Macroinvertebrate community composition and ecosystem health in response to salinity and environmental change in the Draa River basin, Morocco

by

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Summary

Northwest Africa is predicted to undergo a climatic shift from a temperate to an arid climate resulting in increased aridity, water salinity, and river intermittency. These changes have the potential to impact freshwater communities, ecosystem functioning, and related ecosystem services. However, there is still limited data on the impact of climate change and salinity on river ecosystems and the people depending on it, particularly in understudied regions such as Northwest Africa. In this dissertation, I focus on the Draa River basin in southern Morocco to assess the primary factors shaping and altering macroinvertebrate communities. A particular focus is placed on the impacts of salt on the ecosystem and the consequences for human well-being. We conducted a meta-analysis covering 195 sites in Northwest Africa to examine the responses of insect communities and their trait profiles to climate change and anthropogenically induced stressors. To exclude large-scale geographic patterns such as variations in climate conditions we conducted a confluence-based study focusing on tributaries and their joint downstream sections near three confluences in the Draa River basin. Additionally, we investigated the water and biological quality of 17 further sites, aiming to explore the relationship between human well-being and the ecosystem. Our approach involved conducting water measurements, biological monitoring, and household surveys to create water, biological, and human satisfaction indices. Our findings revealed that insect family richness in arid sites of Northwest Africa was, on average, 37 % lower than in temperate sites. Among the strongest factors contributing to reduced richness and low biological quality were low flow and high water salinity. Based on the results of the confluence study only around five taxa comprised over 90 % of specimens per site, with a higher proportion of salt-tolerant generalist species in saline sites. Resistance and resilience traits such as small body size, aerial dispersal, and air breathing were found to promote survival in arid and saline sites. However, low γ-diversity in the basin caused minimal differences in macroinvertebrate community composition suggesting that the community was generally adapted to the arid climate. We observed positive associations between river water quality and biological quality indices. However, no significant associations were found between these indices and human satisfaction. Human satisfaction was particularly low in the Middle Draa, where 89 % of respondents reported emotional distress due to water salinity and scarcity. Inhabitants in areas characterized by higher levels of water salinity and scarcity generally rated drinking and irrigation water quality lower. Considering that large parts of Northwest Africa will become arid by the end of the century, we can expect a loss of macroinvertebrate diversity affecting the entire ecosystem, which might potentially affect human well-being negatively. To protect the integrity of the ecosystem in the face of ongoing climate change, it is crucial to limit anthropogenic stressors such as secondary salinization and the pressures on water resources. Protecting both more and less saline rivers, preserving natural water flow, and maintaining connectivity between habitats will allow to maintain the Draa River biodiversity, ensure ecosystem functioning, and benefit inhabitants through ecosystem services. Future policies and action plans should consider the interdependence between ecosystems and human inhabitants to enhance overall well-being.

Zusammenfassung

Nordwestafrika wird einen Wandel von gemäßigtem zu aridem Klima durchlaufen, was zu einer erhöhten Aridität, Wassersalinität und der Austrocknung von Flüssen führt. Diese Veränderungen wirken sich auf Artengemeinschaften, Ökosystemenfunktionen und damit verbundene Ökosystemdienstleistungen aus. In dieser Dissertation konzentriere ich mich auf das Draa-Tal im Süden Marokkos, um die Hauptfaktoren zu untersuchen, die die Makroinvertebraten beeinflussen. Ein besonderer Schwerpunkt liegt auf den Auswirkungen von Salz auf das Ökosystem und die Konsequenzen für die Menschen. Wir führten eine Meta-Analyse an 195 Standorten in Nordwestafrika durch, um die Reaktionen von Insektengemeinschaften und ihren Merkmalsprofilen auf den Klimawandel und anthropoge Stressoren zu untersuchen. Um geografische Muster wie Variationen der Klimabedingungen auszuschließen, führten wir eine Studie durch, die sich auf Zuflüsse und ihre gemeinsamen Unterlaufabschnitte im Draa-Tal konzentrierte. Zusätzlich untersuchten wir die Wasser- und biologische Qualität von 17 weiteren Standorten, um die Beziehung zwischen dem Wohlergehen der Menschen und dem Ökosystem zu erforschen. Unsere Vorgehensweise umfasste Wasseranalysen, biologisches Monitoring und Haushaltsbefragungen. Unsere Ergebnisse zeigten, dass die Artenvielfalt von Insektenfamilien in ariden Gebieten Nordwestafrikas im Durchschnitt um 37 % geringer war als in gemäßigten Gebieten. Zu den stärksten Faktoren, die zu geringer Artenvielfalt und geringer biologischer Qualität beitrugen, gehörten niedriger Abfluss und hohe Wassersalinität. Basierend auf den Ergebnissen der Studie an der Mündung zweier Zuflüsse machten etwa fünf Taxa über 90 % der Individuen pro Standort aus, wobei ein höherer Anteil an salztoleranten Generalistenarten in salzigen Gebieten zu finden war. Resistenz- und Resilienzmerkmale wie geringe Körpergröße und Luftatmung förderten das Überleben in ariden und salzigen Gebieten. Eine geringe γ-Diversität im Draa-Tal führte jedoch zu minimalen Unterschieden in der Zusammensetzung der Makroinvertebratengemeinschaften, was darauf hindeutet, dass die Gemeinschaft im Allgemeinen an das aride Klima angepasst war. Wir beobachteten positive Zusammenhänge zwischen der Wasser- und biologischen Qualität des Flusses, aber keine signifikanten Zusammenhänge zwischen diesen Indizes und der menschlichen Zufriedenheit. Die menschliche Zufriedenheit war besonders gering im Mittel-Draa, wo 89 % der Befragten emotionale Belastungen aufgrund von Wassersalinität und -knappheit angaben. Bewohner in Gebieten mit höherem Salzgehalt und Wasserknappheit bewerteten die Qualität von Trink- und Bewässerungswasser im Allgemeinen schlechter. Da große Teile Nordwestafrikas bis zum Ende des Jahrhunderts austrocknen werden, ist mit einem Verlust an biologischer Vielfalt zu rechnen, der sich auf das gesamte Ökosystem und vermutlich auch auf das Wohlbefinden der Menschen auswirken wird. Um die Integrität des Ökosystems angesichts des fortschreitenden Klimawandels zu schützen, ist es entscheidend, anthropogene Stressfaktoren wie sekundäre Versalzung und den Druck auf Wasserressourcen einzuschränken. Die Erhaltung sowohl mehr oder weniger salziger Flüsse, die Aufrechterhaltung des natürlichen Wasserflusses und die Aufrechterhaltung der Verbindung zwischen Lebensräumen ermöglichen den Erhalt der Biodiversität des Draa-Tals, gewährleisten die Funktion des Ökosystems und kommen den Bewohnern durch Ökosystemleistungen zugute. Zukünftige Richtlinien und Aktionspläne sollten die Wechselbeziehungen zwischen Ökosystemen und menschlichen Bewohnern berücksichtigen, um das Gesamtwohl zu verbessern.

Résumé

L'Afrique du Nord-Ouest connaîtra une transition d'un climat tempéré à un climat aride, ce qui entraînera une augmentation de l'aridité, de la salinité de l'eau et de l'assèchement des rivières. Ces changements ont un impact sur les communautés d'espèces, les fonctions des écosystèmes et les services écosystémiques associés. Dans cette thèse, je me concentre sur la vallée du Draa, dans le sud du Maroc, afin d'étudier les principaux facteurs qui influencent les macroinvertébrés. Un accent particulier est mis sur les effets du sel sur l'écosystème et les conséquences pour les humains. Nous avons réalisé une méta-analyse sur 195 sites du nord-ouest de l'Afrique afin d'étudier les réactions des communautés d'insectes et leurs profils de traits au changement climatique et aux facteurs de stress anthropogéniques. Afin d'exclure les modèles géographiques tels que les variations des conditions climatiques, nous avons mené une étude axée sur les affluents et leurs sections communes en aval dans la vallée du Draa. En outre, nous avons étudié la qualité de l'eau et la qualité biologique de 17 autres sites afin d'explorer la relation entre le bien-être des personnes et l'écosystème. Notre approche comprenait des analyses de l'eau, un suivi biologique et des enquêtes auprès des ménages. Nos résultats ont montré que la biodiversité des familles d'insectes était en moyenne 37 % plus faible dans les zones arides du nord-ouest de l'Afrique que dans les zones tempérées. Les facteurs les plus importants qui contribuaient à une faible biodiversité et à une faible qualité biologique comprenaient un faible débit d'eau et une salinité élevée de l'eau. Environ cinq taxons représentaient plus de 90 % des individus par site, avec une proportion plus élevée d'espèces généralistes tolérantes à la salinité dans les zones salées. Les caractéristiques de résistance et de résilience, telles que la petite taille et la respiration aérienne, favorisaient la survie dans les zones arides et salées. Cependant, une faible diversité dans la vallée du Draa a entraîné des différences minimes dans la composition des communautés de macroinvertébrés, ce qui indique que la communauté était généralement adaptée au climat aride. Nous avons observé des associations positives entre la qualité de l'eau et la qualité biologique de la rivière, mais aucune association significative entre ces indices et la satisfaction humaine n'a été observée. La satisfaction humaine était particulièrement faible dans le Moyen-Drâa, où 89 % des personnes interrogées ont fait état d'un stress émotionnel lié à la salinité et à la rareté de l'eau. Les habitants des régions où la salinité et la rareté de l'eau sont plus élevées ont généralement évalué la qualité de l'eau potable et de l'eau d'irrigation comme étant moins bonne. Étant donné qu'une grande partie de l'Afrique du Nord-Ouest va s'assécher d'ici la fin du siècle, on peut s'attendre à une perte de biodiversité qui aura des répercussions sur l'ensemble de l'écosystème et probablement aussi sur le bien-être des populations. Pour protéger l'intégrité de l'écosystème face au changement climatique en cours, il est essentiel de limiter les facteurs de stress anthropogéniques tels que la salinisation secondaire et la pression sur les ressources en eau. La conservation de rivières plus ou moins salées, le maintien du flux naturel de l'eau et le maintien de la connectivité entre les habitats permettent de préserver la biodiversité de la vallée du Draa, garantissent le fonctionnement de l'écosystème et profitent aux habitants par le biais de services écosystémiques. Les futures politiques et plans d'action devraient prendre en compte les interactions entre les écosystèmes et les habitants humains afin d'améliorer le bien-être global.

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Chapter 1

1. Introduction

1.1 Climate change and salinization in the Draa River basin

Northwest Africa, an already arid region prone to droughts, is expected to experience an expansion of its arid climate (Beck et al., 2018; Born et al., 2008; Waha et al., 2017). This expansion will lead to a decrease in water resources and a decline in water quality (Bates et al., 2008). Temperatures are projected to rise by two to three °C, while precipitation is anticipated to decrease by 10-20 %, resulting in an increased risk of droughts by 2050 (Schilling et al., 2012). Among the countries in the region, Morocco is particularly vulnerable to the effects of climate change (Schilling et al., 2012; Terink et al., 2013). The already scarce water resources will also face additional challenges due to an increase in river and soil salinity, further compromising both the quantity and quality of available water (Bates et al., 2008; Warner et al., 2013; Williams, 1999).

Saline rivers are commonly found in semi-arid and arid regions with endorheic basins (Williams, 1999). They result from primary salinization processes, which involve the release of salts from rocks and soils into the water, and solar evaporation (Williams, 1999). Additionally, anthropogenic factors contribute to secondary salinization further elevating natural salinity levels, such as the utilization of saline freshwater for irrigation (Bates et al., 2008; Cañedo-Argüelles et al., 2016). The combination of factors including increased water abstraction, alterations in flow patterns, and the growing demand for groundwater as a response to diminishing surface water resources further exacerbate the levels of salinity and intermittency in river systems (Datry et al., 2014; Williams, 1999). The increasing salinization and the decline of available water resources have detrimental impacts on river ecosystems leading to reduced biodiversity and altered ecosystem functions (Berger et al., 2019; Cañedo-Argüelles et al., 2016). Moreover, people relying on these water resources face an increased risk to their livelihoods (Cañedo-Argüelles et al., 2016).

The Draa River basin in southern Morocco faces mounting challenges in sustaining the health of its ecosystem and securing the livelihoods of its people as it suffers from the impacts of climate change and salinization (Karmaoui et al., 2014; Schilling et al., 2020). This basin, characterized by various aridity and salinity gradients, offers an opportunity to explore the associations between these gradients and potential responses of both the river ecosystem and human well-being. In the upper reaches of the basin salinity primarily results from geological factors (Warner et al., 2013). Streams like Dades, M'Goun, and Iriri exhibit relatively low salinity levels ranging from 500 to 1,500 µS/cm (own measurements). However, depending on the composition of rocks, other streams such as El Mellah can reach salinity levels as high as 20,000 µS/cm (own measurements), almost half the level of seawater. In the Middle and Lower Draa basins river salinity increases due to reduced rainfall and an increasingly arid climate (Beck et al., 2018; Williams, 1999). These conditions result in limited water dilution and enhanced evaporation (Warner et al., 2013). Furthermore, the use of saline freshwater for irrigation in the expansive date palm oases along the Draa leads to secondary salinization of the rivers (Hssaisoune et al., 2020; Williams, 1999; Karmaoui et al., 2014; Haj-Amor et al., 2016). The drying of intermittent streams during summer and alterations in the natural flow regime, caused by the presence of the El Mansour Eddahbi dam between the Upper and Middle Draa, further stress the river ecosystem (Karmaoui, 2014). The construction of the dam has resulted in the Draa River no longer reaching the Atlantic Ocean, rendering the basin endorheic and preventing the salt from being washed out into the ocean (Williams, 1999).

