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Social-ecological interactions in the Draa River Basin, southern Morocco: Towards nature conservation and human well-being using the IPBES framework

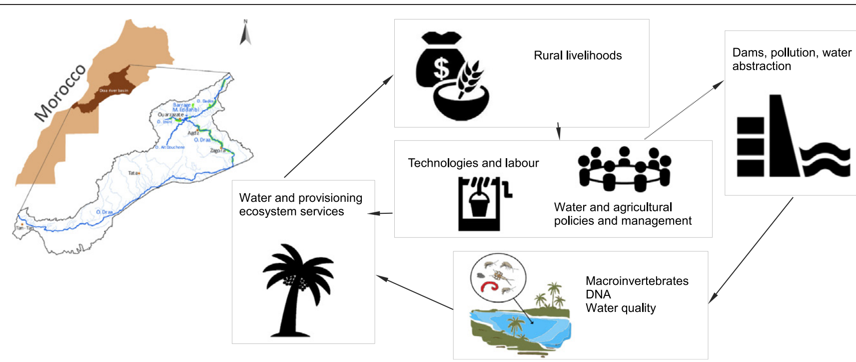
Elisabeth Berger [a,*], Lisa Bossenbroek [a], Arne J. Beermann [b,c], Ralf B. Schäfer [a], Mohammed Znari [d,e], Sina Riethmüller [a], Nanki Sidhu [a], Nils Kaczmarek [a], Hassan Benaissa [d,e], Mohamed Ghamizi [d,e], Sabrina Plicht [b], Souad Ben Salem [d], Fadoua El Qorchi [d], Mohamed Naimi [f], Florian Leese [b,c], Oliver Frör [a]

[a] iES Landau, Institute for Environmental Sciences, University of Koblenz-Landau, Landau, Germany
[b] Aquatic Ecosystem Research, University of Duisburg-Essen, Essen, Germany
[c] Centre for Water and Environmental Research (ZWU), University of Duisburg-Essen, Essen, Germany
[d] Laboratory of Water, Biodiversity and Climate change, Faculty of Sciences Semlalia, Cadi Ayyad University, Marrakech, Morocco
[e] Museum of Natural History of Marrakech, Morocco
[f] Polyvalent Laboratory for Research and Development (LPVRD), Polydisciplinary Faculty, Sultan Moulay Slimane University, Beni Mellal, Morocco

HIGHLIGHTS

- Application of IPBES framework to study interactions between people and nature
- Potential of macroinvertebrates to monitor human impact in Morocco
- First records of macroinvertebrate DNA barcodes may reveal high unknown diversity.
- Farmers' adaptation measures may pave the path for preservation of water resources.
- Re-orientation of water policies is required to preserve water resources.

GRAPHICAL ABSTRACT



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ABSTRACT

Water is essential to human societies and a prerequisite for flourishing nature, especially in arid regions. Yet, climate change and socio-economic developments are expected to exacerbate current and future stresses on water resources, demanding innovative approaches to balance water needs for society and nature conservation.
In this study, we use the IPBES conceptual framework to combine ecological and socio-economic insights and analyse the connections between people and nature in the water scarce Draa River Basin, southern Morocco. We study the diversity of desert benthic macroinvertebrates as one component of nature using DNA barcoding and their potential to serve as bioindicators of human impact by relating species occurrences to environmental parameters. Furthermore, based on 87 interviews with farmers and key institutional stakeholders, we investigate how farmers perceive water related changes and how water is managed in the basin.
Regarding benthic macroinvertebrates, 41 families were identified, 475 DNA barcodes generated and assigned to 118 putative species (Barcode Index Numbers) of which 60 were first records. This indicates a lack of reference sequences for known, but also a potentially high number of undescribed species. Environmental parameters, which are partly influenced by human activities, such as aquatic stages, salinity and intermittency, were the most important variables explaining invertebrate richness and community composition in generalized linear models. We further describe farmers' perceptions of decreasing water quality and quantity. Farmers generally

* Corresponding author.
E-mail address: berger@uni-landau.de (E. Berger).

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believe that they are able to cope with water related changes, although perceptions are regionally differentiated with farmers downstream being less optimistic. With growing concerns, water policies currently focus on increasing water supply and less on reducing water demands.
Based on these findings, the usefulness of the IPBES framework for understanding social-ecological system dynamics is reflected, and recommendations for future freshwater management and research are derived.

1. Introduction

Freshwater ecosystems are degraded worldwide due to human activities that cause biodiversity loss in all its facets — from genes, species, populations, habitats to entire ecosystems (Meybeck, 2003; Tickner et al., 2020; Vörösmarty et al., 2010). Evidence suggests that freshwater ecosystems are more strongly affected than their terrestrial or marine counterparts with freshwater vertebrate populations having declined by more than 80% in the past 50 years (WWF, 2018; Strayer, 2006). Climate and land-use change, pollution, flow and river channel modifications and biological invasions are major drivers of these changes. The degradation of nature can negatively impact ecosystem services and livelihoods of people who depend on these, such as subsistence farmers, rural poor and rural communities (Díaz et al., 2006).

To halt nature's degradation, a profound understanding not only of the impacts of human activities on ecological processes is required, but also of the rationales behind human actions that cause harmful modifications and of the feedback loops between environmental and societal changes (Díaz et al., 2015; Dunham et al., 2018; Mehring et al., 2017). Riverscapes need to be perceived as dynamic, interacting social–ecological systems and conservation success may not come from progress in ecological sciences, ecosystem service analyses, or even economic incentives alone, but from simultaneously addressing causes of human behaviours in conservation planning and implementation. This social-ecological approach has been described as 'disciplined interdisciplinarity' (Scholz, 2011). It requires a conceptual framework to create a shared understanding between different disciplines to facilitate the required interdisciplinary collaboration by providing a common terminology and a basis for common focus and thinking (Binder et al., 2013).

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has developed such a conceptual framework on the connection between people and nature. Its aim is the conservation and sustainable use of biodiversity, long-term human well-being and sustainable development, and it has been developed to embrace various types of scientific knowledge, different disciplines, governments, international organizations and societies (Díaz et al., 2015). Yet, it has rarely been operationalized in real-world case studies (Balvanera et al., 2020).

In arid regions, the relation between riverscapes and human societies is particularly strong. Water is scarce and human activities that may harm freshwater ecosystems are centred around these water-scarce areas. Balancing nature conservation and human well-being is thus particularly challenging and is further complicated by the limited knowledge on desert freshwater ecosystems. Freshwater research is still biased towards perennial, temperate-climate rivers, whereas intermittent and ephemeral rivers and streams (IRES) that dominate arid regions have not been adequately studied (Datry et al., 2017; Gomes-dos-Santos et al., 2019).

The Draa River Basin, southern Morocco, is among the world's top 10 most arid river basins (Revenga et al., 1998), characterized by the above mentioned water scarcity, surrounded by human activities. In 1972, the El Mansour Eddahbi dam was constructed to create a reservoir to feed six downstream oases with irrigation water and to provide drinking water for the growing city of Ouarzazate. However, the dam in combination with climate change, contributed to the drying-up of the endorheic Lake Iriki, where entire freshwater populations vanished (Green et al., 2002; Karmaoui et al., 2014), affecting the livelihoods of local farmers and nomads (Mahdane and Faouzi, 2019). This event and problems of climatic changes have generated a growing need for conservation efforts to preserve the oasian ecosystems.

In this study, we use the IPBES framework (see Box 1, Fig. 1) to analyse links between nature and the rural society in the Draa River Basin. Nature in this article refers to water resources and all living plants and animals inside and outside the water. Accordingly, we report results from ecological, economic and social investigations of the SaliDraaJuj project (https://salidraajuj.uni-landau.de/) using the IPBES framework to understand how the different social-ecological system components are connected and what this means for the Draa River Basin including its ecosystems and rural population. This is a first step to identify suggestions for future management of the basin as well as research gaps for further analysis.

In specific, we studied freshwater ecosystems as one component of *nature* by looking at the diversity of benthic macroinvertebrates. Macroinvertebrates contribute to the functioning of aquatic food webs (Baxter et al., 2005), the maintenance of water quality (Wallace and Webster, 1996) and are widely used as indicators of human impact (Birk et al., 2012). To explore their potential for monitoring environmental change also in the understudied regions of southern Morocco, we asked: What species are present and how can new techniques such as DNA barcoding help uncovering biodiversity? And how do species occurrences relate to environmental parameters such as salinity, intermittency, pH and hydrological conditions? Secondly, we studied water related activities

Box 1
IPBES framework.

