	1	1	no peat	0
10	I-2	Angren Plateau	Wed, 17.07.2019	LH, CM	335	*627016*	*4580902*	3,457	2,773	steep	250	2	1	half peat	20
11	I-2	Angren Plateau	Wed, 17.07.2019	LH, CM	338	*628242*	*4579424*	35,941	2,670	slight	170	1	0	half peat	10
12	I-2	Angren Plateau	Wed, 17.07.2019	LH, CM	340	*626652*	*4580062*	6,990	2,822	steep	70	1	1	peat	35
13	I-2	Angren Plateau	Wed, 17.07.2019	LH, CM	342	*626522*	*4579844*	12,582	2,848	medium	40	1	1	peat	25
14	I-2	Angren Plateau	Thu, 18.07.2019	LH, CM	345	*631597*	*4576584*	1,535	2,416	steep	120	1	1	peat	10
15	I-2	Angren Plateau	Thu, 18.07.2019	LH, CM	348	*622536*	*4571624*	127,338	2,383	slight	120	1	1	peat	19
16	I-2	Angren Plateau	Thu, 18.07.2019	LH, CM	350	*621118*	*4571162*	359,832	2,394	steep	110	5	7	peat	70
17	I-2	Angren Plateau	Thu, 18.07.2019	LH, CM	356	*620472*	*4567323*	8,381	2,437	slight	75	1	0	peat	22
18	I-7	Urgut	Sat, 20.07.2019	LH, CM	358	*320308*	*4350839*	1,317	1,636	flat	-	1	1	no peat	0
19	-	Tashkent Reservoir	Tue, 23.07.2019	LH, CM	363	*531458*	*4533900*	7,733	386	flat	-	1	1	peat	25
20	II-1	Syrdarya	Tue, 23.07.2019	LH, CM	365	*514716*	*4482101*	23,383	260	flat	-	2	2	half peat	35
21	II-2	Syrdarya	Tue, 23.07.2019	LH, CM	368	*511858*	*4476138*	0	270	flat	-	1	1	half peat	15
22	II-3	Syrdarya	Tue, 23.07.2019	LH, CM	371	*512071*	*4475393*	13,199	263	flat	-	2	2	half peat	45
23	-	Aydar Kul	Wed, 24.07.2019	CM	375	*382708*	*4487531*	3,379	258	flat	-	1	0	no peat	0
24	-	Aydar Kul	Wed, 24.07.2019	CM	376	*383078*	*4487628*	179	242	flat	-	1	0	no peat	0
25	-	Aydar Kul	Wed, 24.07.2019	CM	378	*387201*	*4484340*	3,379	247	flat	-	2	2	no peat	0
26	-	Aydar Kul	Wed, 24.07.2019	CM	377	*383059*	*4487580*	1,633	241	flat	-	1	0	no peat	0
27	I-2	Angren Plateau	Wed, 17.07.2019	LH, CM	344	*629127*	*4578978*	12,199	2,590	flat	-	1	0	no peat	0
28	I-7	Urgut	Sat, 20.07.2019	LH, CM	357	*320303*	*4350753*	1,475	1,640	flat	-	1	0	no peat	0
29	-	Zerafshan river	Sun, 21.07.2019	LH, CM	361	*337394*	*4391926*	754	269	flat	-	1	0	no peat	0
30	II-1	Syrdarya	Tue, 23.07.2019	LH, CM	367	*512737*	*4480781*	8,674	269	flat	-	1	0	no peat	0

Annex 15: Laboratory analysis of soil samples - OM content

Laboratory soil analysis: Organic matter content (OM)