1.2 The Draa River ecosystem and its macroinvertebrate community

Freshwater ecosystems play a vital role in ensuring the survival of numerous lifeforms in desert environments (Bunn et al., 2006), including the Draa River situated in the northern region of the Saharan desert. The Draa River harbors diverse aquatic and semi-aquatic species, ranging from diatoms and plants to macroinvertebrates, fish, and mammals such as otters (Benlasri et al., 2023; Berger et al., 2021; Clavero et al., 2015; Lazrak et al., 2022; Mostakim et al., 2020; Riesco et al., 2020). The presence of freshwater not only supports these aquatic lifeforms but also has a positive impact on terrestrial life, providing essential water and food resources (Bunn et al., 2006). Each species contributes to the overall health of the desert ecosystem which offers various ecosystem services benefiting the local people (Lynch et al., 2023). However, desert rivers face escalating threats from climate change, salinization, flow modifications, and water abstractions, posing a significant risk to their unique ecosystems (Cañedo-Argüelles et al., 2016; Sabater et al., 2018). Therefore, it is crucial to comprehend the impacts of climate change, salinization, and human activities on these ecosystems. Addressing existing research gaps (Cunillera-Montcusí et al., 2022) is imperative to efficiently safeguard desert freshwater systems, preserving their distinct ecosystems and ensuring the sustainability of human livelihoods (Berger et al., 2021).

Benthic macroinvertebrates including insects, crustaceans, snails, and worms, represent important organisms to assess the impacts of various stressors on freshwater ecosystems and the organisms themselves. They contribute to the stability of these ecosystems by performing important functions such as processing both dead and living material and transferring energy to freshwater and adjacent terrestrial food webs (Wallace & Webster, 1996; Covich et al., 1999; Giller et al., 2004). When faced with increasing environmental stressors such as salinity, water temperature, and flow intermittency, macroinvertebrate abundance and richness can decline (Arribas et al., 2019; Beauchard et al., 2003; Durance and Ormerod, 2007; Kefford, 1998; Smeti et al., 2019; Stubbington et al., 2009). Consequently, essential ecosystem functions such as nutrient cycling and organic matter breakdown can be negatively affected (Cao et al., 2018; Smeti et al., 2019). Since macroinvertebrates are ubiquitous in most streams, easily sampled in large numbers, and can serve as indicators for water quality and the impact of stressors using diversity and multimetric indices (Hering et al., 2006), they are ideal for study purposes (Myslinski & Ginsburg, 1977).

The macroinvertebrate fauna of Northwest Africa predominantly comprises species that are commonly found in Europe, with only a limited number of Afrotropical species present in the region (Beauchard et al., 2003). As climate conditions are expected to shift northward, leading to increased water temperature, salinity, and flow intermittency (Beck et al., 2018), macroinvertebrate species may also migrate northward to follow suitable habitat conditions (Hickling et al., 2005). However, the vast expanse of the Saharan desert in the south acts as a significant natural barrier, and the lack of species adapted to even drier conditions may result in a loss of macroinvertebrate diversity or species extinction in Northwest Africa. While the functions performed by locally extinct species may be partially compensated by functionally similar species (Solan, 2004), a reduction in diversity could reduce the ecological stability of the system (i.e., the ability of the ecosystem to retain its state under changing conditions or perturbations; Meerbeek et al., 2021).

Elevated salinity levels can have detrimental effects on macroinvertebrates at various levels, ranging from individual organisms to populations, communities, and entire ecosystems (Cañedo-Argüelles et al., 2013). High salinity imposes stress and increases the energy required for osmoregulation which can limit the development, growth, and fertility of macroinvertebrates (Cañedo-Argüelles et al., 2013; Kefford et al., 2016). The response of different species to increasing salinity levels can lead to changes in the composition of the entire macroinvertebrate community (Cañedo-Argüelles et al., 2013). Consequently, sensitive taxa may decline in abundance or even face local extinction, while salt-tolerant species may benefit from reduced competition and predation (Kefford et al., 2016; Velasco et al., 2006). Similarly, intermittency and rising water temperatures, particularly in stagnant ponds, can also alter macroinvertebrate communities, favoring species that can adapt to these conditions (Bonada et al., 2007; Dewson et al., 2007). Despite increasing scientific interest in freshwater salinization and intermittent rivers in recent years, significant knowledge gaps remain regarding the effects on ecosystems, particularly in less-studied regions such as Africa (Cunillera-Montcusí et al., 2022).

To survive in saline and arid environments, specific adaptations are necessary to cope with increased environmental stress. Generally, organisms that exhibit r-strategist characteristics (MacArthur & Wilson, 1967), such as short life cycles, multiple reproductive cycles per year, and smaller body sizes, have a better capacity to withstand harsh conditions like high salinity (Díaz et al., 2008; Piscart et al., 2006). Furthermore, possessing resistance traits such as desiccation resistance can enable species to withstand prolonged droughts, while the ability for aerial dispersal can aid in escaping drying rivers or recolonizing them once flow resumes (Stubbington et al., 2017). Studying the associations between environmental stressors and the functional traits of macroinvertebrate communities can provide further insights into the necessary adaptations and the consequences of climate change and anthropogenic-induced stressors on species. This research can help to understand how organisms respond to these challenges and how their populations and ecosystems are affected.

1.3 The Draa River basin as a social-ecological systems

By adopting a broader perspective that encompasses not only the river ecosystem but also the people living in its vicinity and their dependence on it, we can gain a comprehensive understanding of the entire system from a social-ecological standpoint. Social-ecological systems can be characterized as complex and adaptive systems, comprising both the bio-geophysical components and the social actors and institutions associated with them (Glaser et al., 2008). With a “humans-in-nature” perspective it is important to recognize that human actions exert direct impacts on the ecosystem, while the state of the ecosystem affects the livelihoods and well-being of humans (Berkes et al., 2000). It was demonstrated that access to nature and the presence of biodiversity in the surrounding environment enhance overall well-being (Hartig et al., 2014; Marselle et al., 2019). Furthermore, livelihoods are sustained by "nature's contributions to people" (Díaz et al., 2018). Consequently, any degradation of the ecosystem's condition, such as the loss of macroinvertebrate diversity can have detrimental effects on ecosystem services and human health (Strange et al., 1999). Understanding the direct and indirect connections between ecosystem health and human well-being can provide crucial insights that inform future conservation efforts (Gonzáles et al., 2008). By acknowledging the interdependence of these systems, we can strive towards sustainable practices and ensure the preservation of both ecological integrity and human welfare.

Rivers play a crucial role in promoting human well-being by providing water and food resources, regulating climate, and offering cultural services (Akinsete et al., 2019). However, anthropogenic actions have significantly impacted river ecosystems, leading to hydromorphological changes and pollution, which reduce ecosystem health and pose threats to human well-being (Akinsete et al., 2019; Cunillera-Montcusí et al., 2022). Various factors such as water scarcity, ecosystem degradation, soil erosion, pollution, and unpredictable ecological flows have been shown to limit human well-being (Zuo et al., 2020). Furthermore, the natural environment, including riverscapes, has been found to have a positive impact on mental and physical health (Kaplan, 2001; Russell et al., 2013; White et al., 2010). Studies have shown a correlation between river naturalness and human well-being, emphasizing the importance of preserving natural river systems (White et al., 2010). However, it is important to note that most of these studies have been conducted in developed countries, primarily focusing on large perennial rivers (Cruz-Garcia et al., 2017). Thus, it remains unclear to what extent these findings can be applied to intermittent, ephemeral, and dry rivers in countries of the Global South (Ferreira et al., 2022; Messager et al., 2021; Nicolás-Ruiz et al., 2021). As climate change continues and anthropogenic pressures persist, it is crucial to recognize that these systems and regions, especially in the Global South, may face significant threats to both ecological and human health (Liu et al., 2022; Zuo et al., 2020).

The livelihoods of the inhabitants of the Draa River basin rely directly on the river ecosystem. This ecosystem serves as a vital source of water for irrigating the traditional date palm oases enabling the local population to survive the harsh arid conditions of the northern Sahara (Karmaoui et al., 2016). However, the reduction in water availability and an increase in salinity has placed the farmers' livelihoods at risk (Berger et al., 2021). The challenges faced by the region are exacerbated by poor water resource management and the cultivation of unsustainable crops such as watermelons (Karmaoui et al., 2016). These practices have detrimental effects on the benefits derived from the natural environment ultimately leading to potential social tensions or conflicts (Berger et al., 2021; Mahjoubi et al., 2022; Silva-Novoa Sánchez et al., 2022). Therefore, ensuring sustainable use of the scarce water resources and protecting the river ecosystem is of utmost importance in securing livelihoods in the Draa River basin for the future. Addressing the future challenges for the Draa River basin posed by climate change requires a comprehensive consideration of all aspects of the social-ecological system.

1.4 Objectives and outline

Within the Salidraa-juj project, in my dissertation, I focus on the impacts of climate change and anthropogenic stressors, such as salinity and water scarcity, on river ecosystems and its organisms in Northwest Africa and mainly the Draa River basin (Figure 1). To assess the water and biological quality of the rivers I utilized benthic macroinvertebrates as indicator organisms.

Moreover, recognizing the interdisciplinary background of the project, I expanded my research focus beyond the river ecosystem alone to assess the interactions between the river and the local communities reliant on it as part of the social-ecological system (Figure 1). This broader perspective enables a more comprehensive examination of the various factors influencing the sustainability and well-being of both the ecosystem and the human population it supports. As this cumulative thesis is based on three scientific publications, written together with several co-authors the first-person plural is used subsequently.

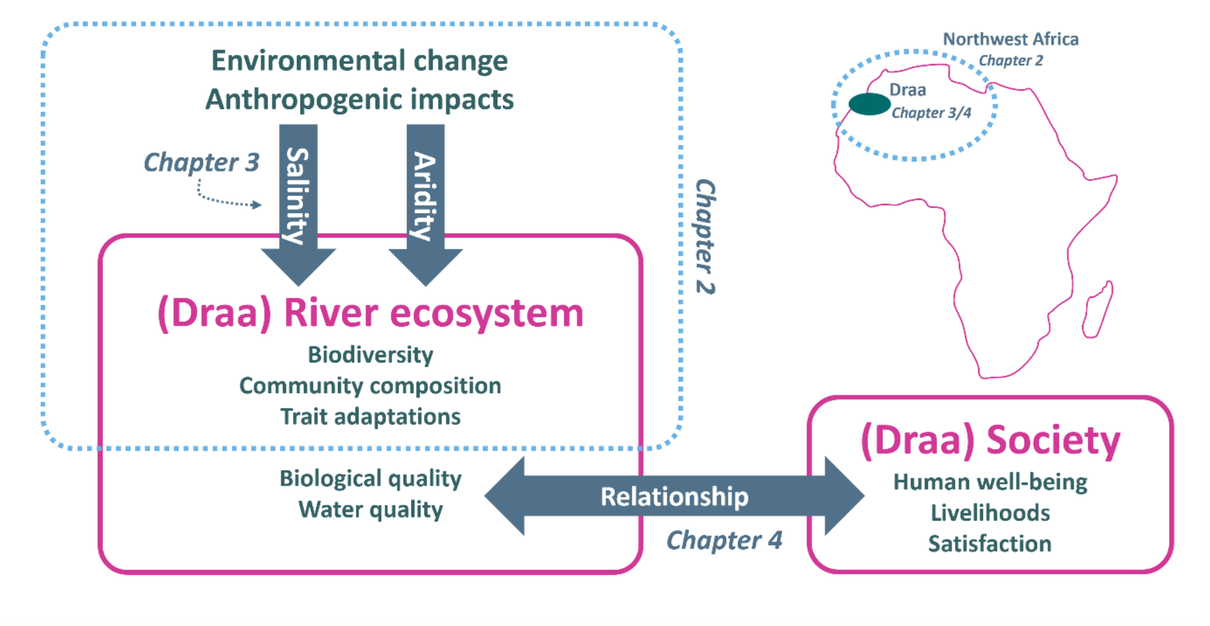

Figure 1. Graphical overview of the topics covered in this dissertation with the main objectives of chapters 2, 3 and 4. The map of Africa shows the focus region of each chapter.