In brief, the IPBES framework (Díaz et al., 2015) provides a simple conceptual model on the complex interactions between nature and people by defining six main components and eight uni-directional interactions between components that are relevant for the framework's aim (Fig. 1). "**Institutions and governance and other indirect drivers**" are the ways in which people and societies organize themselves and their interactions with nature at different scales. They are placed in the centre as they mediate on the one hand (arrow to the left) how humans access, distribute and thus benefit (contributing to human well-being) from components of nature (water in our case), either directly or indirectly by controlling "**anthropogenic assets**" (e.g. built infrastructure, knowledge, technology, labour and financial assets). On the other hand, (arrow to the right) they are the underlying cause of changes in "*anthropogenic drivers*" that affect the considered ecosystem or "**nature**" (freshwater in this case with indirect impacts and macroinvertebrates as living components of the river ecosystem) either positively or negatively. "*Anthropogenic drivers*" (e.g. pollution, climate change, habitat degradation or restoration) are thus the result of human activities and together with the "*natural drivers*" that are beyond human control (e.g. natural climate and weather patterns including droughts and floods) they form the category of "**direct drivers**". "**Nature**" is shaped by "**direct drivers**" and refers to the natural world with an emphasis on the diversity of living organisms as opposed to the non-living things, however we here focused on water as indispensable habitat for aquatic organisms. "**Nature's contributions to people**" include detrimental as well as beneficial effects of "**nature-focusing on water**" on the achievement of a "**good quality of life**" by different people (in our case farmers) and in different contexts (i.e. Morocco). This category includes provisioning, cultural and regulating ecosystem services and it is acknowledged that these benefits are usually co-produced by both "**nature**" and "**anthropogenic assets**". Finally, "**good quality of life**" is defined as "the achievement of a fulfilled human life" allowing for very broad and inclusive interpretation and analysis of this category that we, however, limited to the central aspect of livelihoods.

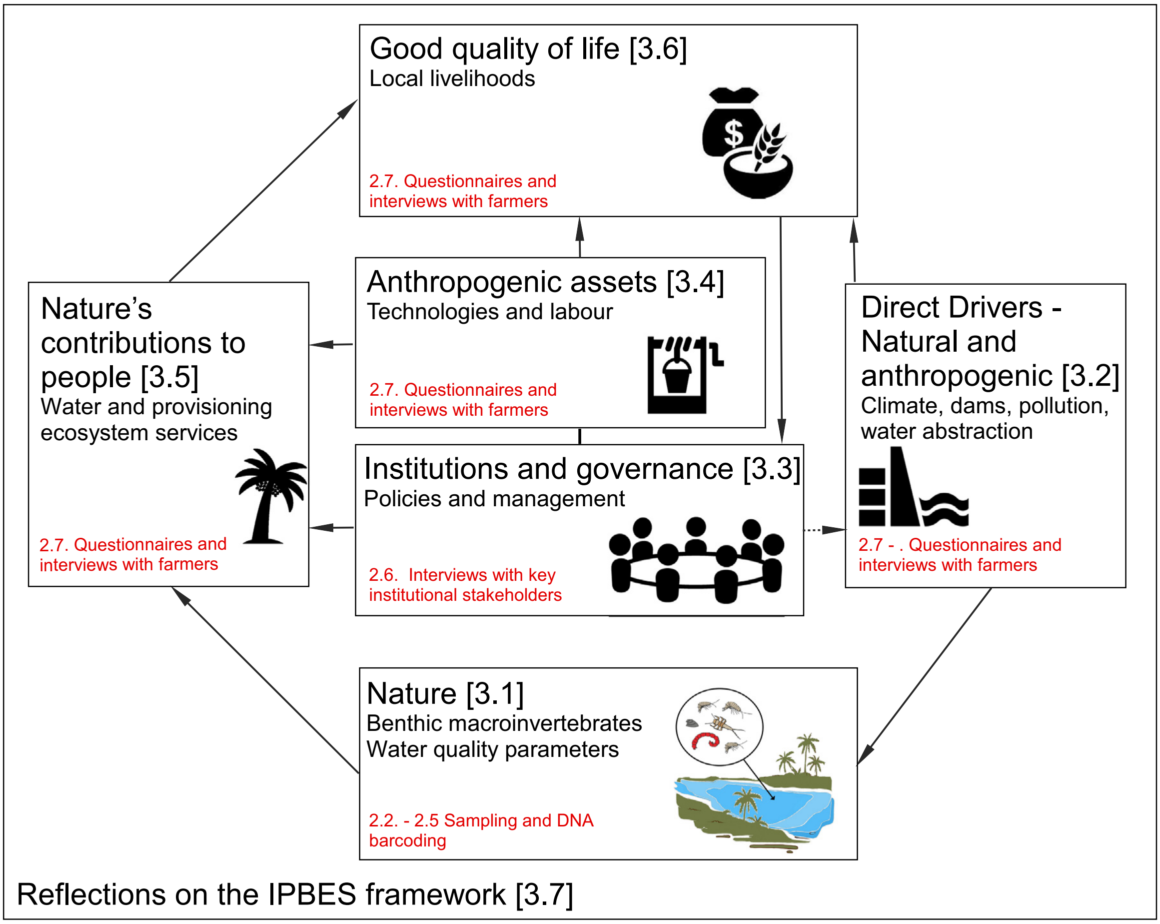

Fig. 1. Adaptation of the Conceptual Framework of the Intergovernmental Platform on Biodiversity and Ecosystem Services (Díaz et al., 2015) to our case study. The different components of the conceptual framework (titles in capitals) and their interactions (arrows) are explained in Box 1. Numbers in brackets refer to the paragraphs, where the respective research results are presented and discussed. The sub-headings summarize the content on which this study focused and the writing in red to the method section for their analysis. Note that alternative terms to describe the same system component as defined in the original framework were omitted for clarity, only. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

and perceptions of farmers, because the region is mainly rural and its economy remains strongly dependent on irrigated agriculture (Karmaoui et al., 2014): What are the changes that farmers perceive in *nature* and what do they see as *drivers* causing these changes? How do changes in water availability and quality influence the realisation of farmers' livelihoods as an important component of *good quality of life* and what role do certain technologies and other *anthropogenic assets* play in how they can access water and may benefit (i.e. *nature's contribution to people*)? Thirdly, we wanted to know: How have water management and policies (i.e. *institutions and governance and other indirect drivers*) shaped the distribution and the use of water resources for human benefits? And how may they have caused *anthropogenic drivers* influencing *nature?* Finally, in the last section of the paper, we reflect on the usefulness of the IPBES framework for understanding social-ecological system dynamics, followed by recommendations for future freshwater management and research.

2. Methods

2.1. Study area

The Draa River Basin is located in south-eastern Morocco and covers an area of ~115,000 km^2 spanning from the High Atlas Mountains to the Atlantic Ocean in the west and to the Sahara Desert in the south, with increasing aridity along a north-southeast direction (Carrillo-Rivera et al., 2013); Fig. 2). Annual precipitation across the basin is low, ranging from <50 to 800 mm along this gradient (Karmaoui et al., 2015), and extremely variable with droughts being interrupted by extreme floods. The frequency of dry years has increased since the 1970s (Klose et al., 2008). Rivers in the basin are mostly ephemeral, depending on rainfall or snowmelt, with only few perennial watercourses (Dadès and M'goun rivers, Fig. 2).

The Draa River Basin spans three administrative regions; (i) Dra-Tafilalet (Zagora and Ouarzazate province), (ii) Souss-Massa (Tata province) and (iii) Guelmim-Oued Noun (Guelmim province). The upper and middle Draa sub-basins are more densely populated (approx. 600,000 inhabitants) with increased agriculture and tourism related economic activities (HCP, 2015). The lower Draa provinces are far less populated. The two major cities in the basin are Ouarzazate situated up-stream with 71,067 inhabitants (HCP, 2015) and Zagora situated in the middle of the basin with 40,067 inhabitants (HCP, 2015). The Sultan Moulay Ali Cherif dam (previously called Tiouine dam) constructed in 2013 and the El Mansour Eddahbi dam are important in providing water to the cities located up-stream and for agricultural use in the area. The latter regulates the water flow to a 200-km long valley in the middle Draa, in which six major oases are situated. Each oasis has an underlying alluvial aquifer, whose recharge depends primarily on the water releases from the dam (Klose et al., 2010).