Study site ID	Core placement ID	Crucible empty weight [g]	Sample weight before ignition [g]	Total weight before ignition [g]	sample weight after ignition [g]	Loss of ignition [g]	Soil organic matter [%]
4	*1a*	31.7311	2.1764	33.0548	1.3237	0.8527	**39.18**
4	*1b*	29.8674	3.4265	33.1489	3.2815	0.1450	**4.23**
6	*2a*	29.9671	1.5987	30.7069	0.7398	0.8589	**53.72**
6	*1b*	34.8937	2.8934	37.7000	2.8063	0.0871	**3.01**
6	*1a*	32.4878	2.3848	34.2871	1.7993	0.5855	**24.55**
7	*1a*	29.8432	1.4113	30.7182	0.8750	0.5363	**38.00**
7	*3a*	27.8100	1.4295	28.8815	1.0715	0.3580	**25.04**
7	*2a*	33.7829	1.3155	34.2486	0.4657	0.8498	**64.60**
8	*1a*	30.2230	1.9170	32.0426	1.8196	0.0974	**5.08**
9	*1a*	30.4570	2.6527	32.8664	2.4094	0.2433	**9.17**
10	*2a*	27.0268	1.6643	28.3872	1.3604	0.3039	**18.26**
12	*1a*	33.4369	0.9502	33.7931	0.3562	0.5940	**62.51**
12	*1b*	27.2755	1.2992	28.2387	0.9632	0.3360	**25.86**
14	*1a*	32.8105	1.4667	33.7487	0.9382	0.5285	**36.03**
15	*1a*	32.0642	2.0014	33.2920	1.2278	0.7736	**38.65**
16	*2c*	32.1668	1.7267	33.8184	1.6516	0.0751	**4.35**
16	*2b*	27.2416	1.2625	28.1052	0.8636	0.3989	**31.60**
16	*5a*	31.6215	2.6425	34.0505	2.4290	0.2135	**8.08**
16	*1a*	31.1349	1.5921	32.0887	0.9538	0.6383	**40.09**
16	*3b*	32.4436	1.6902	33.3352	0.8916	0.7986	**47.25**
16	*2a*	30.0402	1.6154	30.4667	0.4265	1.1889	**73.60**
16	*3a*	27.6662	1.3360	28.0840	0.4178	0.9182	**68.73**
19	*1a*	31.5431	0.7829	31.8588	0.3157	0.4672	**59.68**
20	*1a*	28.0502	2.2480	30.2133	2.1631	0.0849	**3.78**
20	*2a*	29.2997	2.1741	31.2334	1.9337	0.2404	**11.06**
21	*2a*	32.4934	2.5099	34.8522	2.3588	0.1511	**6.02**
22	*1b*	29.6526	1.5775	30.9740	1.3214	0.2561	**16.23**