Given the projected expansion of arid climate in Northwest Africa (Beck et al., 2018) and the increasing pressures of aridity, intermittency, and salinity on river ecosystems, our study aimed to assess the primary factors shaping and altering the composition of river communities, with a specific focus on macroinvertebrates. We conducted a meta-analysis covering Northwest Africa to investigate the responses of macroinvertebrate communities to climate change and anthropogenically induced stressors, including heightened salinity, water temperatures, and intermittency. In Chapter 2, our objectives were as follows:

- Evaluate differences in aquatic insect richness between temperate and arid regions of Northwest Africa and identify families that are characteristic of each climate.
- Identify environmental parameters that explain variations in insect family richness and quantify associations between these parameters and insect families.
- Quantify associations between resistance and resilience traits and various environmental parameters.

Increasing salinization, resulting from both primary and secondary (i.e., anthropogenic) sources, is a growing global concern, negatively impacting river ecosystems and their communities (Kefford et al., 2016). However, large-scale geographic patterns, such as variations in climate conditions and altitude, can obscure the effects of individual stressors on macroinvertebrate communities (Kefford, 1998). Therefore, in Chapter 3, we conducted a confluence-based study in the Draa River basin focusing on the response of macroinvertebrate communities to salinity at tributaries and their joint downstream sections in the immediate vicinity of three confluences. Our objectives were as follows:

- Compare macroinvertebrate taxon richness in response to salinity at confluences of less saline and more saline tributaries.
- Assess community composition between less saline and more saline tributaries, with a specific emphasis on the presence of salt-sensitive and salt-tolerant species.
- Compare trait profiles between less saline and more saline tributaries and investigate the proportional differences in the occurrence of resilience and resistance traits.
- Consider the joint downstream section to examine dispersal-related processes that may lead to a community combining taxa from both the less saline and more saline tributaries.

Humans are an integral part of social-ecological systems directly impacting the ecosystem, while the state of the ecosystem, in turn, affects the livelihoods and well-being of humans (Berkes et al., 2000). Our aim was to find associations between the water and biological quality as well as human satisfaction in the Draa River basin. Therefore, in Chapter 4, our objectives were as follows:

- Describe water quality, biological quality, and human satisfaction through physico-chemical water quality parameters, aquatic macroinvertebrate metrics, and standardized household surveys, respectively. We calculated a water quality index (WQI), biological quality index (BQI), and human satisfaction index (HSI) for this purpose.
- Analyze the main environmental parameters (e.g., water salinity and flow rate) associated with low values of BQI and HSI.
- Correlate WQI, BQI, and HSI to investigate the relationship between the river, its biological communities, and the people dependent on it.

The results and conclusions obtained in chapters 2-4 are discussed in an overall discussion and outlook in Chapter 5.

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Chapter 2

Environmental Change Threatens Freshwater Insect Communities in Northwest Africa: A Meta-Analysis

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2.1 Abstract

A climatic shift from temperate to arid conditions is predicted for Northwest Africa. Water temperature, salinity, and river intermittency are likely to increase, which may impact freshwater communities, ecosystem functioning, and related ecosystem services. Quantitative data and information on the impact of climate change on insect communities (e.g., richness, taxonomic and trait composition) are still scarce for Northwest Africa. In this study, we extracted information on freshwater insect occurrence and environmental variables in Northwest Africa from the results of a literature search to study potential consequences of changing climatic conditions for these communities. Our data set covered 96 families in 165 sites in Morocco and Algeria. We quantified the impact of several explanatory variables (climate, altitude, water temperature, conductivity, intermittency, flow, aridity, dams, and land cover) on richness, taxonomic and functional trait composition using negative binomial regression models and constrained ordination. Family richness in arid sites was on average 37 % lower than in temperate sites in association with flow, river regulation, cropland extent, conductivity, altitude, and water temperature. With 36 % of the studied temperate sites predicted to turn arid by the end of the century, a loss of insect families can be predicted for Northwest Africa, mainly affecting species adapted to temperate environments. Resistance and resilience traits such as small body size, aerial dispersal, and air breathing promote survival in arid climates. Future research should report insect occurrences on species level to allow for better predictions on climate change effects.

2.2 Introduction

Northwest Africa is characterized by the temperate Mediterranean and arid Saharan climate and is subject to droughts (Schilling et al., 2012; Waha et al., 2017). In this region, rivers can be considered the arteries of life because all life is clustered around them. Arid climate is predicted to extend northwards covering increasing parts of the Maghreb until the mid- and late-21st century (Born et al., 2008; Beck et al., 2018). This will likely lead to increased salinity levels and flow intermittency in rivers (Williams, 1999) potentially affecting biodiversity and dependent human livelihoods (Arthington et al., 2010; Berger et al., 2018) through changes in the supply of ecosystem goods and services. Besides climate change, water abstraction (Dewson et al., 2007), flow modification (Martínez et al., 2013) and additional human-induced forms of secondary salinisation (Cañedo-Argüelles et al., 2013) related to human land use in the river catchment may exacerbate salinity levels and flow intermittency.

Benthic macroinvertebrates play an important role in the functioning of freshwater ecosystems (Wallace & Webster, 1996; Covich et al., 1999). By processing dead and living material and transferring the energy to freshwater and adjacent terrestrial food webs, macroinvertebrates contribute to ecosystem stability (Wallace and Webster, 1996; Giller et al., 2004). Macroinvertebrate abundance and richness has been shown to decrease with environmental stressors such as high water temperature (Durance and Ormerod, 2007), high salinity (Kefford, 1998; Arribas et al., 2019), and flow intermittency (Beauchard et al., 2003; Stubbington et al., 2009; Smeti et al., 2019). This, in turn, has been associated with a reduction in ecosystem functions such as nutrient cycling (Cao et al., 2018) and organic matter breakdown (Smeti et al., 2019). The anticipated increase in water temperature, salinity, and flow intermittency with future climate change suggests a reduction in macroinvertebrate abundance and richness, which may result in the local extinction of species in Northwest Africa. A loss of species can potentially be compensated by functionally similar species (Solan, 2004) as long as this species can maintain or increase its abundance. However, in the absence of compensation, the reduction of ecosystem functions through the loss of insect abundance and richness could adversely affect ecosystem services and human health (Strange et al., 1999).

Species that can thrive in arid climates show adaptations to drought and salinity or the ability to quickly recolonize after droughts. Resistance traits (e.g., desiccation resistance) can enable species to withstand long droughts (Stubbington et al., 2017). Ovoviviparity, multi-voltinism, and filter- and deposit-feeding, have been associated with increased salinity (Piscart et al., 2006; Szöcs et al., 2014). High female dispersal and short life cycles promote recolonization after droughts (Stubbington et al., 2017). Traits that increase resistance and resilience typically increase in communities that persist in harsh climatic conditions, because species that lack such traits go locally extinct. Notwithstanding, the occurrence of specific traits is not only driven by environmental conditions but complex abiotic and biotic interactions under phylogenetic constraints (Hamilton et al., 2020).

Studies on macroinvertebrates in Northwest Africa are still scarce and often focus on water quality and anthropogenic stressors on a local scale, and less on climate effects in the whole region. Trends in macroinvertebrate distribution and richness patterns in North Africa can be assessed by using a combination of climatic and hydrological variables (Beauchard et al., 2003).

However, little is known about the impact that climate change can have on insect communities. While insect richness and abundance are decreasing as a response to anthropogenic land use intensification (Seibold et al., 2019), macroinvertebrate richness may increase in temperate regions of Europe by a northward shift of species from the highly diverse Mediterranean climate (Bonada et al., 2007). As a consequence of the increasing arid climate in Northwest Africa (Beck et al., 2018), a loss of richness, however, can be expected. Understanding the effects of arid and temperate climate on insect communities in Northwest Africa may help establish future scenarios for insect communities and identify consequences for food webs, ecosystem functions, and related ecosystem services.

We compiled data for Northwest Africa to quantify the associations between aquatic insect communities and environmental variables. The aim of our study was to study the response of aquatic insect richness to a change of climates based on an increase of arid conditions. Furthermore, we aimed to identify insect families that are likely vulnerable to climate change and traits that enable insects to thrive under arid conditions.

We hypothesized that (i) aquatic insect richness in Northwest Africa is lower in arid than in temperate climates; (ii) insect family composition differs between arid and temperate climates, in association with (iii) changes in specific traits, such as small body size, short life cycles, resistance against drought and salinity, and the ability for air breathing.

2.3 Materials and Methods

2.3.1 Data Collection

2.3.1.1 Literature Search and Insect Occurrence Data

We used Web of Knowledge, Google Scholar, and the database MacroMED (Blanco-Garrido et al., 2013) to search for publications about macroinvertebrates in Northwest Africa using the keywords “macroinvertebrate*,” “invertebrate*,” and “insect*” together with “Algeria,” “Morocco,” and “Tunisia,” as well as their French translations. Given that most publications were limited to aquatic insects and Morocco and Algeria, we limited our study to this group in these two countries (Figure 2.1). Moreover, the references of the retrieved publications were screened for additional studies, called footnote chasing. The literature search was completed on June 15th, 2020. Publications that reported (i) presence/absence data for aquatic insects (not restricted to specific orders), (ii) water temperature and conductivity, (iii) and were conducted in intermittent or permanent rivers, were used in the analysis (Figure A.1). This resulted in 18 publications (Table A.1). In all studies, aquatic insects were sampled by using either a Surber sampler or hand/kick net, except for Khebiza et al. (2006) that used a membrane pump. The sampling method was not reported in Giudicelli and Dakki (1984).

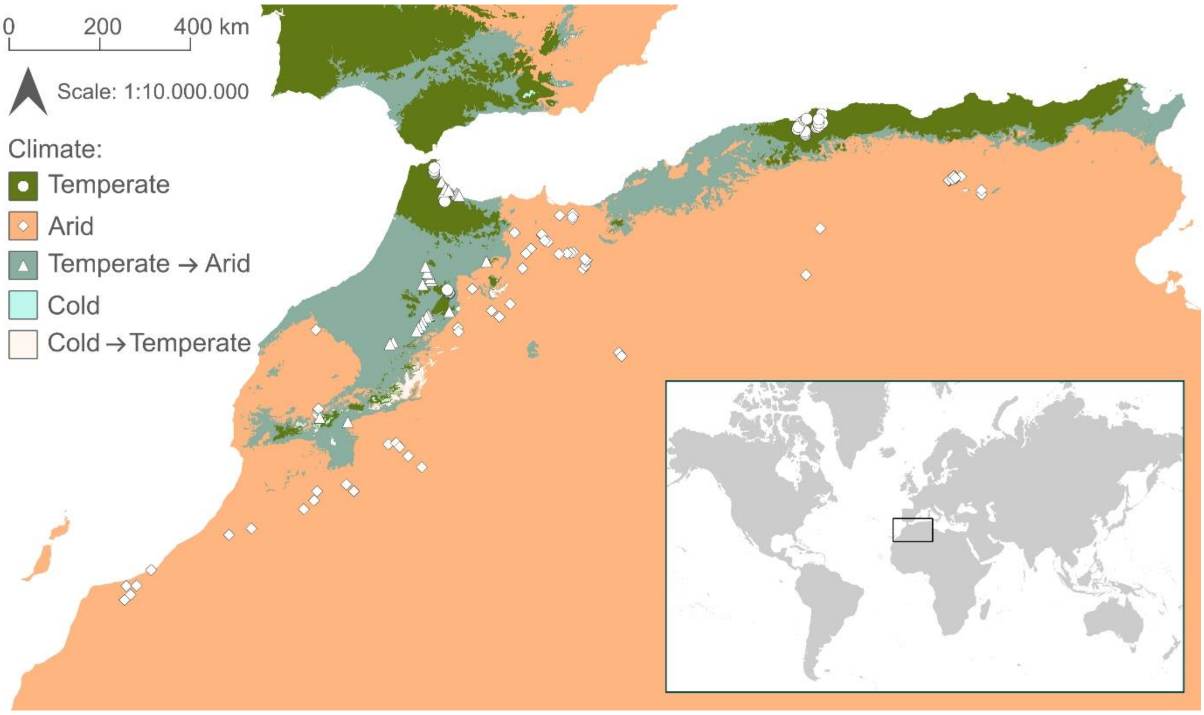

Figure 2.1. Map of sample sites in Northwest Africa. Shape of points indicates climatic region (dots = temperate; diamonds = arid; triangles = temperate climate predicted to shift to arid by 2071–2100). Climate classification is based on Beck et al. (2018).

2.3.1.2 Insect and Environmental Variables

Insect and environmental variables were sampled one to 12 times per site. Therefore, we included "Number of samples per site" as a variable, to allow for checking the effect of the sampling frequency per site on family richness. Based on the given taxonomic resolution, we used the family level.