2.2. Benthic macroinvertebrate sampling

Benthic macroinvertebrates were collected from 14 sites across the Draa River Basin in May 2017 (Fig. 2). At each site, 20 kick-samples were collected using a slightly modified AQEM approach (Haase et al.,

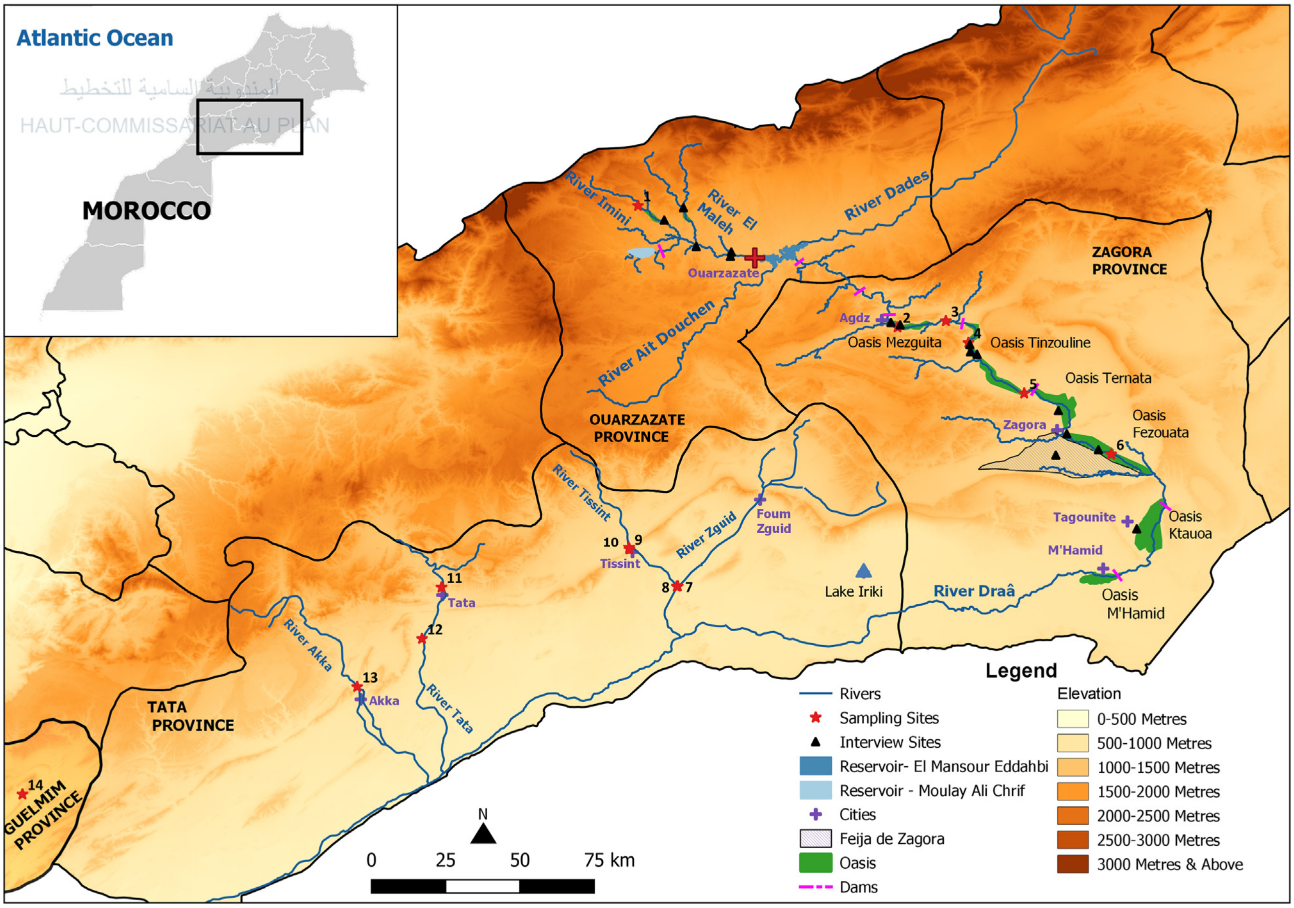

Fig. 2. Location of sampling sites for benthic macroinvertebrates (see Section 2.2.) and interview sites with local farmers (see Section 2.7). Only a subset of the ephemeral watercourses in the study area are shown. Boundaries delimit administrative units. (For map and figure legend in colour, the reader is referred to the web version of this article.)

2004): sampling was carried out using a 0.25 × 0.25 m hand-net with 500 μm mesh sized bag across a 100 m long section to sample all microhabitats in riffles and pools, including vegetation and substrate types with at least 5% coverage. All 20 microhabitats were combined into one sample per site. Rare microhabitats and individual stones were additionally washed into the combined sample. Samples were preserved in 70% ethanol and transferred to the laboratory, where macroinvertebrates were sorted and identified to the lowest possible taxonomic level using the identification key of Tachet et al. (2010). Macroinvertebrate individuals (ind.) were counted and grouped into the following abundance classes: (1) rare: 1–2 ind.; (2) few: 3–9 ind.; (3) medium: 10–49 ind.; (4) many: 50–199; (5) abundant: 200–399; (6) very abundant: ≥400 ind.

2.3. DNA barcoding

DNA barcoding was used to facilitate the species-level identification of macroinvertebrates. For each sample, 1–5 macroinvertebrate specimens from morphologically different groups were selected. DNA was extracted from leg and thorax muscle tissue in a 10% Chelex solution (Bio-Rad, Hercules, USA) that was heated to 96 °C for 20 min and vortexed every 5 min. PCRs were performed targeting a 658 bp long fragment of the cytochrome C oxidase subunit I (COI) gene using the LCO1490 and HCO2198 primer pair (Folmer et al., 1994). PCRs of 25 μL volume contained 1 μL extracted DNA, 0.5 μM of each primer and 1× Allin™ RPH mastemix (HighQu, Kraichtal, Germany), and were carried out at 95 °C for 2 min, 38 cycles of denaturation at 95 °C for 20 s, annealing at 46 °C for 20 s and extension at 72 °C for 20 s, followed by a final extension at 72 °C for 15 min. In some cases, extractions were repeated using a modified salt precipitation extraction protocol (Sunnucks and Hales, 1996; modified by Weiss and Leese (2016)) and in cases where amplification failed, PCRs where repeated with the degenerated primers LCO-JJ and HCO-JJ (Astrin and Stüben, 2008), targeting the same 658 bp long fragment, or BF2 and BR2 (Elbrecht and Leese, 2017) targeting an internal 421 bp long fragment. Success of the PCR was validated using 1% agarose gel electrophoresis. Bidirectional Sanger sequencing of all PCR products was carried out by Eurofins Genomics (Ebersberg, Germany). The generated barcode sequences were compared to the Barcode of Life Datasystem Database (BOLD; boldsystems.org) for species identification.

The Barcode Index Number (BIN) system (Ratnasingham and Hebert, 2013) was used to group all specimens to sequence clusters, which have been shown to have a high concordance with species. Due to the lack of reference sequences for limnophilic species of Morocco, the majority of specimens could not be formally assigned to existing BINs as proxy for species. Instead, they were assigned to new BINs and BIN richness was calculated as a proxy of species richness. For sequences below a length of 500 bp, that did not meet the BOLD criteria, no BINs were assigned. A Neighbor-Joining (NJ) tree was developed in Geneious 6.1.8 (https://www.geneious.com/) to evaluate specimen affiliation, when no BIN was assigned. All barcodes from this project are available on BOLD (sequence pages MZBM001-19 to MZBM485-19).

2.4. Environmental variables

Temporal variation in the presence of water at each site was assessed using Copernicus Sentinel-2 imagery to calculate the Normalized Difference Water Index (NDWI; McFeeters, 1996) in Google Earth Engine (Gorelick et al., 2017). For each site and for the El Mansour Eddahbi dam the NDWI was calculated for a surrounding area of

1 km^2 using all pictures with a cloud coverage of <3% for the period from 2015 to 2020. The area covered by water at the El Mansour Eddahbi dam was used as a proxy for the water availability of the upper Draa. Images with dark shadows were omitted from analysis. The number of pixels representing water were counted by using the software ImageJ (vers. 1.52a) and the water surface area was calculated in m^2. Intermittency was thus calculated for each site as the percent of images with a water surface area equal to 0 m^2. This intermittency index was used to compare sites, though satellite resolution (10 m^2) did not allow for exact quantification and may occasionally miss remnants of water of smaller surface areas. Dissolved oxygen (mg/L), pH, temperature (°C) and electrical conductivity (μS/cm) were measured *in-situ* using a Hanna HI98194 multiparameter device (Hanna Instruments, USA). Substrate types and stream width were recorded and the aquatic stage of the intermittent rivers was defined *sensu* Gallart et al. (2012) into: (i) arheic — isolated pools, (ii) oligorheic — pools connected by thin water threads and (iii) eurheic — surface flow with abundant riffles. Direct human impact (washing clothes and animal keeping) were also visually recorded.