Peat: > 30% dry mass of organic material

Half-peat: > 10% dry mass of organic material

Annex 16: Vegetation

Vegetation

Class	Family	Species	Nuratau 1,650 m	Angren Plateau 2300-2450 m	Angren Plateau 2700-2800 m
Dicotyledonae	Apiaceae	*Angelica tschimganica*		+	
Dicotyledonae	Apiaceae	*Berula erecta*	+		
Dicotyledonae	Apiaceae	*Carum carvi*	+	+	
Dicotyledonae	Asteraceae	*Centaurea iberica*	+		
Dicotyledonae	Asteraceae	*Cirsium esculentum*		+	+
Dicotyledonae	Asteraceae	*Inula rhizocephala*		+	+
Dicotyledonae	Asteraceae	*Ligularia alpigena*			1-2
Dicotyledonae	Asteraceae	*Ligularia heterophylla*		1	
Dicotyledonae	Asteraceae	*Taraxacum sp.*	+		
Dicotyledonae	Boraginaceae	*Myosotis caespitosa*		+	
Dicotyledonae	Caryophyllaceae	*Cerastium cerastoides*			1
Dicotyledonae	Caryophyllaceae	*Spergularia rubra*		+	
Dicotyledonae	Fabaceae	*Lotus sergievskiae*	+		
Dicotyledonae	Fabaceae	*Medicago lupulina*	+		
Dicotyledonae	Fabaceae	*Trifolium repens*	2	1-2	1-2
Dicotyledonae	Gentianaceae	*Centaureum pulchellum*	+		
Dicotyledonae	Geraniaceae	*Geranium collinum*		1	+ - 1
Dicotyledonae	Lamiaceae	*Prunella vulgaris*		+	
Dicotyledonae	Onagraceae	*Epilobium minutiflorum*		+	
Dicotyledonae	Onagraceae	*Epilobium nervosum*		1	
Dicotyledonae	Orobanchaceae	*Pedicularis rhinanthoides*		+	+
Dicotyledonae	Parnassiaceae	*Parnassia laxmannii*		+	
Dicotyledonae	Plantaginaceae	*Plantago lanceolata*		1	
Dicotyledonae	Plantaginaceae	*Plantago major*		+	
Dicotyledonae	Polygonaceae	*Polygonum (Aconogonon) hissaricum*			1
Dicotyledonae	Primulaceae	*Primula algida*		+	+
Dicotyledonae	Primulaceae	*Primula olgae*	+		
Dicotyledonae	Ranunculaceae	*Harlerpestes sarmentosa*	+		
Dicotyledonae	Ranunculaceae	*Ranunculus alajensis*			+
Dicotyledonae	Ranunculaceae	*Ranunculus rufosepalus*			+
Dicotyledonae	Ranunculaceae	*Ranunculus sp.*		+	
Dicotyledonae	Ranunculaceae	*Trollius komarovii*		+	+
Dicotyledonae	Rosaceae	*Alchemilla chionophila*			1
Dicotyledonae	Rosaceae	*Alchemilla tianschanica*		1	
Dicotyledonae	Rosaceae	*Potentilla bifurca ssp. orientalis*		1	1
Dicotyledonae	Rosaceae	*Potentilla gelida*			1
Dicotyledonae	Rosaceae	*Potentilla sp.*	1		
Dicotyledonae	Scrophulariaceae	*Euphrasia regelii*		+	
Dicotyledonae	Plantaginaceae	*Veronica anagalloides*	1		
Dicotyledonae	Plantaginaceae	*Veronica beccabunga*	+	1	
Dicotyledonae	Urticaceae	*Urtica dioica*		+	
Monocotyledonae	Cyperaceae	*Carex atrata ssp. aterrima*			+
Monocotyledonae	Cyperaceae	*Carex diluta*	+		
Monocotyledonae	Cyperaceae	*Carex duriuscula ssp. stenophylloides*	2		
Monocotyledonae	Cyperaceae	*Carex enervis*			1-2
Monocotyledonae	Cyperaceae	*Carex melanantha*			+

Class	Family	Species	Nuratau 1,650 m	Angren Plateau 2300-2450 m	Angren Plateau 2700-2800 m
Monocotyledonae	Cyperaceae	*Carex orbicularis*		1	+
Monocotyledonae	Cyperaceae	*Carex pseudofoetida*		1	2
Monocotyledonae	Cyperaceae	*Carex serotina*		2	
Monocotyledonae	Cyperaceae	*Carex songorica*		+	
Monocotyledonae	Cyperaceae	*Carex sp.*	1		
Monocotyledonae	Cyperaceae	*Kobresia stenocarpa*			3-4
Monocotyledonae	Juncaceae	*Juncus articulatus*	2	1	
Monocotyledonae	Juncaceae	*Juncus bufonius*		+	+
Monocotyledonae	Juncaceae	*Juncus lufonicus*	+		
Monocotyledonae	Juncaceae	*Juncus rechingeri*	1		
Monocotyledonae	Juncaginaceae	*Triglocin palustris*	+	+	
Monocotyledonae	Poaceae	*Catabrosa aquatica*	1	+	
Monocotyledonae	Poaceae	*Digitaria sanguinalis*	2		
Monocotyledonae	Poaceae	*Phleum alpinum*			1
Monocotyledonae	Poaceae	*Phleum phleoides*		+	
Monocotyledonae	Poaceae	*Phragmites australis*	1		
Monocotyledonae	Poaceae	*Poa alpina*			1
Monocotyledonae	Poaceae	*Poa bulbosa*	1	1	1
Monocotyledonae	Poaceae	*Poa diaphora*		+	+
Monocotyledonae	Poaceae	*Poa palustris*		+	
Equisetidae	Equisetaceae	*Equisetum arvense*		+	

Key:

	Hydrophytes (medium wet)
	Hydrophytes (very wet and under water)
	Xerophytes
	Mesophytes
1/2/3/4	Dominant species for respective study location

Key:	**r**	**+**	**1**	**2**	**3**	**4**	**5**
Abundance:	very few individuals	few individuals	numerous individuals	any number of individuals	any number of individuals	any number of individuals	any number of individuals
Cover:	**<1%**	**<1%**	**1-5%**	**6-25%**	**26-50%**	**51-75%**	**75-100%**