11 variables were gathered for analysis (Table 2.1), which describe the hydrological, geographic, and climatic conditions, as well as land cover. Water temperature and water electrical conductivity as a surrogate measure for salinity (hereafter conductivity) were extracted directly from tables or graphs in the selected papers using WebPlotDigitizer (Rohatgi, 2020). In the case of repeated measurements, a mean was calculated, because several publications already reported mean values. Coordinates (World Geodetic System 1984 Coordinate system (WGS-84)) and altitude were extracted directly from the publications. If information was missing, the location and altitude of the sites were estimated based on the presented maps. The general flow regime (permanent or intermittent) was extracted from the publications. River area, degree of regulation, Global Aridity Index, cropland extent, and urban extent (spatial extent of cropland/urban areas in reach catchment), were extracted from the RiverATLAS (version 1.0; Linke et al., 2019) using QGIS 3.8.2-Zanzibar (QGIS.org, 2021). Finally, the current and future climatic class of each site (arid, temperate) was assigned using the Köppen-Geiger climate classification map for present-day and future climate (Beck et al., 2018).

Table 2.1. Environmental and anthropogenic variables used in the analyses with their unit, minimum (Min), maximum (Max) and average (Avg) values, standard deviation (SD), used transformation before data analysis and the source of the variables ("direct" indicates direct extraction from publications). Values for temperate and arid climate are reported in brackets, separated by a slash.

Variable	Description	Unit	Min	Max	Avg	SD	Transformation before data analysis	Source
Climate	Type of climate (temperate or arid)	-	-	-	-	-	-	Köppen-Geiger climate classification map, Beck et al., 2018
Altitude	Height above sea level	Meters [m]	(7/0)	(1910/1710)	722.7 (530/839)	555.5 (612.1/477.5)	-	direct / maps
Water tempera-ture	-	Degrees Celsius [°C]	(8.9/7.8)	(28.7/33.1)	19 (17.7/20.1)	5 (3.7/5.7)	-	direct
Flow regime	Type of flow (permanent or intermittent)	-	-	-	-	-	-	direct
Global Aridity Index	Mean annual precipitation over mean annual evapotranspira-tion	Index value	(30/3)	(90/49)	39.5 (59.3/23.4)	22.1 (12.5/13.3)	-	RiverATLAS, Zomer et al. 2008
Number of samples per site	Number of samples taken per site	-	(1/1)	(12/12)	5.4 (8.1/3.2)	4.7 (4.8/3.3)	-	direct
Conducti-vity	Water conductivity	[µS/cm]	(167.6/202)	(4059/93667)	5282.1 (1124.4/8663.1)	17061.3 (772.3/22453.7)	log	direct
River area	Surface area of river reach in a 15 arc-second grid	Hectares [ha]	(0.47/0.15)	(20.43/70.94)	6.1 (6.4/5.9)	8 (5.3/9.6)	log	RiverATLAS, Lehner & Grill 2013
Degree of regulation	Effect of upstream dams on natural flow regime. Ratio between total reservoir storage volume of upstream dams and total annual discharge volume available at reach.	Percent [%]	(0/0)	(5095/1968)	74.5 (116.5/40.3)	443.3 (616.9/216.2)	log(x+1)	RiverATLAS, Lehner et al. 2011
Cropland extent	Percentage of cropland land cover at river reach	Percent [%]	(0/0)	(100/100)	25.5 (43.7/10.7)	34.5 (34.8/26.2)	log(x+0.1)	RiverATLAS, Ramankutty et al. 2008
Urban extent	Percentage of urban land cover at river reach	Percent [%]	(0/0)	(100/71)	15.2 (23.9/8.1)	23.8 (29.6/14.3)	log(x+0.1)	RiverATLAS, Pesaresi & Freire 2016

2.3.1.3 Trait Data

We used the trait database of Tachet et al. (2010) to obtain information for the insect families, including 11 biological traits with 60 modalities (Table A.2) associated with resilience and resistance to disturbances (Bonada et al., 2007). Among these are included traits such as size, life-cycle duration, reproduction, and feeding behavior. For each of these biological traits, different trait modalities are defined and the affinity of the taxa to each trait modality is represented by fuzzy coded scores (0 = no affinity, 1 = low affinity, 2 = moderate affinity, 3 = high affinity). These codes were transformed to relative frequencies for a given family. If traits were defined for a lower taxonomic level than family in the trait database, we assigned traits as follows: (i) If only one species of a family occurred in the study region and traits were available for the species, these traits were assigned to the family. (ii) In the case of multiple species from a family, we calculated a weighted mean based on its relative frequency of occurrence with respect to the total number of sites. For each site, we calculated an insect assemblage trait profile based on the relative frequencies of trait modalities for each family and the presence data of these families at a given site, by taking the sum for each trait modality from all present insect families and transforming these sums into relative frequencies for each trait (similar to Mondy et al., 2016). Trait information was missing for 15 out of 96 families and for four families few specific traits were missing. These families or traits were not considered for the calculation of the insect assemblage trait profiles.

2.3.2 Data Analysis

For all data analyses, we used RStudio (version 1.2.5019) and the packages “Vegan” (Oksanen et al., 2019), “car” (Fox and Weisberg, 2018), “DHARMa” (Hartig, 2020), “MASS” (Venables and Ripley, 2002), and “faraway” (Faraway, 2016), “reghelper” (Hughes and Team, 2017), “modEvA” (Márcia Barbosa et al., 2013), “indicspecies” (De Cáceres et al., 2016), “beanplot” (Kampstra, 2008), “MuMIn” (Barton and Barton, 2015).

2.3.2.1 Association Between Family Richness and Environmental Variables

To analyze for differences in the richness of insect families between arid and temperate climate (hypothesis 1), we used Welch’s t-test given heterogeneous variances (Figure 2.2). To identify environmental variables that can explain family richness, we used negative binomial regression models. The variable “Climate” was removed from analyses due to collinearity (VIF >5) with the Global Aridity Index, which captures climatic conditions in terms of evaporation and precipitation. Five variables were log-transformed prior analysis because they were left-skewed (Table 2.1). We used a backward stepwise model selection by AIC to select the best fitting model. The resulting best-fit model was checked for model assumptions.

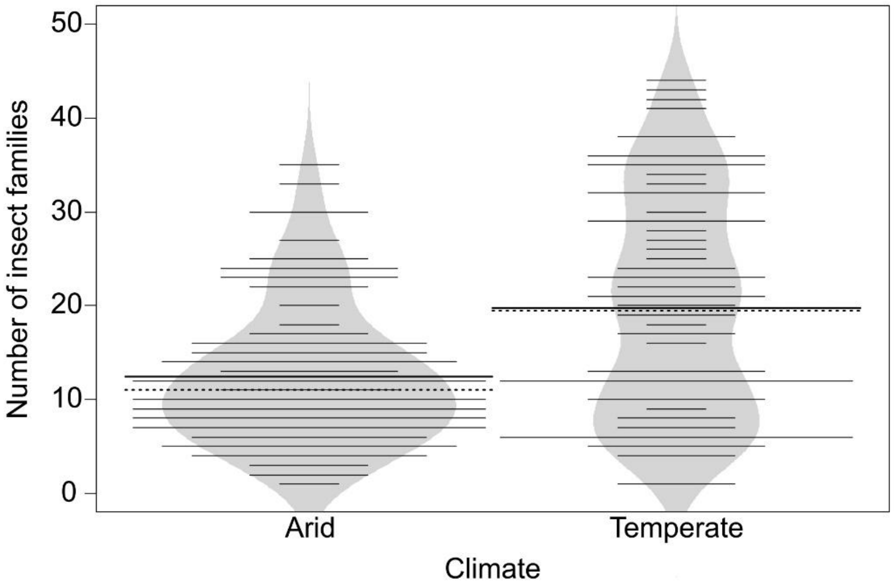

Figure 2.2. Beanplot for number of insect families for arid (n = 91) and temperate climate (n = 74) in Northwest Africa. Bold line indicates mean of each group (arid = 12.44; temperate = 19.76), dashed lines indicate median of each group (arid = 11; temperate = 19, thin lines individual observations, polygon and length of lines density of observations. Means differ significantly between the two climates (Welch's t-test, n = 165, t (116.47) = −4.6, p = < 0.001). For details on beanplots see Kampstra (2008).

2.3.2.2 Association Between Family Composition and Environmental Variables

Before analysis, we excluded rare families that occurred in less than five percent of sites (<8 sites) from the analysis (Legendre and Gallagher, 2001). Canonical Correspondence Analysis (CCA) was used to analyze the relationship between insect families and environmental variables (hypothesis 2). We selected CCA because a detrended correspondence analysis (DCA) showed a unimodal gradient (gradient length of 3.29) (Legendre and Legendre, 2012). The best fit model was selected using a stepwise model selection with the adjusted R^2 as the goodness of fit metric.

To identify families that are characteristic for arid and temperate climate, we used an Indicator species analysis. For each family, an indicator value was calculated, which is highest when taxa are either present in one of the climates but not the other or present in all sites of one climate (Borcard et al., 2018). We checked for a significant association of families with the climate types by using a permutational test.

2.3.2.3 Association Between Traits and Environmental Variables

To analyze the association of traits with climate change-related environmental variables (hypothesis 3), we used Redundancy Analysis (RDA) given a gradient length of 1.37 in DCA (Legendre & Legendre, 2012), by using the insect assemblage trait profiles. As in CCA, stepwise model selection was used to identify the best-fit model.

2.4 Results

The literature search resulted in 766 publications, of which 724 were excluded after screening titles and abstracts (Figure A.1). Of the remaining 42 publications, we included 18 in our analysis that met the inclusion criteria (Table A.1). Most publications were excluded based on missing taxa lists or environmental parameters. The number of sites in the publications ranged from 1 to 28 (mean = 9.2). In total there were 165 sites covering a wide range of environmental conditions (Table 2.1). 91 sites were located in arid climate and 74 in temperate climate, of which 27 (36 %) are predicted to shift towards arid climate by 2071–2,100 (Figure 2.1).

2.4.1 Association Between Family Richness and Environmental Variables

The number of families per site ranged from 1 to 44 (mean = 15.72, SD = 10.33), with 96 families in total. Family richness was 37 % lower in arid (n = 91, mean = 12.44, SD = 7.39, median = 11) compared with temperate (n = 74, mean = 19.76, SD = 11.94, median = 19.5) climate (Welch's t-test, n = 165, t (116.47) = −4.6, p < 0.001) (Figure 2.2).

Variation in family richness was associated with altitude, flow regime, conductivity, cropland extent, degree of regulation, and water temperature. Family richness was lower in sites with higher altitude, higher regulation, higher conductivity, and intermittent flow, but increased with higher water temperature and larger extent of cropland areas (Table 2.2). The variables "Number of samples per site," "Global Aridity Index," "River area," and "Urban extent" were not included in the best-fit model.

Table 2.2. AIC model selection with regression estimates for the included environmental variables (altitude (Alt), Global Aridity Index (GAI), intermittent flow regime (Flow), conductivity (log-transformed; logCond), cropland extent (log-transformed; logCrop), degree of regulation (log-transformed; logReg), river size (log-transformed; logSize), number of samples per site (Samp), water temperature (Temp)), degrees of freedom (Df), Log-likelihood (LL), information score of the model (AIC), delta and AIC weight for all models within a delta of 2 (* = final model). Regression estimates with standardized variables are indicated in brackets for the final model.

Model	**574***	**576**	**830**	**638**	**62**
Intercept	3.48 (2.83)	3.02	3.32	3.76	3.76
Alt	-0.0002 (-0.13)	-0.0002	-0.0002	-0.0002	-0.0003
GAI	-	0.004	-	-	-
Flow	-0.42 (-0.42)	-0.4	-0.4	-0.4	-0.4
logCond	-0.12 (-0.16)	-0.1	-0.12	-0.13	-0.1
logCrop	0.06 (0.19)	0.05	0.05	0.06	0.06
logReg	-0.11 (-0.2)	-0.11	-0.11	-0.11	-0.1
logSize	-	-	-	0.03	-
Samp	-	-	0.01	-	-
Temp	0.02 (0.11)	0.03	0.02	0.02	-
Df	8	9	9	9	7
LL	-567.01	-566.11	-566.4	-566.82	-569.05
AIC	1150.9	1151.4	1152	1152.8	1152.8
Delta	0	0.43	1.01	1.85	1.86

2.4.2 Association Between Family Composition and Environmental Variables

The best-fitting CCA model for community composition included water temperature, number of samples per site, altitude, flow regime, conductivity, cropland extent, urban extent, Global Aridity Index, river area and degree of regulation. These variables explained 18 % of the variation, where 7.1 % of the total variation (39 % of constrained variation) was explained by the first two axes. Axis 1 shows a gradient of water temperature, conductivity, and aridity

(Figure 2.3). Axis 2 shows a gradient of number of samples per site and urban extent. Most insect families occurred in less arid sites with low or medium water temperature and conductivity (Figure 2.3) such as Ephemeroptera and Plecoptera. The family *Micronectidae* was associated with aridity and high water temperature and conductivity. Most families of Diptera occurred more frequently in sites characterized by a higher extent of croplands and urbanization. In the Indicator Species Analysis, one family (*Micronectidae*) was associated with arid climate and 33 (48%) families were associated with temperate climate (Table 2.3).