2.5. Statistical analysis

To identify the most relevant explanatory variables for macroinvertebrate family richness, we fitted a GLM with aquatic stage, intermittency [%], conductivity [μS/cm] and pH as explanatory variables, using a Poisson distribution and a log-link function. Then we employed stepwise backwards model selection based on the AIC (Akaike information criterion). Moreover, a multivariate Generalised Linear Model (mvGLM) was fitted with the same explanatory variables and the abundance scores of all invertebrate families that occurred at >2 sites as response matrix (Warton, 2011). This model was specified with a negative binomial distribution. The statistical significance of each explanatory variable was assessed using the log-likelihood ratio test and permutation-based *p*-values. Dissolved oxygen and water temperature were omitted from both analyses as these variables exhibited only low variation. Mean water surface area was omitted due to high correlation with intermittency (Spearman Rank correlation coefficient $r = 0.75$, $p = 0.002$). All statistical analyses were carried out in the computing software R version 4.0.2 (R Core Team, 2020) with the aid of the vegan (Oksanen et al., 2016) and mvabund packages (Wang et al., 2012).

2.6. Interviews with key institutional stakeholders

Twelve interviews with key institutional stakeholders (Table S1, "S" refers to supplementary material of this article) were conducted in February 2020. The interviews followed a semi-structured outline with predefined topics and questions (Gilgun, 2014). The topics discussed focused on the impact of anthropogenic and climate change induced pressures on the ecosystems and human populations of the Middle Draa, the dam releases, and on the recent agricultural developments and policies that influence the water and land resources of the area. In addition, documents shared by the institutional stakeholders and policies, which were referred to during the interviews, were systematically analyzed.

2.7. Farmers' survey and interviews

Twenty-two semi-structured interviews based on Brinkmann (2014) with different kinds of farmers and other local actors were conducted in June and October 2019 and during the spring of 2020 (Fig. 2, Table S2). Interview partners were selected randomly and six of them were interviewed multiple times, to clarify statements. In addition, fifty-three farmers were interviewed in March 2018 using a structured standardized questionnaire (see Supplementary material) with 53 mostly close-ended questions (Hoffmeyer-Zlotnik and Warner, 2008). Semi-structured interviews and questionnaires were conducted in three areas (i) the Upper Draa (UP): Amerzgane, Tamdahte, Oasis of Ouarzazate (12 questionnaires); (ii) the Northern-Middle Draa (NMD): Oasis of Mezguita, Tinzouline and the northern part of Ternata (17 questionnaires and 11 semi-structured interviews); and (iii) Southern-Middle Draa (SMD): Feija plain, southern part of the Oasis of Ternata, Fezouata and Ktaoua (24 questionnaires and 11 semi-structured interviews) (Fig. S1). Both interview techniques focused on better understanding rural households' agricultural activities in relation to water availability, water quality, vegetation, soil quality and quality of life for the past 30 years. Also challenges of and options for adapting to water scarcity were discussed.

3. Results and discussion

3.1. Nature

Nature is a very broad category and is understood as water resources and all living plants and animals inside and outside the water in this article. However, in this section the results regarding benthic macroinvertebrate as a specific component of nature are presented and discussed.

3.1.1. DNA barcoding and macroinvertebrate diversity

Kick-net samples collected in May 2017 from 14 river sites in the Draa River Basin contained approx. 9300 macroinvertebrate specimens belonging to 41 taxa on the family level or higher. DNA barcodes were generated for 475 specimens with an average length of 588 base pairs (320–658 bp) of which 39 were not assigned to BINs due bp length < 500 or other reasons. The remaining 436 specimens were assigned to 118 BINS (putative species), of which 58 already existed in BOLD and 60 were newly generated (first records). Species information was available for only 20 of those BINs, while references at genus level or higher existed for 95 BINs. Three BINs consisted of reference specimens with more than one species name, indicating hybridizing species, species with recent speciation events, misidentified voucher specimens in the database or taxonomic synonyms. Overall, macroinvertebrate family and BIN richness averaged to 12.2 and 15.6 per site, respectively. This taxonomic richness can be considered low compared to temperate or Mediterranean bioclimatic regions (Bonada et al., 2007), but comparable to other dryland catchments (Boulton et al., 2006; Sheldon et al., 2002). The 60 newly generated BINs may highlight a high amount of unknown species diversity in the Draa River Basin, a lack of reference sequences for the species of this region in the reference databases, or, most likely, a combination of both. As new species from other taxonomic groups, such as the Dades trout (Doadrio et al., 2015) or the freshwater gastropod *Pseudamnicola ouarzazatensis* (Boulaassafer et al., 2020), were recently discovered in the Draa, also unknown insect diversity appears likely. However, the lack of reference sequences for described species in Morocco also contributed to the high number of new BINs (the combined number of publicly available EPT reference sequences from Morocco in BOLD is one; data assessed 06.04.2020). DNA barcoding can offer a fast first step into exploring species diversity that can also be used to evaluate species richness and diversity in the context of environmental parameters, even without species names, through genetically derived proxies for species such as BINs, Automatic Barcode Gap Discovery clades (ABGD; Puillandre et al., 2012) or Generalized Mixed Yule Coalecent groups (GMYC, Fujisawa and Barraclough, 2013). However, traditional taxonomic expertise is still required to identify species, if the species identity is important for example to assess conservation status. Sequencing of adequately identified specimens will help complete references databases for a fast DNA barcode identification in future. Moreover, specimens that still show "new" BINs can subsequently be explored (reverse taxonomy) and help uncovering endemic species. Ephemeroptera, Diptera and Hemiptera, followed by Trichoptera and Coleoptera were the most frequently encountered and most abundant taxonomic groups (Table 1, Fig. 3). In particular, *Baetis* and *Caenis* as genera within the ephemeropteran families

Baetidae and Caenidae occurred at almost all sites, whereas the less abundant Leptophlebiidae (based on DNA barcoding a single species) were restricted to the Middle Draa. Diptera was the most diverse group with 11 families and 53 BINs of which the most abundant families were Chironomidae and Ceratopogonidae followed by Tabanidae, Simuliidae and Culicidae. The majority of Hemiptera belonged to the family Corixidae and specifically to a small sized (ca. 2 mm) *Micronecta* sp. Of the 4 identified Trichoptera families; Hydropsychidae and Ecnomidae were the most abundant. The most frequently found Coleoptera were Dytiscidae, Hydrophilidae and Hydraenidae. The non-insect groups were comparatively poorly represented, but the gastropod *Melanopsis* sp., the decapod crustacean *Atyaephyra desmarestii* and an ostracod crustacean (Podocopida: Cyprididae) showed low to medium abundances at few sites. Rather diverse, but not abundant was the group of water mites (Hydrachinidia) that consisted of 11 putative Trombidiformes species. Family abundance scores per site and a complete taxonomic list are shown in Table S3 and S4. Unfortunately, DNA barcodes could not be generated for all intended specimens. Therefore, the species diversity assessment (BINs) is neither complete nor comparable between sites and the analysis of relationships between environmental parameters and macroinvertebrates was therefore done on the family level (Section 3.1.2). Failure of DNA barcode generation was, however, not due to the applied sequencing methods, but due to degeneration of DNA during sample preservation. In face of high temperatures and fast evaporation in the study region, higher ethanol concentrations, and cooling of samples is recommended in future studies in arid climates. Thus, this pioneer study demonstrates the high potential of applying DNA-based identification tools in understudied, arid regions.

3.1.2. Relation between environmental parameters and macroinvertebrate richness and community composition

Surface water was mostly reduced to isolated or weakly connected pools (11 sites), either due to small weirs or groundwater springs, with varying degrees of intermittency and large variations in water surface area throughout the years (Table 2). Sampling time coincided with a period of receding water availability after wetter winter months (Fig. 4). All sites were well oxygenated despite rather high temperatures (Table 2) indicating high productivity of photosynthetic organisms. Only three sites were eurheic and interestingly also marked by high salinity (conductivity up to 13 mS/cm). In the GLM (aquatic stages, intermittency, pH and conductivity as explanatory variables) moderate explanation of family richness was achieved (adjusted $R^2 = 0.36$, AIC = 79.8). However, the optimal model identified with backwards stepwise variable selection only contained conductivity and aquatic stages as explanatory variables of family richness (AIC = 75.9). Regression coefficients for both models are reported in Table S5. In the multivariate GLM with the abundance score matrix as response variable statistically significant explanatory variables were: intermittency, aquatic stages and conductivity (see Table S6 for full results). Our results confirm that the macroinvertebrate community is shaped by environmental conditions, which is a prerequisite for serving as indicators of environmental conditions (biomonitoring). To date, indicator metrics for the ecological status based on macroinvertebrates that are adapted to the region are missing. Our results clearly show the impact of hydrological conditions, via the proxy aquatic stage, on macroinvertebrate communities (Gallart et al., 2012; Stubbington et al., 2018). Natural climate, anthropogenically altered climate, geology, water abstraction and land-use can all modify salinity, intermittency, pH and aquatic stages. The differentiation of natural and anthropogenic drivers would require sophisticated models to estimate natural background conditions and deviations thereof (i.e. Le et al., 2019), for which the required data was lacking. This substantiates the need for environmental monitoring in the region. Overall, the results indicate the potential of macroinvertebrates for biomonitoring, but more background information and datasets on spatial and seasonal variation are required, if informative bioindicators are to be developed.

Table 1
Summary statistics on benthic macroinvertebrate taxonomic groups. No of BINs per group reflects the potential number of different species. Abundance classes: 1 = 1–2 specimens, 2 = 3–9, 3 = 10–49, 4 = 50–199, 5 = 200–399 and 6 ≥ 400. The relative abundance refers to the relation between the sum of family abundance scores across sites within each taxonomic group and the sum of all family abundance scores across all sites.

Taxonomic group	No of sites at which present	No of families	No of BINs	Average abundance class	relative abundance in [%]
Ephemeroptera	14	3	10	4	26
Diptera	14	11	53	5	25
Hemiptera	14	6	12	4	18
Trichoptera	11	4	7	3	8
Coleoptera	9	5	14	2	8
Odonata	8	4	7	2	5
Hydrachinidia	8	?	11	2	4
Gastropoda	3	2	3	3	3
Crustacea	3	2	2	3	2
Oligochaeta	3	1	3	2	1
Hirudinea	1	1	NA	1	0

3.2. Direct drivers (natural and anthropogenic)

To investigate drivers of change in nature, farmers were first asked about changes they observed regarding water availability, water quality and vegetation during the past 30 years and then asked to specify the causes of these changes. The majority of respondents perceived a decrease in water availability (Fig. 5a) and at the same time an increase in its variability. This perception is influenced by local specificities like e.g. the construction of the Sultan Moulay Ali Cherif dam in the UD (Fig. 2), where more people perceived an improvement of water availability, whereas more respondents in the MD reported decreasing water availability (Fig. 5a). Farmers reported only little changes in salinity, as an important water quality parameter of surface water, but reported more frequently increasing salinities for groundwater, especially in the lower oases (Fig. 5b). During the semi-structured interviews with local farmers conducted in 2019 and 2020 all interviewed farmers mentioned the poor water quality of surface water after releases from the dam without specifying what defines this poor water quality. The washing of clothes in the rivers with use of detergent was frequently observed during field visits, but contamination with direct household effluents or effluents from septic tanks or waste water treatment plants was not directly visible.

Vegetation, both natural and agricultural, was perceived to worsen in the UD (Fig. 5c). By contrast, changes in vegetation were seen as positive in the NMD, which some respondents attributed to the beneficial effect of agrochemicals. No systematic changes in soil quality were reported by respondents, although some respondents mentioned an increase in soil salinization in the SMD. When asked in an open-ended way, respondents saw climate related factors as the most important reason for the perceived changes (Fig. 5d). More specifically (not shown in Fig. 5), in the UD, changes in precipitation were identified as a more important driver of change in water availability, quality and related vegetation (up to 90%) than temperature changes (up to 75%), while respondents in the MD stated these reasons less frequently (around 50–60%). Extreme weather events were also named by respondents (50% in UD, ca. 20% in NMD and ca. 30% in SMD). In addition to these climate-related factors, respondents mentioned the overuse of water resources by new agricultural activities (e.g. the cultivation of watermelons), but in UD also by recreational facilities like golf courses or industrial facilities like the region's large solar power station (Fig. 5d) that is located next to the Eddahbi Mansour dam. In line with Díaz et al. (2015), water management installations like dams and reservoirs are perceived to contribute both positively as well as negatively to changes in nature, depending on the specific location of the households.

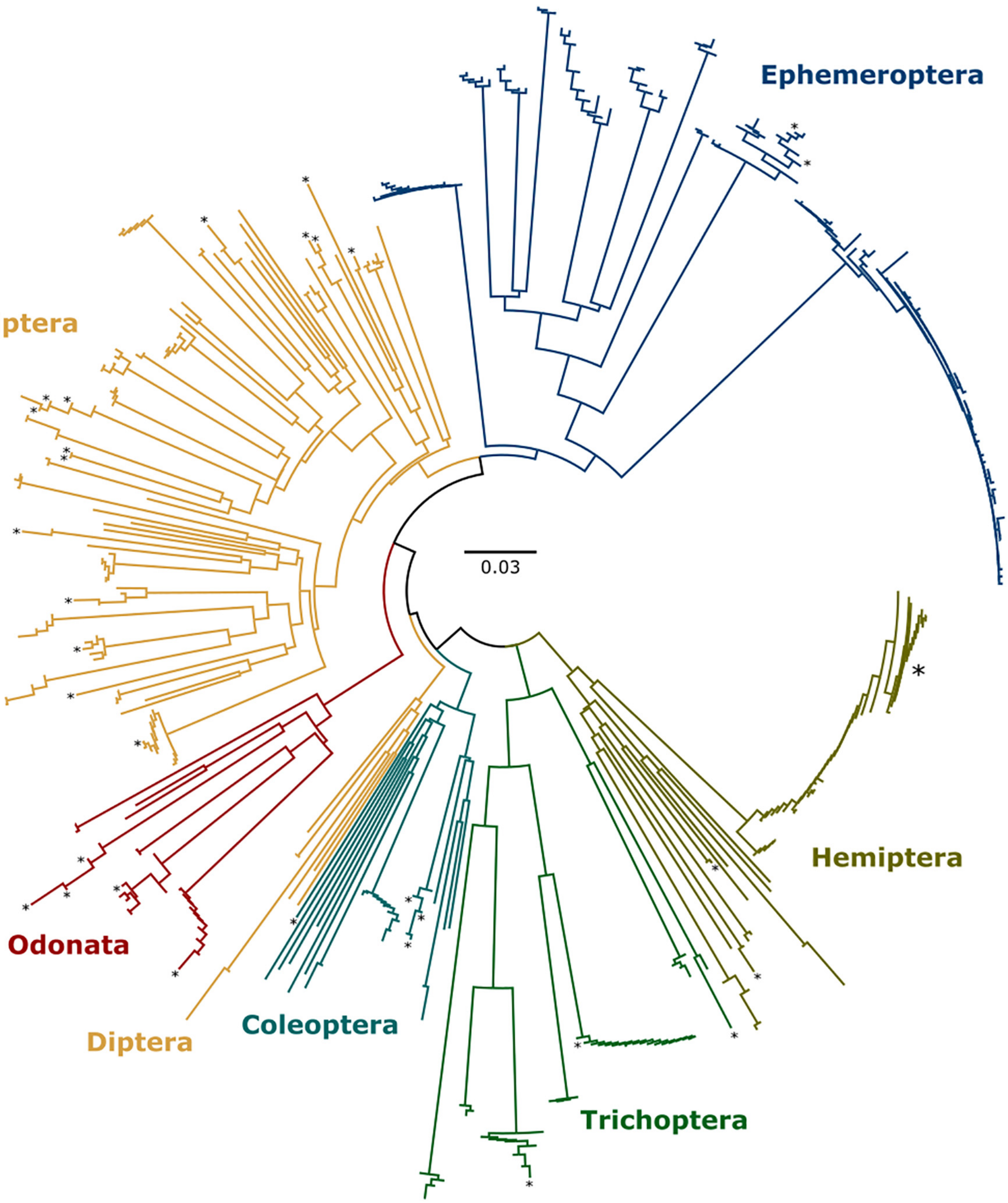

Fig. 3. Neighbor-joining tree of all barcoded insect specimens. Species (indicated by long branches) and specimens (visible as single terminal tips) from the same order have the same colour. Note that this COI gene tree does not accurately reflect deeper phylogenetic relationships. Asterisks mark specimens without assignment to BINs. Large asterisk at Hemiptera marks a complete branch of specimens without assignment to BINs. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The new agricultural activities were further discussed in subsequent in-depth interviews with farmers and stakeholders. Watermelons, melons and palm trees are increasingly grown on so-called extensions: newly irrigated lands outside the traditional oasis boundaries. Traditionally, many of these lands were used for grazing purposes. The vocation of these lands gradually changed from the 1970s onwards. Pastoralists began to settle in the area and engaged in irrigated agriculture in combination with pastoral activities. From 2006 to 2008 onwards, newly set up farms foremost consisting of fully irrigated high value crops, the use of drip irrigation and deep tube-wells gradually increased. The expansion of the irrigated lands outside of the oases (i.e. Feija plain, Fig. 2, Fig. S1) increases the pressure on freshwater resources. This type of agriculture is also linked to an intensified use of plastic mulch, fertilizers and pesticides as reported by farmers, potentially putting water quality at risk.