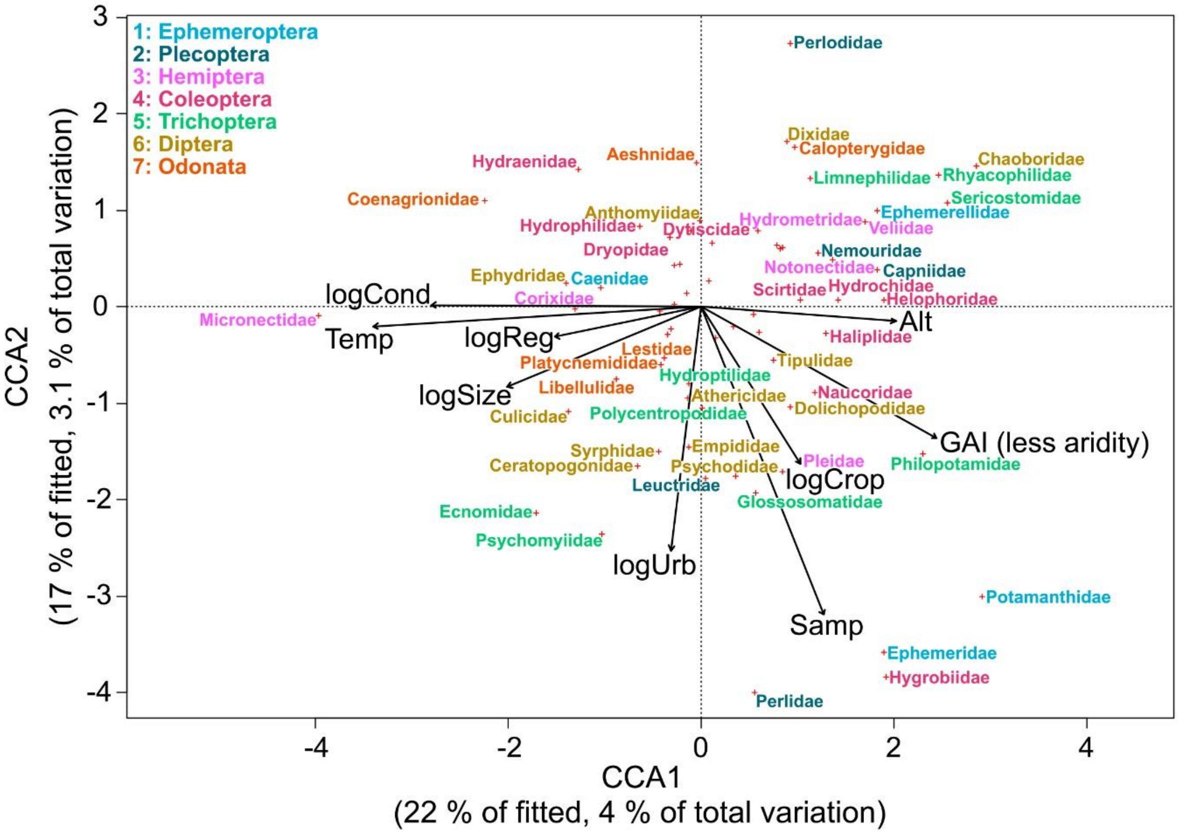

Figure 2.3. CCA ordination distance triplot (scaling 1) with the relationship of environmental variables (altitude (Alt), water temperature (Temp), conductivity (log-transformed; logCond), number of samples per site (Samp), river area (log-transformed; logSize), degree of regulation (log-transformed; logReg), urban extent (log-transformed; logUrb), cropland extent (log-transformed; logCrop), Global Aridity Index (GAI)), and aquatic insect families in Northwest Africa. To avoid cluttering, overlapping labels were omitted from the plot.

Table 2.3. Results of Indicator Species Analysis showing families associated with arid and temperate climate, test statistics and indicator value (IndVal).

Arid climate			Temperate climate					
Family	IndVal	p-value	Family	IndVal	p-value	Family	IndVal	p-value
Micronectidae	0.25	0.003	*Psychodidae*	0.42	<0.001	*Gyrinidae*	0.23	0.05
			Hygrobiidae	0.36	<0.001	*Limoniidae*	0.22	0.006
			Gomphidae	0.36	<0.001	*Ephemeridae*	0.21	0.01
			Leuctridae	0.34	<0.001	*Chironomidae*	0.21	0.01
			Tipulidae	0.32	<0.001	*Glossosomatidae*	0.21	0.01
			Perlidae	0.31	<0.001	*Rhyacophilidae*	0.21	0.01
			Nemouridae	0.31	<0.001	*Elmidae*	0.2	0.01
			Calopterygidae	0.3	<0.001	*Simuliidae*	0.2	0.02
			Potamanthidae	0.3	<0.001	*Mesoveliidae*	0.2	0.02
			Empididae	0.3	<0.001	*Notonectidae*	0.2	0.01
			Veliidae	0.28	<0.001	*Tabanidae*	0.19	0.02
			Ceratopogonidae	0.28	<0.001	*Dryopidae*	0.19	0.02
			Philopotamidae	0.27	<0.001	*Perlodidae*	0.19	0.02
			Syrphidae	0.27	0.005	*Heptageniidae*	0.19	0.02
			Anthomyiidae	0.26	<0.001	*Ephemerellidae*	0.18	0.03
			Haliplidae	0.25	0.001	*Athericidae*	0.17	0.05
			Polycentropodidae	0.24	0.003			

2.4.3 Association Between Traits and Environmental Variables

In the best-fitting RDA model, the assemblage trait profile was explained by conductivity, degree of regulation, water temperature, urban extent, aridity, and flow regime. These variables explained 19 % of the variation, of which 16 % of the total variation (82 % of the constrained variation) was explained by the first two axes. Axis 1 represents a gradient of conductivity urban area extent and degree of regulation (Figure 2.4), whereas axis 2 shows a gradient of water temperature, conductivity, degree of regulation, and flow regime. The traits “Life cycle duration,” “Reproduction,” and “Respiration” were mainly associated with axis 1, whereas “Potential number of cycles/year,” “Dispersal,” and “Food” were mainly associated with axis 2 (Figure 2.4).

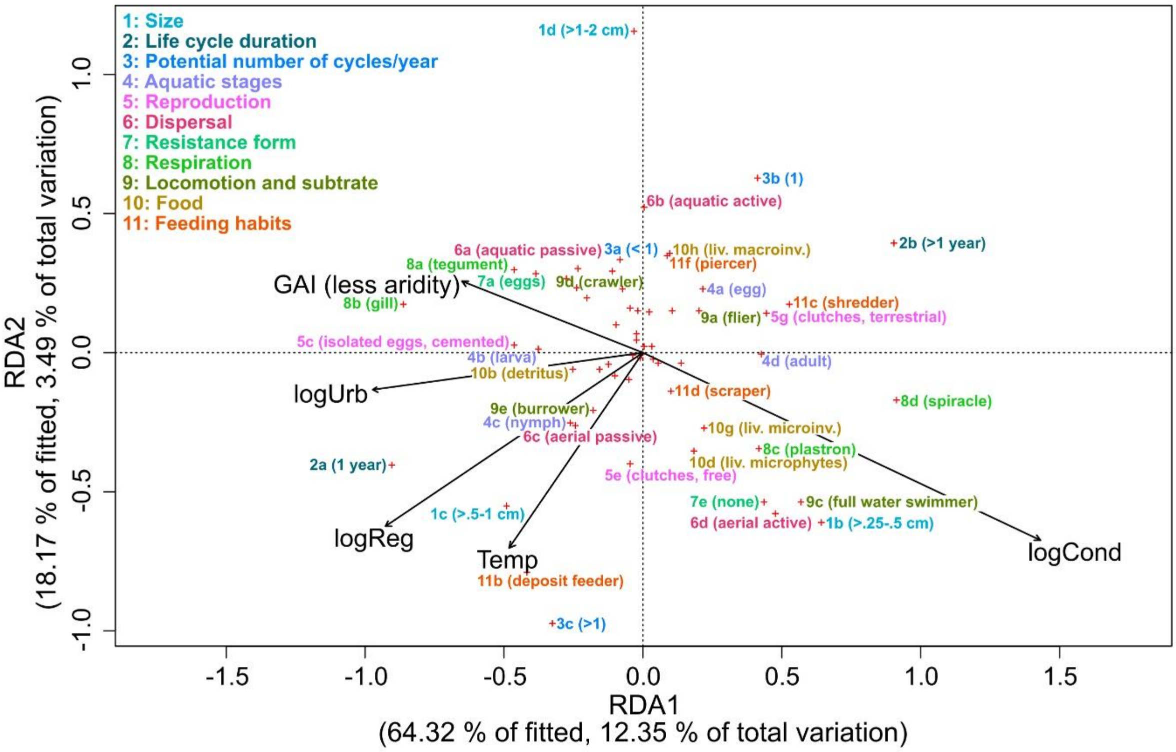

Figure 2.4. RDA ordination distance triplot (Scaling 1) with the relationship of environmental variables (conductivity (log-transformed; logCond), degree of regulation (log-transformed; logReg), water temperature (Temp) urban extent (log-transformed; logUrb), and Global Aridity Index (GAI)), and traits in Northwest Africa. Only traits that correlate strongly with the environmental variables are displayed with names.

2.5 Discussion

2.5.1 Association Between Family Richness and Environmental Variables

In Northwest Africa, large parts of temperate climate are predicted to turn to arid climate by the end of the century (Beck et al., 2018), and this will likely affect 36 % of the temperate sites in our study. On average family richness was 37 % lower in arid than in temperate climates, supporting our first hypothesis. Hence, the family richness of sites that will shift towards an arid climate will likely decrease over time. Although the loss of some families could be partly compensated by the invasion of other families adapted to arid environments, this may be insufficient to maintain the current level of richness (Dornelas et al., 2019; Morghad et al., 2019).

The loss of insect family richness was associated with a shift towards intermittent flow and higher conductivity. These findings are in accordance with several studies on macroinvertebrate richness in intermittent (Beauchard et al., 2003; Soria et al., 2017) and highly saline rivers (Velasco et al., 2006; Arribas et al., 2019; Berger et al., 2021). With the decrease of precipitation and the increase of evapotranspiration predicted in future climate scenarios for Northwest Africa (Terink et al., 2013), intermittency is likely to increase (Döll & Schmied, 2012). An increase in water and soil salinity can also be expected in association with droughts, as well as a reduction in flow due to human alterations of rivers, and water abstraction for irrigation of agricultural lands (Williams, 1999; Pitman and Läuchli, 2002; Herbert et al., 2015). This suggests future species loss. With family richness being on average

37 % lower in arid than in temperate sites, our model suggests that intermittent flow and increasing conductivity will play major roles in the loss of richness.

Water temperature increased insect family richness in our model, whereas altitude had a negative effect. We have hypothesized a decrease of insect families with rising water temperatures based on the assumption of impaired oxygen uptake in species lacking respiratory adaptations to cope with reduced oxygen, such as plastron and spiracle (Datry et al., 2017). The increase of family richness with increasing water temperature may be explained by the low family richness of high altitude streams with colder water temperature (Jacobsen, 2004) in our study. By contrast, other studies found an increase in family richness with altitude in Northwest Africa (Beauchard et al., 2003; Benzina et al., 2020), while abundance decreased (Benzina et al., 2020). In our dataset, we further saw a decrease of family richness in water temperatures that exceed around 20 °C. If rising water temperatures exceed the temperature tolerances of specific insect families, these could be threatened by local extinction (Dallas and Ketley, 2011).

Variables related to human activities, such as a higher degree of regulation, were negatively associated with insect family richness, while the extent of cropland showed a positive association. This is in line with previous findings that hydromorphological alterations of rivers can reduce macroinvertebrate richness (Martínez et al., 2013), due to reduced water quality, disconnection of river sections, and changes in flow regime (McAllister et al., 2001; Navarro-Llácer et al., 2010). Increasing water demand under climate change in Northwest Africa reinforces the importance of water reservoirs for agricultural and potable water use likely resulting in more water regulation (Ayt Ougougdal et al., 2020). This reflects a global trend of increasing river regulation putting freshwater biodiversity at risk (Zarfl et al., 2015). We were surprised to find a positive association between the extent of cropland and insect family richness because most studies suggest a negative impact of agricultural activities on family richness (Genito et al., 2002; Hepp et al., 2010). In our study, cropland areas were more frequently located in temperate areas with lower aridity, which may have masked the negative impact of agriculture.

We used family level data to study associations with environmental variables. Taxonomic richness at the species level and the use of abundance data could show stronger associations with environmental conditions and help to detect variability on a smaller scale (Leung and Dudgeon, 2011).

2.5.2 Association Between Family Composition and Environmental Variables

The Indicator Species analysis showed that nearly half of the insect families in our study were associated with temperate climate and only rarely or never occurred in arid climate, which is in line with the finding of reduced family richness in the latter. These families will likely be foremost affected by changing environmental conditions, whereas only a few families, like *Micronectidae*, seem to better tolerate arid conditions and could potentially profit from an extension of arid climate (Domisch et al., 2013). The occurrence of insect families is mostly associated with lower aridity, and lower to medium water temperatures and conductivity, explaining their absence in arid environments. Thus, local extinction of species by loss of suitable habitats in Northwest Africa could be minimized by limiting global warming to 1.5° C (Warren et al., 2018).

However, the variance explained by the CCA was relatively low, probably due to the variability of single species inside a family with species showing different associations with environmental variables. Missing stressors (such as local pollution and pesticides) which we did not cover in our model and biogeographic limitations in species distribution could further explain the low variance. As "number of samples per site" was also explaining the distribution of families, consistent sampling methods (e.g., AQEM Consortium (2002)) and the use of metabarcoding for species identification (Elbrecht et al., 2017) could help to overcome these problems.

While the orders of Ephemeroptera, Plecoptera, and Trichoptera (EPT taxa) were mainly associated with low aridity, low water temperature, and low conductivity, we saw a higher variability in the other insect orders. This matches the results of Díaz et al. (2008), where the EPT taxa were more associated with pristine mountain environments than with saline sites. Also, 12 out of 23 EPT families included in the analysis were associated with temperate climate in the Indicator Species Analysis, which suggests these taxa to be good indicators for measuring effects of present and future environmental changes (Wallace and Webster, 1996) in North Africa.

Climate conditions shifting along altitudinal gradients may increase the importance of high altitude habitats with low water temperatures as potential refuge habitats for lowland species (Walther et al., 2009). Insect families, such as *Capniidae*, were associated with high altitudes and low water temperatures. While species from lowland sites could escape increasing water temperatures by moving upwards to colder mountain streams, suitable habitats for families associated with high altitudes and low water temperatures in our analysis could get lost by changes in environmental conditions (Domisch et al., 2011; Domisch et al., 2013).

Our results suggest that many insect families benefit from agricultural and urban areas in the catchment. This could be due to rich food sources entering the river from the surrounding cropland (MacFarlane, 1983) and suitable conditions in areas of human settlements. Kietzka et al. (2018) found that the loss of most dragonfly species mainly affected endemics, while generalists can cope with the increase of anthropogenic land use. Similarly, other generalist insect species were found to better cope with the change in environmental conditions than endemic species (Domisch et al., 2013). However, we do not know if endemic species were less able to cope with environmental stressors in our case since we only looked at the family level.

Some aquatic insects such as the vector mosquito *Culex pipiens* transmit diseases like malaria, West Nile virus, and Zika virus (Farajollahi et al., 2011). In our analysis, the family *Culicidae* (mosquitoes) was positively correlated with higher water temperature and conductivity and thus may profit from climate change as was previously reported (Ramasamy and Surendran 2012). However, not all species within the family of *Culicidae* are vectors of diseases. Species level identification is required in future studies to better understand potential human health effects through an increase of disease-transmitting mosquitoes (Marselle et al., 2021).

2.5.3 Association Between Traits and Environmental Variables

Environmental conditions shape trait profiles of insect communities by acting as a filter (Statzner et al., 2001). In our study, conductivity, degree of regulation, water temperature, urban extent, aridity, and flow regime explained the differences in insect trait profiles. Similarly, conductivity and water temperature were among the most influential variables of trait profiles in a study from a Mediterranean semi-arid climate (Díaz et al., 2008).

Resilience traits can promote recolonization after natural events such as droughts (Leigh et al., 2016; Stubbington et al., 2017). The environmental variables related to arid climate, aridity, high water temperatures, and conductivity were associated with active aerial dispersal in Redundancy Analysis (RDA). Also, the degree of regulation was positively correlated to aerial dispersal. Aerial dispersal can promote recolonization and help to maintain local populations (Bogan et al., 2017). If large parts of rivers dry out, aquatic insects with the ability to fly, such as coleopterans and hemipterans, are the main colonizers (Díaz et al., 2008; Stubbington et al., 2017).

Resistance traits can help to cope with stressors such as drying rivers and high salinity (Leigh et al., 2016; Stubbington et al., 2017). In the RDA, full water swimmers, respiratory adaptations, and small body size were associated with aridity and high conductivity. The ability to swim (full water swimmers) becomes more important when flow recedes and river sections are separated (Datry et al., 2017) because it allows to reach food sources that are no longer transported by the water current. Due to a fast ion-uptake in saline water and lower oxygen levels in standing or slow running water of intermittent streams, special strategies of respiration are required (Kefford et al., 2016; Datry et al., 2017). In the RDA, adaptations that allow air breathing such as plastron and spiracle show to be associated with high conductivity and aridity (Chessman, 2015; Datry et al., 2017), whereas tegument and gill show the opposite affinity in the model. Resistance against droughts like housing against desiccation and terrestrial clutches also support survival in dry conditions (Díaz et al., 2008; Vidal-Abarca et al., 2013; Datry et al., 2017). However, these traits were non-responsive in our analysis to the environmental variables related to arid climate. Matching the concept of r-strategists (MacArthur & Wilson, 1967), smaller body size and a higher number of reproductive cycles per year were associated with an increase of arid environmental stressors, suggesting that these traits provide resistance in arid environments (Díaz et al., 2008; Stubbington et al., 2017).

With a change of environmental conditions towards arid environments with higher water temperature and conductivity, aquatic insect communities need to adapt to changing food sources by a change of feeding habits (Díaz et al., 2008). Similar to Díaz et al. (2008), we found a change of food sources from macroinvertebrates to microphytes, along a gradient of rising water temperatures and conductivity. Further, deposit feeders were associated with high water temperatures, which is in accordance with the river continuum concept (Vannote et al., 1980).

2.6 Conclusion

Our results show that a change towards hot and arid climate will likely reduce aquatic insect family richness in temperate regions of Northwest Africa. Climate change induced aridity, high water temperatures, high conductivity and intermittent flow could be intensified by a higher water demand and hydromorphological alterations. Droughts and reduced water quantity and quality could put various insect families, mainly endemics from temperate regions, at risk of local extinction. Traits that increase the ability to survive in arid environments (such as small size, aerial dispersal, ability for air breathing) increase the potential to cope with high water temperatures and conductivity, whereas species lacking such adaptations could be highly affected by a changing environment. A loss of family richness could lead to negative impacts on nature's contribution to human well-being. Protecting and restoring river ecosystems and promoting sustainable water use could limit species loss driven by climate change. Future studies should analyze abundances and use species level identification for a more refined assessment of climate change impact on local insect communities, which could be achieved using metabarcoding.

2.7 References

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Chapter 3

Macroinvertebrate community responses to salinity around non-saline – saline confluences in the Draa River basin, Morocco

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3.1 Abstract

Freshwater salinization increasingly threatens river ecosystems and their communities, especially in arid and semi-arid regions. However, large-scale geographic patterns make *in situ* studies of specific stressors challenging. To compare macroinvertebrate communities and their trait profiles in differing salinity levels, we conducted a confluence-based study in the Draa River basin in Morocco by focusing on two tributaries and their joint downstream sections, in the immediate vicinity of three confluences. Our study revealed that α-diversity differences were only minimal. Although only around five taxa comprised over 90 % of specimens in each section, the more saline sections exhibited a higher proportion of salt-tolerant generalist species. There was lower β-diversity between the joint downstream section and each tributary compared to between tributaries, indicating a mixed community after the confluence. The trait profile of the saline El Mellah displayed a greater abundance of resistance and resilience traits to disturbances than that of the less saline Iriri. Furthermore, our findings indicated that flow influenced community composition. Overall, we observed minimal differences in macroinvertebrate community composition, due to a low γ-diversity in the basin. However, the confluence-based study design remains valuable for investigating the effects of specific stressors on ecosystems by excluding large scale patterns.

3.2 Introduction

Despite increasing scientific interest in the issue of freshwater salinization in recent years, there are still significant knowledge gaps on the effects of salinity on ecosystems, particularly in less studied regions such as Africa (Cunillera-Montcusí et al., 2022). Saline rivers are common in semi-arid and arid regions with endorheic basins, and result from so-called primary salinization; the release of salts from rocks and soils into the water, followed by solar evaporation (Warner et al., 2013; Williams, 1999). Increasingly arid conditions induced by climate change (Beck et al., 2018) and anthropogenic activities (i.e., secondary salinization), such as the use of saline freshwater for irrigation, cause further salinization of the rivers. This is posing a growing threat to ecosystems, their functions and services, and human well-being, by diminishing the quality and usability of water and impacting aquatic communities through a loss of saline-sensitive species or a change in the community composition (Berger et al., 2018; Cañedo-Argüelles et al., 2013; Cañedo-Argüelles et al., 2016; Cunillera-Montcusí et al., 2022; Herbert et al., 2015; Hssaisoune et al., 2020; Kaczmarek et al., 2023; Williams, 1999).

Macroinvertebrates play a crucial role in river ecosystems (Wallace & Webster, 1996), yet high salinity can negatively impact them at individual, population, community, and ecosystem levels (Cañedo-Argüelles et al., 2013). High salinity levels limit macroinvertebrate development, growth, and fertility by increasing stress and the energy required for osmoregulation (Cañedo-Argüelles et al., 2013; Kefford et al., 2016). Variations in species' responses to elevated salinity levels alter the composition of the entire community (Cañedo-Argüelles et al., 2013), resulting in a decline in abundance, or local extinction, of sensitive taxa and an advantage for salt-tolerant species that may benefit from reduced competition and predation (Kefford et al., 2016; Velasco et al., 2006). Resistance and resilience traits for adaptation to high salinities, such as small body size, multi-voltinism, and ovoviviparity, promote survival in saline conditions (Díaz et al., 2008; Kaczmarek et al., 2021; Piscart et al., 2006). Additionally, a lower abundance of scrapers and piercers and higher abundance of filter and deposit feeders have been associated with higher salinity levels (Piscart et al., 2006).

Tributaries with lower salinity levels in saline river basins serve as important refuges for salt-sensitive species (Benson et al., 2019; Robson et al., 2013), and often exhibit distinct macroinvertebrate community compositions compared to their saline counterparts (Kefford, 1998). They also play a role in reducing downstream salinity through dilution. However, water withdrawals for agricultural use and the return of salinized water (Thorslund et al., 2021) can compromise their ability to dilute and to serve as refuge. On the other hand, naturally saline ecosystems harbor unique species adapted to high salinities that can colonize habitats affected by secondary salinization (Kefford et al., 2016; Velasco et al., 2006). Therefore, it is essential for the conservation of macroinvertebrate communities to consider protecting both fresh and saline rivers (Cañedo-Argüelles et al., 2013; Cañedo-Argüelles et al., 2016) and the connectivity of entire stream networks of a basin.

The composition of macroinvertebrate communities is shaped by multiple environmental conditions, such as differences in climate, the presence or absence of different mineral and organic substrates, and anthropogenic impacts such as pollution. Such environmental conditions change naturally, especially on a large geographic scale (i.e., river basin wide changes in habitat characteristics; Heino et al., 2004; Kefford, 1998). Laboratory or mesocosm experiments can be used to study the effects of specific stressors on biotic communities in isolation of confounding factors. However, they can only reflect the natural environmental conditions to a certain extent and results are often influenced by the selection of the initial community composition (Kefford et al., 2021). Therefore, results do not necessarily predict effects in natural ecosystems (Kefford et al., 2023). Kefford (1998) implemented a paired difference design to study the effect of salinity on the dissimilarity between macroinvertebrate communities *in situ* at closely-spaced pairs of saline and non-saline tributaries. In his study design, macroinvertebrate communities were not influenced by large scale geographic patterns. Therefore, the design proved to be useful for investigating dissimilarities in community structure associated with electrical conductivity (Kefford, 1998).

Following the study design of Kefford (1998), we conducted an *in situ* study in the Draa river basin in southern Morocco with the aim of providing further insights into the effects of salinity on the composition of macroinvertebrate communities and their trait profiles in the immediate vicinity of confluences, while excluding large scale geographic patterns. To do so, we compared the macroinvertebrate communities at two confluences with tributary pairs of similar size but differing salinity levels and one confluence with tributaries of similar salinity levels. In contrast to Kefford (1998), we also included the joint downstream section of each confluence to receive additional insights into community responses after the two tributaries merge, as intermediate salinity levels, dispersal-related processes (e.g., dispersal from source sites), and macroinvertebrate drift could result in a combination of communities (Cellot, 1996; Heino, 2013).

We hypothesize (1) that the tributaries with higher electrical conductivity show lower macroinvertebrate taxon richness compared to the less saline tributaries, due to the exclusion of salt-sensitive taxa that are not able to survive or complete their life cycles in saline environments (Kefford et al., 2016). We further hypothesize (2) that beta-diversity between upstream macroinvertebrate communities is higher than between up- and downstream communities, based on the coexistance of salt-tolerant and salt-sensitive taxa, dispersal-related processes, and source-sink dynamics (Cellot, 1996; Heino, 2013; Velasco et al., 2006). We expect community composition consisting of more and a higher abundance of generalist taxa (e.g., Diptera, Coleoptera, Hemiptera) adapted to saline conditions in the more saline tributaries, while we expect to find more sensitive taxa (e.g., sensitive taxa of Ephemeroptera and Trichoptera) in the less saline tributaries (Kefford et al., 2016). Therefore, we hypothesize (3) that we find a larger proportion of traits associated with resilience and resistance to disturbances (e.g., smaller size and multivoltine species) in the trait profiles of the macroinvertebrate communities of the more saline tributary, compared to the less saline one, as these traits are needed to guarantee survival in saline environments (Díaz et al., 2008).