As such, newly emerging farming practices may directly impact the groundwater quality and affect the availability of water resources both positively and negatively. This is further illustrated by the farmers' survey where 50% to 60% of the interviewed farmers took adaptation measures to cope with decreased water availability (Fig. 5e). In the UD changes in cropping area and types of crops were the most frequently mentioned measures. In the Middle Draa farmers focused on deepening existing or building new wells as well as reducing the quantity of irrigation water by water saving techniques. When asked about adaptation measures planned for the future, only 21% of respondents stated that they were planning any, and the responses were rather unspecific. However, they

Table 2
Summary of site characteristics including taxonomic richness of benthic macroinvertebrates on the family level and the level of assigned BINs. Mean water surface area ± standard deviation (SD) is based on remote sensing observations for the time period 2015–2020. Intermittency is the percentage of records equal to a water surface area of 0 m^2 for the same time frame. Aquatic stages are coded as follows: a = arheic – isolated pools, o = oligorheic – pools connected by thin water threads and e = eurheic – surface flow with abundant riffles. Subcatchments (SC): UP = Upper Draa, MD = Middle Draa, LD = Lower Draa.

SC	River	Site nr.	Altitude (m.s.l.)	Conductivity [μS/cm]	Temperature [°C]	Oxygen [mg/L]	pH	Aquatic stage	Intermittency %	Mean water surface area ± SD [m^2]	Family richness	BIN richness
UD	Imini	1	1442	1935	28.7	8.3	7.3	o	96.8	150 ± 50	18	26
MD	Draa	2	919	1792	29.9	10.3	8.2	a	16.2	4423 ± 4566	11	18
MD	Draa	3	878	2890	25.4	10.1	7.9	a	11.1	12,359 ± 10,053	12	14
MD	Draa	4	836	2340	27	10.0	8.1	o	14.2	13,914 ± 10,301	17	15
MD	Draa	5	769	6220	26.9	8.6	8.0	a	39.6	8054 ± 5714	7	10
MD	Draa	6	679	3750	30.3	10.3	7.7	a	17.6	6101 ± 6686	8	13
LD	Zguid	7	462	13,150	30.4	12.1	8.8	a	30.9	3825 ± 3124	10	19
LD	Tissint	8	464	13,120	33.1	NA	8.3	e	8.0	23,588 ± 7322	8	9
LD	Tissint	9	587	5400	32.6	NA	7.2	e	27.0	2219 ± 2314	14	19
LD	Aff. Tissint	10	590	6200	29.2	NA	7.2	e	51.4	726 ± 676	19	14
LD	Tata	11	712	1120	30.5	NA	8.8	a	62.2	2390 ± 2988	12	19
LD	Tata	12	604	1340	30.3	NA	7.8	a	33.1	919 ± 2190	8	13
LD	Akka	13	558	771	30.7	NA	7.8	a	9.7	3538 ± 2366	16	16
LD	Siyad	14	585	2440	29.8	9.7	8.3	a	41.3	571 ± 568	11	14

had more specific ideas regarding adaptation measures at a higher political level, e.g. at the community or provincial levels (Fig. 5f).

Based on the above described results, we conclude that changes in water quality and quantity are more strongly felt downstream, illustrating the disparate effects of direct drivers on the rural society. Up-stream and down-stream dynamics are therefore important to be considered in any future management plan. In terms of future research, pollution sources as drivers of reduced water quality require better characterisation and monitoring in the future, in addition to changes in water abstraction affecting water quantity. Although some adaptation measures may further harm nature, some can also provide insightful lessons of preserving water resources.

3.3. Institutions and governance

Stakeholder interviews illustrate how water policies and their management actions altered over time the distribution and use of water resources in the Draa River Basin. For example, since the construction of the Eddabhi Mansour dam in the early 1970s, water flow is regulated artificially with a top-down control, with a strong intervention of the regional office of the Ministry of Agriculture, Fisheries, Rural Development, Water and Forests (ORMVA – Office Régional de la Mise en Valeur Agricole) and the Water Basin Agency (ABH – Agence Bassin Hydraulique). Depending on the water availability, four times a year water is released from the dam for the six oases. Each dam release is between 30 and 40 million m^3. Also, the five diversion dams, which have been constructed at the level of each oasis, generate change in terms of water availability. They control the river flow and are important for the recharge of the aquifer.

The construction of the Eddahbi Mansour dam and its linked management actions drastically altered how water is distributed. Before its construction, the up-stream oases had the right to access the water first without any restrictions in terms of volume, except for emergency situations, e.g. severe water shortages in the downstream oases

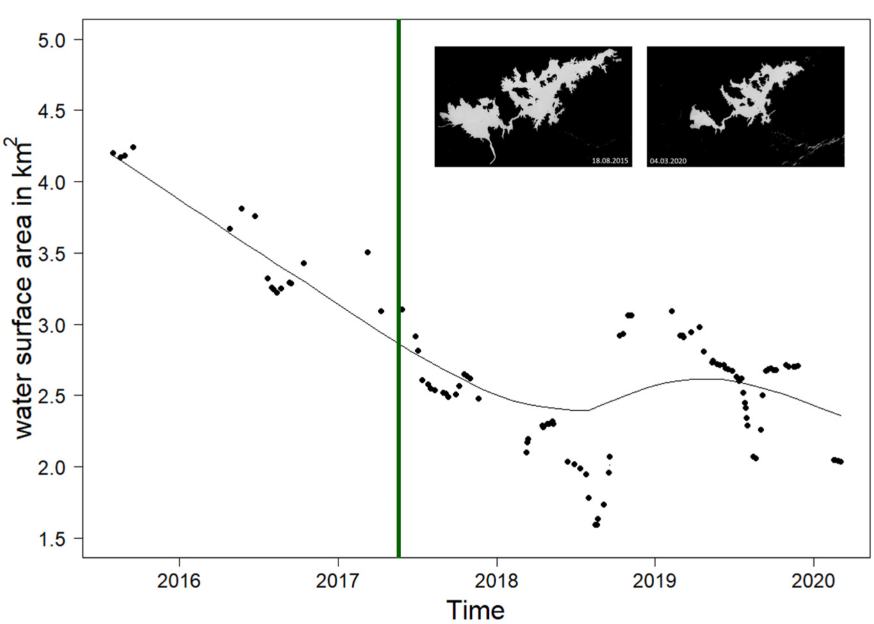

Fig. 4. Changes in the water surface area of the El Mansour Eddahbi reservoir from 2015 until 2020 as a proxy for surface water availability in the region with a fitted LOESS smoothing line. Each data point represents the water surface area calculated from satellite images as exemplified on the top right (left and right picture from August 2015 and March 2020, respectively). The vertical line represents the time of invertebrate sampling.

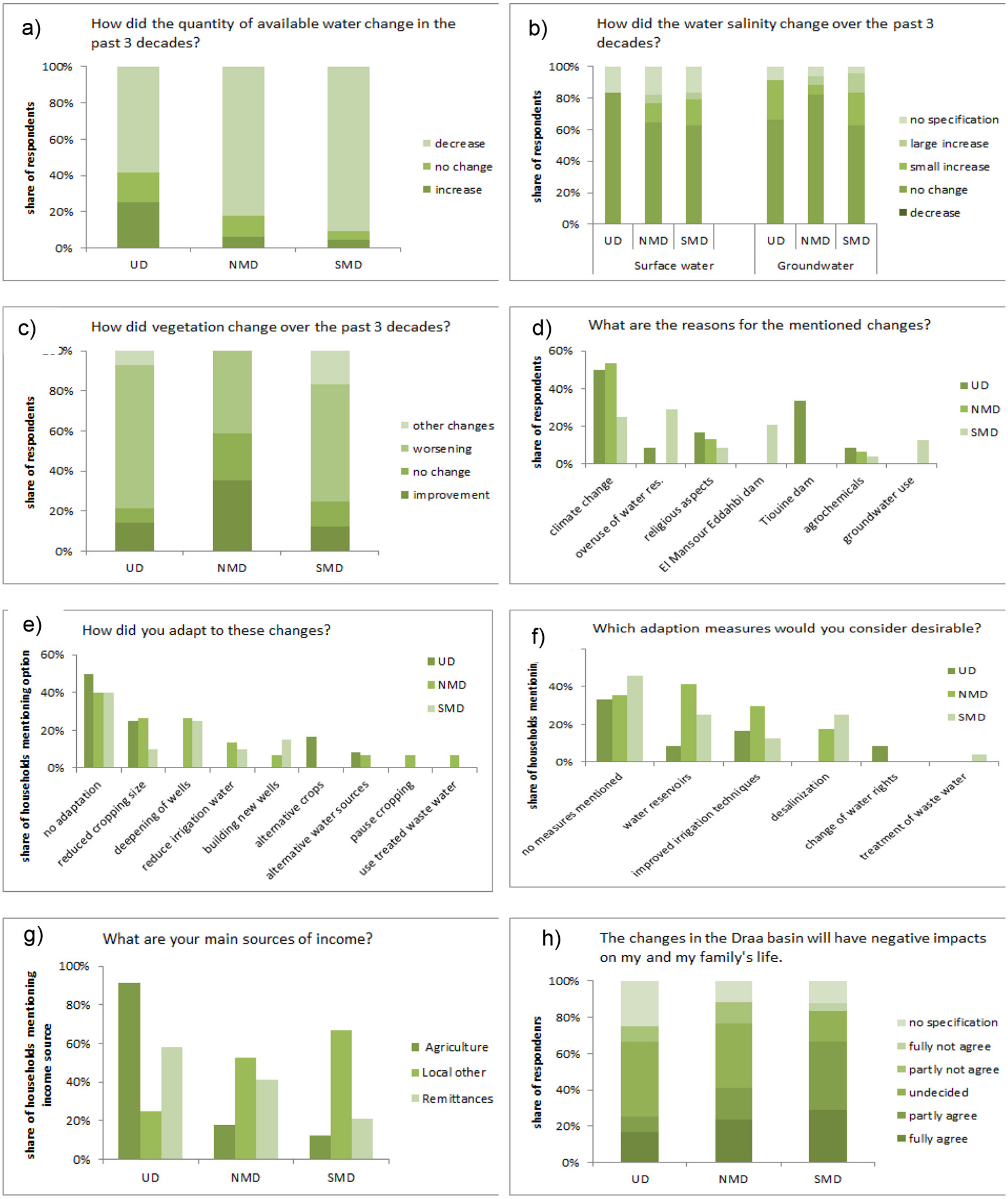

Fig. 5. Farmer responses to survey questions compared between the Upper Draa (UD, $n = 12$), the Northern Middle Draa (NMD, $n = 17$) and Southern Middle Draa (SMD, $n = 24$). Questions are indicated above each sub-figure: a) perceived changes in quantity of available water; b) perceived changes of salinity in surface water (left) and groundwater (right); c) perceived change of vegetation; d) reasons for perceived changes (open-ended question format); e) adaptation measures taken by farmers against decreased water availability in the three survey sections; f) ideas for adaptation measures; g) income sources; h) expected impacts of the perceived changes on livelihoods in the future.

(Hammoudi, 1982). Today, the water turn is organized in a top-down way and starts with the downstream oases, moving gradually upstream, towards the oases closer to the dam.

Recent water policies continue to promote the construction of dams. As part of the National Plan for Drinking Water and Irrigation two new dams are under construction in the research area. One dam is under construction upstream, near Agdz (about 70 km south of Ouarzazate) and will be finished in 2021. In addition, a new dam will be constructed near the plain of Feija, which is marked, since 2008, by important agricultural dynamics.

Stakeholder interviews further illustrate how the number of wells and tubewells increased over the last decades. Although nowadays an official authorization is required for both digging a well as well as for pumping up the water, many wells are dug without authorizations. Currently, sanctions are lacking for digging wells without authorization. To deal with this situation and to improve the management of the aquifer, the Water Basin Agency (ABH) and the Regional Office of Agriculture plan to develop a groundwater contract together with local key stakeholders.

In addition to the above discussed water policies and management actions, or the absence of it, our interviews illustrate how the distribution and the use of water resources in the research area is further influenced by the promotion and use of modern water management technologies and agricultural policies. For example, over the last decades, the Moroccan government widely promoted the use of drip irrigation. The promotion of this technology began with the National Program for Saving Water in Irrigation (PNEEI — Plan National d'Economie d'Eau en Irrigation) adopted in 2007, which aimed to convert in 15 years 550,000 ha of land from regular surface irrigation to drip irrigation (PNEEI, 2007). The following year, Morocco's agricultural policy plan, the Green Morocco Plan (PMV — Plan Maroc Vert), was launched (Ministry of Agriculture, Fisheries, Rural Development, Water and Forests, 2008). As part of this agricultural policy, various subsidies, for example for drip irrigation and water basins for groundwater storage, were offered. Until recently, the installation costs of a drip irrigation system on a land plot of less than five hectares were fully subsidized.

The Green Morocco Plan was substituted in early 2020 by a newly designed plan “Generation Green” of the Ministry of Agriculture, Fisheries, Rural Development, Water and Forests (2020). It is founded on two pillars. First, human development consists of creating an agricultural middle class, supporting young farmers, promoting new farmers' organizations, and aims at creating of a new generation of accompanying mechanisms. The second pillar aims for an agricultural development that is sustainable by consolidating agricultural supply chains, setting up an efficient and effective distribution network, promoting innovation and green-tech, improving the resilience of the agricultural sector and its eco-efficiency. Yet, how the plan will be put into practice, and if this new agricultural policy will follow the line of promoting water intensive agricultural growth, remains unclear.

Water policies tend to rather focus on supply management approaches (e.g. construction of more dams, construction of desalination stations) and on new water technologies, such as the promotion of water saving technologies like drip irrigation, than on demand management approaches (Kuper et al., 2016). This tendency is further accentuated by the Green Morocco Plan (Ministry of Agriculture, Fisheries, Rural Development, Water and Forests, 2020). Based on the idea that sustainability can be combined with agricultural intensification, drip irrigation and the installation of water basins were subsidized. As discussed in Section 3.2. the use of these technologies is associated with new land acquisitions outside the traditional oases, the installation of new farms, which often fully rely on groundwater extraction, and the cultivation of high value crops. Consequently, water demand increases despite its negative impact on existing water resources.

3.4. Anthropogenic assets

Interviews with stakeholders and farmers as well as the questionnaire illustrated the importance of anthropogenic assets to benefit from water resources. A product of such a human effort and cooperation is the traditional irrigation system in the oases, called *seggya.* The total length of the *seggya* system is estimated to be 1160 km (ORMVA, 2020) and the availability of water flowing through the *seggyas* is dependent on the dam releases. As the farmers' survey illustrates, 96% of respondents stated that they use the traditional canals to irrigate their lands. The second main source of water used for irrigation is groundwater that is accessed through private and public wells and the use of water pumps. In the Upper Draa 50% of the farmers use groundwater and 100% and 90%, respectively, in NMD and SMD (see also Section 3.5). Although the current numbers of wells and tube-wells is uncertain, their number rose over the last four decades. In 1977, the number of wells was estimated to be 4200 of which 2000 were equipped with a motor pump (Outabiht, 1981). In 1985, the number of motor pumps doubled, and further rose up to 7000 in 2005 and 10,000 in 2011 (Karmaoui et al., 2016). It remains unclear whether these estimates encompassed authorized and non-authorized wells. Notwithstanding, these estimates demonstrate how the access to groundwater has increasingly become more widespread.

For farmers, access to groundwater is important as it allows them to farm on their own terms and to liberate themselves from the state-controlled dam releases. In the extensions, it opens up possibilities to young farmers to take up new farming practices (e.g. produce watermelons) (Bossenbroek et al., 2020). As such, as also mentioned by Kuper et al. (2016), access to groundwater can be an emancipatory act.

The use of assets is not only fundamental for how people may benefit from nature but also for how people may contribute to nature. For example, much biodiversity in semi-natural landscapes is dependent on particular human practices such as herding and tree coppicing (Kenter, 2018). In our case, farming labor is an essential asset contributing to sustaining the oases. As oases are cultural landscapes that could not exist without human intervention (de Mas, 2006), they would not exist nor survive without human effort, technical inventions and a community structure which is characterized by a level of cohesion and cooperation (de Mas, 2006). As discussed by de Haas (2007), the degradation of the oases in the Todgha-Ferkla basin, about 200 km north-east of Zagora, is mostly due to anthropogenic factors, i.e. the poor maintenance of the irrigation systems and the crisis in the management of water resources, rather than caused by climate change and desertification. Migration plays an important role in the study area (see Section 3.6). Therefore, labour as an anthropogenic asset and how it plays a role in maintaining specific components of nature deserves more attention.

3.5. Nature's contribution to people

Regarding the benefits farmers receive from nature the farmers' survey assessed how water quantity and quality contributes to farmers' well-being or in what way their benefits are limited. All respondents stated that water is an essential resource for their farming activities as illustrated in the previous section. Most water use occurs from June to August followed by the period from March to May. In the rest of the year, water use for agriculture is rather low. Water use per area is highest for lucerne, followed by wheat and barley and a variety of vegetables according to farmers. While in the UD one third of surveyed farmers report no scarcity of water for their farming activities, in the NMD 87% report restrictions in their agricultural activities by water scarcity in each year, in the SMD all surveyed farmers report such restrictions. In UD 92% of farmers assess the water quality as good for agricultural production, in the NMD only 67% think the water has good quality for agriculture, dropping to 35% in SMD.