3.3 Materials and Methods

3.3.1 Study area

The Draa River flows through a semi-arid to arid basin in southern Morocco, situated south of the High Atlas Mountains and originates in the Barrage El Mansour Eddahbi (BEME) reservoir (Figure 3.1). Tributaries to the BEME reservoir in the Upper Draa basin, such as the rivers Dades, M'Goun, and Iriri typically have low levels of salinity. An exception is the saline El Mellah river, which can reach electrical conductivity (EC) levels of up to 20,000 µS/cm through primary salinization from the release of ions from rocks and soils into the water (Warner et al., 2013; own measurements). Tributaries to the Draa River downstream of the BEME reservoir, such as Tissint river, generally have higher salinity levels due to an increasingly arid climate in the lower reaches of the basin close to the Saharan desert and processes of secondary salinization (Warner et al., 2013).

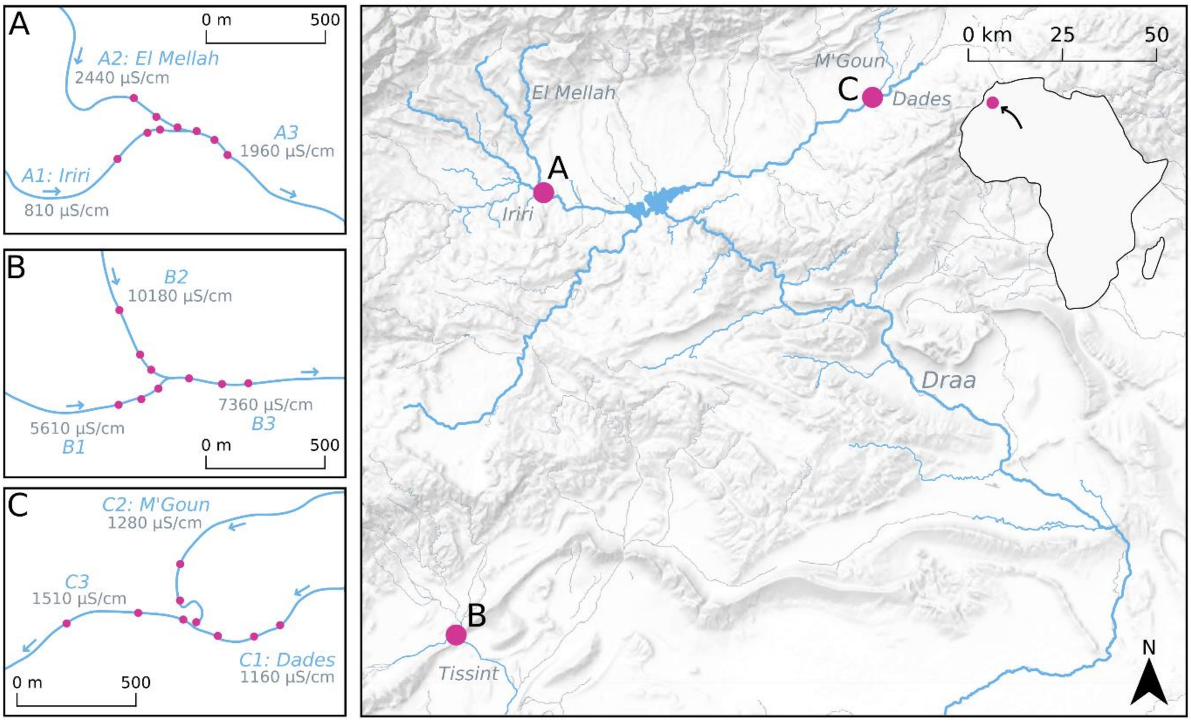

Figure 3.1. Map of the three confluences in the Draa river basin showing the nine sites per confluence with mean EC values per section (A: Iriri / El Mellah; B: Tissint; C: Dades / M'Goun) (terrain-basemap: © EOX).

3.3.2 Site Selection

Two confluences in the Draa river basin were selected, with tributaries per confluence characterized by similar flow rate and differing EC levels (Figure 3.1). In the first confluence (A, altitude = 583 m), the mean EC levels were 810 ± 60 µS/cm (A1) and 2440 ± 280 µS/cm (A2). In the second confluence (B, 1191 m), the mean EC levels were 5610 ± 20 µS/cm (B1) and 10180 ± 1150 µS/cm (B2). A third confluence (C, 1357 m) was selected, characterized by similar EC levels (1160 ± 200 µS/cm (C1) to 1280 ± 20 µS/cm (C2)) for the tributaries, but the flow rate varied by 13.4 times (0.014 to 0.188 m^3/s). Due to changes of habitat characteristics within small distances, we selected three 50-meter-long sites within each tributary (A1, B1, and C1 with lower and A2, B2, and C2 with higher salinity; Figure 3.1) and downstream section (A3, B3, C3). Distances between sites ranged between 50 and 300 meters (Figure 3.1). Sites were selected to be comparable to the sites selected in the other sections of each confluence (e.g., comparable low and high flow sites in A1, A2, and A3) and pooled afterwards to account for a larger variety of site conditions per section. Sampling took place in June 2022 and September/October 2022. A prolonged dry period followed by a strong flood, prevented sampling in September/October at the confluence C.

3.3.3 Environmental parameters

Physical and chemical parameters and stream bed characteristics were measured to describe the river sites and to detect differences in habitat characteristics. A multi-parameter meter (WTW MultiLine® Multi 3510 IDS) was used to measure water temperature, pH, and EC. River width and depth were measured using a tape measure. Flow velocity was measured using a hydrological impeller (SEBA Hydrometrie) and subsequently combined with the area of the cross profile to calculate flow rate. We used a MACHEREY-NAGEL VISOCOLOR reagent case with the photometer PF-12Plus and VISOCOLOR Eco colorimetric test kits to measure ion composition in field, measuring chloride (Cl^-), sulfate (SO_4^{2-}), nitrate (NO_3^-), nitrite (NO_2^-), ammonium (NH_4^+), orthophosphate (PO_43^-), potassium (K^+), total hardness (TH) and carbonate hardness (CH). Concentrations of nitrate, nitrite, ammonium, orthophosphate, and potassium lower than 4, 0.02, 0.1, 0.6, and 2 mg/l, respectively, were below detection level. If a value was below detection level, we used half of the detection level (see Clarke, 1998). Ion composition was measured in the midstream sites of each section, only. Additionally, stream bed characteristics were assessed at all sites by estimating percentages of coverage for mineral (megalithal (> 40 cm), macrolithal (> 20 - 40 cm), mesolithal (> 6 - 20 cm), microlithal (> 2 - 6 cm), akal (> 2 mm - 2 cm), psammal/psammopelal (> 6 µm - 2 mm)) and organic (algae, macrophytes) substrates. Flow measurements are missing for two sites and nitrate and sulfate values for September/October due to technical issues.

3.3.4 Macroinvertebrates

Macroinvertebrates were sampled using a 25 x 25 cm Surber sampler (mesh size 500 µm). Quantitative samples were taken at 10 spots per site which were selected to cover all microhabitats based on the proportion of microhabitats in a 50-m reach. The samples were conserved in 95 % ethanol. Taxa were identified to species level, except for Diptera (family or subfamily), Odonata (family or genus), some Crustacea (order), some Mollusca (genus), Annelida (sub-class), and Tricladida (class). For each taxon, the number of specimens were counted.

We calculated α- (taxon richness for each section), β- (number of taxa of two sections that are unique to only one of them), and γ-diversity (taxon richness at confluence) for the three confluences for each season and all seasons summarized. Additionally, we calculated the ratio of the generally more sensitive Ephemeroptera and Trichoptera to the generally more tolerant Diptera, Coleoptera, Odonata, and Hemiptera taxa (Kefford et al., 2016).

We calculated the IBMWP (Iberian biological monitoring working party; Jáimez-Cuéllar et al., 2002) and IBGN (Indice Biologique Global Normalisé; Archaimbault & Dumont, 2010) to indicate differences in the presence of sensitive taxa. These multi-metric biotic indices describe the biological quality of rivers by using indicator organisms. Sampling methods differed from the methods described in the protocols of each index.

We performed non-metric multidimensional scaling analysis (NMDS; two dimensions, 50 runs) to check for similarities of macroinvertebrate communities between confluences and seasons using log-transformed (log(x+1)) abundance data and Bray-Curtis distance. We used R v.4.0.4 (R Core Team, 2021) and RStudio (version 1.2.5019) with the packages "ggplot2" (Wickham, 2011) and "vegan" (Oksanen et al., 2019).

3.3.5 Trait profiles

To compare adaptations in biological traits associated with resilience and resistance to disturbances of the macroinvertebrate communities (Bonada et al., 2007), we used the trait database of Tachet et al. (2010) to obtain information for the macroinvertebrate taxa, including 11 biological traits with 62 modalities (Table B.1). For each of these biological traits, different trait modalities are defined and the affinity of the taxa to each trait modality is represented by fuzzy coded scores (0 = no affinity, 1 = low affinity, 2 = moderate affinity, 3 = high affinity). These codes were transformed to relative frequencies for a given taxon. For each section, we calculated a macroinvertebrate community trait profile based on the relative frequencies of trait modalities for each taxon and the log-transformed (log(x+1)) abundance data (to reduce the weight of abundant taxa) at a given section, by taking the sum for each trait modality from all present taxa and transforming these sums into relative frequencies for each trait (similar to Mondy et al, 2016). If traits were defined for a lower taxonomic level than the level to which we identified the taxon, we assigned the traits of the lower levels using mean values for all available taxa (Kunz et al., 2022). Trait information of *Melanopsis cariosa* was added based on Bonada & Dolédec (2011). Trait information was missing for four out of 38 taxa. These taxa were not considered for the calculation of the macroinvertebrate community trait profiles.

3.4 Results

3.4.1 River section characteristics

High EC in tributaries was associated with high concentrations of major ions (chloride, sulfate, and potassium), while intermediate concentrations were observed after the confluences (Table B.2 and Figure B.1). Other ion values were mostly close to or under detection level. Water temperature and pH were similar among sites at each confluence. The percentage of coverage of mineral and organic substrate, width, depth, and flow velocity differed between sites within a section, with habitat changing within a few hundred meters. Therefore, site samples per section were pooled (see section "Site selection").

3.4.2 Macroinvertebrate community composition

We found 38 taxa (γ-diversity overall), with the highest number of taxa (γ-diversity per confluence) at the least saline confluence C (Dades / M'Goun) and lowest in the most saline confluence A (Tissint; Figure 3.2). Taxon richness (α-diversity) was only slightly higher in the less saline tributaries than in the more saline ones and the joint downstream sections for the confluences A and B (Iriri / El Mellah). α-diversity was only slightly higher in the lower flow tributary C1 than in C2. Communities showed only slightly more unique species (β-diversity) between the two tributaries than between each tributary and the joint downstream section. The ratio of Ephemeroptera and Trichoptera to Diptera, Coleoptera, Odonata, and Hemiptera taxa was lower in the more saline than in the less saline tributaries of the confluences A and B, with the joint downstream sections showing higher or intermediate values (Table 3.1). All these trends varied sometimes within the two sampling seasons (Figure 3.2) and taxon richness varied between the up-, mid-, and downstream sites per section (Table B.2 and B.3).

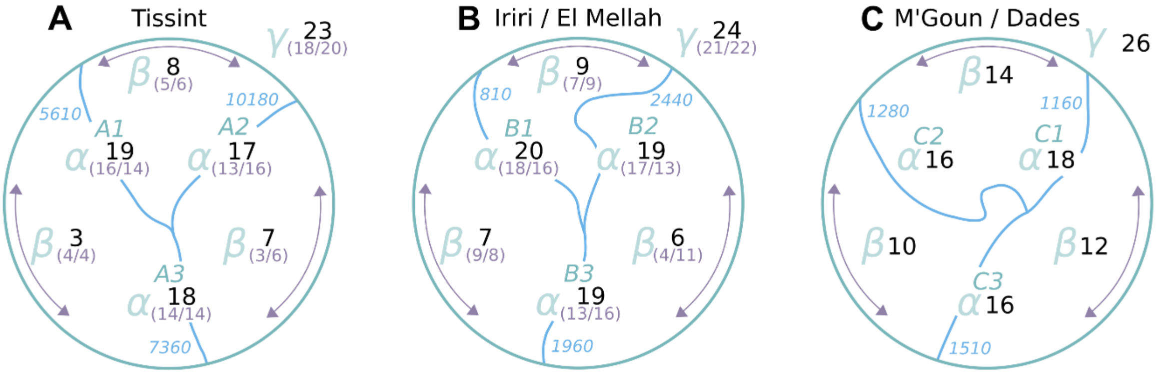

Figure 3.2. α-, β-, and γ-diversity at the three confluences. α- and γ-diversity (per section; γ-diversity overall = 38) describe taxon richness, β-diversity describes the number of taxa for two sections, which are unique to only one of them. Numbers in brackets represent diversity values for the first/second sampling. Numbers at river lines indicate electrical conductivity in µS/cm.