Stakeholder interviews nevertheless illustrate that benefits people derive from nature may negatively affect others resulting in social tensions and conflicts. This became especially apparent in the Feija plain. As already discussed in the previous parts, in this area farmers access groundwater resources to produce watermelons. At the same time the population of Zagora also depends on this resource to fulfill their drinking water needs. In 2017, the inhabitants of the parched districts of Zagora were deprived of drinking water and protested, demanding their right to water (Le Monde, 2017). According to the local population, the problem was attributed partly to poor management of water resources and high water use of watermelon production (cultivated close to the city).

In sum, benefits that farmers obtain from nature are strongly differentiated by location (up-stream and down-stream). Moreover, benefits for some may not extend to others. For future conservation recommendations and activities, it is therefore important to follow a holistic approach and to anticipate possible trade-offs. Furthermore, although cultural services were omitted from the household survey, the conducted in-depth interviews with farmers illustrate the importance of access to water to fulfill one's identity as a farmer. Also the oases seem to play a crucial role in the construction of the identity of the local people. The conducted interviews provide anecdotal evidence for the importance of water and nature in fulfilling cultural services, and therefore remain subject for subsequent studies.

3.6. Human well-being and quality of life

In the study area, agriculture is central in fulfilling livelihoods, with 100% and 85% of surveyed farmers practicing agriculture in the Upper Draa and Middle Draa, respectively. Further, non-agricultural sources of income such as casual labour, trade, work in the gardens and fields of other households or beekeeping have gained importance in terms of contribution to total household income. Remittances of migrated family members also play an important role for household incomes (Fig. 5g). Semi-structured farmers' interviews indicate migration as a way to cope with negative impacts related to water availability. Mostly young men migrate and seek for alternative income sources in cities. Yet, there is a general lack of data available to quantify national migration dynamics (Rössler et al., 2010).

Parallel to the subsistence-oriented farm practices, entrepreneurial farming practices emerged since 2006–2008. Both investors from outside of the region engage in these new farming practices, as well as the local populations. In the latter case, watermelons are often cultivated on small parcels (<5 ha) and combined with different vegetables, mainly used for subsistence.

Although the majority of respondents reported that water availability has decreased both in quantity and regularity over the last three decades (see Section 3.2.) a slight majority agreed with the statement that the quality of life in the region had improved overall over the last three decades. Yet, the responses of the UD differ significantly from those of the MD with 43% strongly agreeing in the UD compared to 70% in the MD. In the UD 25% strongly disagreed, while only 5–10% strongly disagreed in the MD.

Thus, less water availability is a main concern regarding future livelihoods. Farmers seem to realize that the common pool resource groundwater is becoming increasingly scarce. However, they stated various adaptation measures that could be undertaken, either on the individual farm level or on a higher political level (see Section 3.2). Consequently, farmers of the region generally believe that they are able to cope with those changes, but these perceptions are regionally differentiated with the downstream areas being less optimistic (Fig. 5h).

Overall, these results show that rural people's livelihoods are strongly connected to water availability and security to maintain their livelihoods. Therefore, changes in the availability or quality of water may affect their livelihoods and their well-being. These may in particular negatively affect the households that fully rely on agriculture, pushing them to find alternative income sources. As labor opportunities in the area are limited, such changes may also contribute to people wishing to migrate, which is already observed in the downstream oasis of M'hamid and Ktaoua. On the other hand, local populations developed a variety of adaptation strategies as discussed in Section 3.2, some of which are insightful in terms of water conservation.

3.7. Reflections on the IPBES framework

The IPBES framework supported our analysis of the relationship between nature and people. The fact that it aims for mutual recognition and enrichment among different disciplines and knowledge systems (Díaz et al., 2015) enhanced the integration of different disciplinary methods and results in this study. Working with an interdisciplinary team on the application of the IPBES framework to the context of the Draa River Basin revealed its well thought out choice of system components and arrangement for such a social-ecological system analysis. For instance, putting institutions and governance structures at the centre recognizes that to tackle issues of nature requires alertness to the way ecosystems are governed in addition to scientific knowledge on the state of the ecosystems (Borie and Hulme, 2015). However, limitations were also encountered. Although the debate on the use of the ecosystem service concept is beyond the scope of these reflections, we noted how central this concept features in the framework, making it difficult to feature results that highlight the reciprocal relations between nature and humans. Humans can also take up a role of caregivers to nature, which is currently largely overlooked. As we have also shown in this article, human investments are also essential for maintaining the oases.

In addition, human agency is too little recognized in the framework. What people actually do and the social reasons for that is ignored. This seems an important point because it will influence policies and decision making actions. For example, in the case of the Feija plain, groundwater access is crucial for young men as it opens up new farming activities and may be regarded as an emancipatory act. As such, the growing pressure on groundwater resources is not only a story of economic benefits and the depletion of water resources. It is also a story, in this case, of farmers wishing to farm on their own terms, independent from the state. This kind of information is crucial to consider in any management action. Yet, in the current IPBES framework such dynamics can be overlooked.

Finally, as we illustrated, the distribution of benefits from nature is largely overlooked, potentially causing social tensions and conflicts. The framework gives the impression that achieving conservation is a smooth process (the term “conflict” is only mentioned once) and tends to ignore potentially conflict-laden issues and disagreements (Löfmarck and Lidskog, 2017). Hence, how to deal with such conflicts remains open.

In this regard, we share the view that the IPBES framework is foremost useful to frame a certain way of thinking about the goodness of nature and the need to conserve it (Maier and Feest, 2016) and that it can serve as a boundary object facilitating lively discussions and exchange of knowledge between researchers from different scientific disciplines (Borie and Hulme, 2015). However, it is less suitable as an analytical framework to generate a sound understanding of social-ecological interactions such as feedback loops, conflicts, trade-offs, rebound effects and resilience in the system in great detail.

4. Recommendations for freshwater management and future research

Since the majority of farmers face problems with regard to the quality and quantity of water to meet their needs, water policies and governance structures currently focus on increasing water supply. In light of climate change this can only be a short-term solution and a stronger focus on demand-side management is recommended. The reorientation of policies could be supported by initiating public debates on the social, environmental and economic impacts of depleting water resources. It is essential to include local farmers and other local concerned actors (e.g. non-governmental organizations, associations, decision makers, rural leaders) to learn from their insights and how they shape outcomes for adaptation and conservation (see Bossenbroek et al., 2020). With the farmers' and stakeholder interviews our study has taken a first important step to facilitate this. Measures developed by farmers may pave the path for the preservation of water resources, such as reduction of cropped area, water saving techniques, and changes in crop types. In oases, nature and humans are deeply interwoven and as such nature conservation and sustaining local livelihoods appear to be complementary aims on the long-term. While in Europe the conservation or restoration of water bodies to achieve the aim of a good ecological status, assessed based on biological communities, is mandatory as defined in the EU Water Framework Directive, no such law exists in Morocco. We show the potential of benthic macroinvertebrates either through morphological identification or DNA barcoding for biomonitoring in this region. However, consultation with water managers and policy makers is required to discuss whether such approaches are desired and the aim of nature conservation is a societal priority. In the survey, people mentioned vegetation and larger mammals when asked in an open-ended way about nature, but not insects or other invertebrate groups. Therefore, changes in and research on other animal or plant groups may be more meaningful to people when aiming to raise awareness of nature's degradation. However, most pressing appears to be monitoring of water pollution, including nutrients, pesticides and salinity that are likely on the rise, but pass unnoticed due to a lack of monitoring.

CRediT authorship contribution statement

Elisabeth Berger: Conceptualization, Formal analysis, Investigation, Writing – original draft, Funding acquisition, Writing – review & editing. **Lisa Bossenbroek:** Conceptualization, Investigation, Writing – original draft, Writing – review & editing. **Arne J. Beermann:** Conceptualization, Investigation, Writing – original draft, Writing – review & editing. **Ralf B. Schäfer:** Conceptualization, Investigation, Supervision, Funding acquisition, Writing – review & editing. **Mohammed Znari:** Funding acquisition, Project administration, Writing – review & editing. **Sina Riethmüller:** Investigation, Formal analysis, Writing – review & editing. **Nanki Sidhu:** Visualization, Supervision, Writing – review & editing. **Nils Kaczmarek:** Investigation, Writing – review & editing. **Hassan Benaissa:** Investigation, Writing – review & editing. **Mohamed Ghamizi:** Supervision, Writing – review & editing. **Sabrina Plicht:** Investigation, Writing – review & editing. **Souad Ben Salem:** Investigation, Writing – review & editing. **Fadoua El Qorchi:** Investigation, Writing – review & editing. **Mohamed Naimi:** Project administration, Writing – review & editing. **Florian Leese:** Supervision, Writing – review & editing. **Oliver Frör:** Conceptualization, Investigation, Writing – original draft, Funding acquisition, Writing – review & editing.

Declaration of competing interest

No conflict of interests.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2020.144492.

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