Table 3.1. Percentage of Ephemeroptera, Trichoptera (%ET), percentage of Diptera, Coleoptera, Odonata, and Hemiptera (%DCOH), their ratio (ET/DCOH), IBMWP, and IBGN for the sections at each confluence.

Confluence/Section	%ET	%DCOH	ET/DCOH	IBMWP	IBGN
A (Tissint)					
A1	36.8	42.1	0.9	56	10
A2	29.4	41.2	0.7	60	10
A3	38.9	38.9	1.0	63	10
B (Iriri / El Mellah)					
B1 (Iriri)	35.0	35.0	1.0	71	10
B2 (El Mellah)	31.6	47.4	0.7	65	10
B3	36.8	42.1	0.9	62	10
C (Dades / M'Goun)					
C1 (Dades)	33.3	61.1	0.6	58	10
C2 (M'Goun)	37.5	43.8	0.9	56	9
C3	56.3	37.5	1.5	50	9

Non-metric multidimensional scaling analysis (NMDS) revealed a distinct macroinvertebrate community for confluence A, while C showed similarities with B (Figure 3.3). A shift of communities can be seen from June to September/October, which was smaller for the confluence A (Figure 3.3).

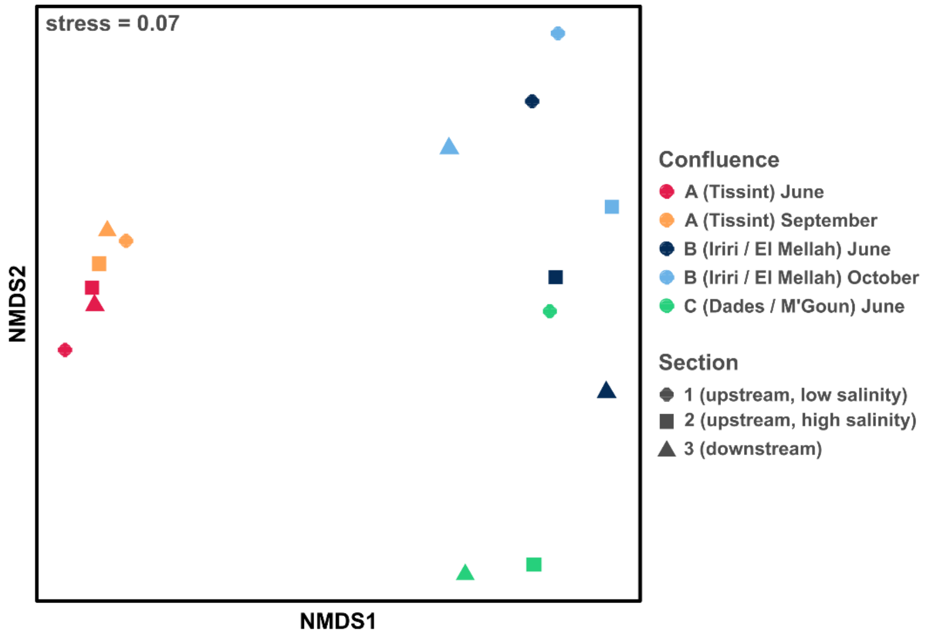

Figure 3.3. Non-metric multidimensional scaling analysis (NMDS; 2 dimensions, n = 59, Bray Curtis Distance with log-transformed (log(x+1)) abundance data) for macroinvertebrate communities for all sections in the two seasons.

At each section 91.2 ± 2.2 % of the total number of specimens made up only 5 ± 1.1 taxa, while only 8.8 ± 2.2 % of the community contained 13 ± 1.3 taxa (Figure 3.4). While the freshwater snail *Melanopsis cariosa* and the *Chironomidae* subfamily *Orthocladiinaea* made up a large proportion of specimens of the less saline tributary (A1; 5613 µS/cm) of confluence A, the more saline (A2; 10177 µS/cm) and downstream sections (A3) were characterized by a higher abundance of the Ephemeropterans *Caenis luctuosa* and *Baetis pavidus*. These two Ephemeropterans also made up large parts of the communities in the confluences B and C. *Simulium* sp. and Tricladida were present in the less saline B1 (807 µS/cm), whereas Oligochaeta were present in the more saline B2 (2442 µS/cm). C1 (1160 µS/cm) showed three abundant species, of which *Caenis luctuosa* represented 78 % (Figure 3.4). The number of specimens was similar in the two tributary sections for the confluences A and C, but lower in the joint downstream section. In the confluence B, the number of specimens was lower in the more saline tributary (B2), while it was similar in the other two sections (Figure 3.4).

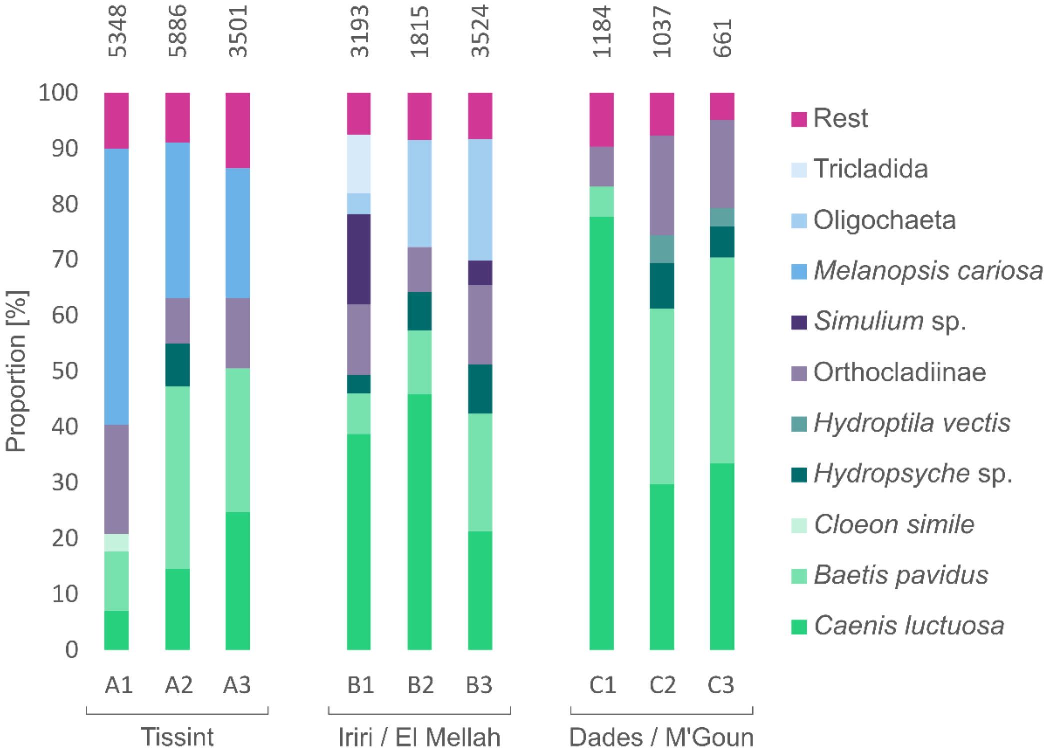

Figure 3.4. Proportion of most abundant taxa (> 3 %) for the two tributaries and the joint downstream section at the three confluences. Numbers above bars represent the total number of specimens in each section. "Rest" contains 11 to 15 taxa for each site.

The highest IBGN scores were ten out of 20, mostly with no consistent differences between sections (Table 3.1). The ecological status by IBWMP was moderate to good. Only small differences were observed for the confluence A, while the less saline section B1 attained a higher score than the more saline B2 and their joint downstream section (B3; Table 3.1).

3.4.3 Trait profiles

Differences in trait profiles per confluence were generally small (Figure 3.5; Figure B.2). The trait profile of B1 indicated macroinvertebrate communities with taxa of larger sizes, longer life cycle duration, less cycles per year, no respiration through plastron, and a higher presence of taxa that use living micro- and macroinvertebrates as a source of food compared to B2 and B3 (Figure 3.5). Differences tended to be smaller for the other traits and at the other confluences (Figure 3.5; Table B.1 and Figure B.2).

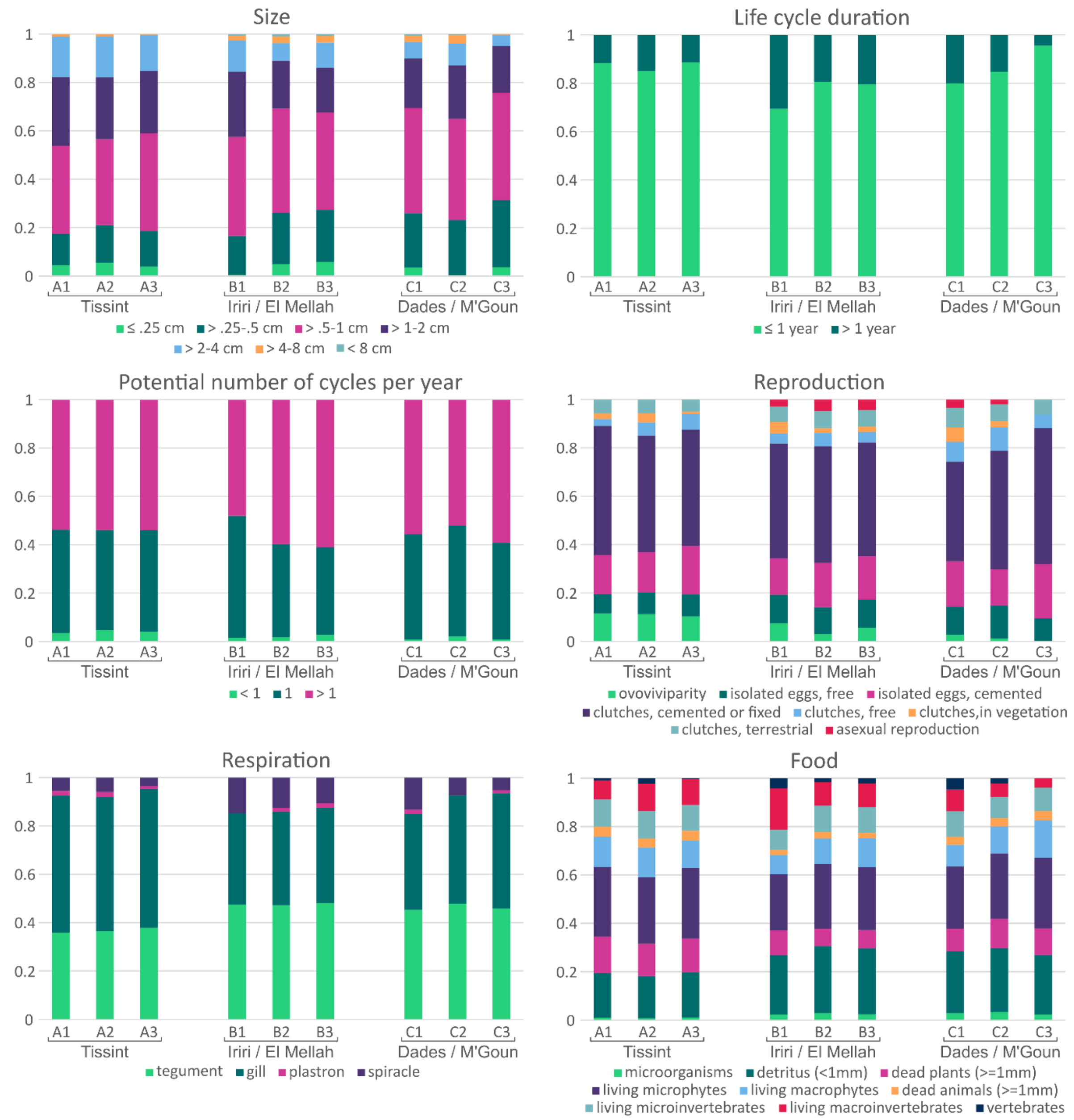

Figure 3.5. Proportion of trait modalities (for all traits see Figure B.2) for the two tributaries and the joint downstream section at the three confluences.

3.5 Discussion

We observed only a slightly lower α-diversity in the more saline tributaries. However, differences only consisted of one to three taxa and were not congruent over both seasons. Therefore, the hypothesized lower taxon richness in the more saline tributaries could not be confirmed. The generally low α-diversity per section in the entire study area, which aligns well with the results of other studies conducted in arid regions of Northwest Africa (Kaczmarek et al., 2021), is likely the reason for the minor differences between sites. The observed low taxon richness can largely be attributed to the mostly high aridity levels in the basin, which increase towards the Saharan desert (Beauchard et al., 2003; Kaczmarek et al., 2023; Warner et al., 2012). Only minimal differences in macroinvertebrate community composition between sections in the most saline and least diverse Tissint confluence indicate a salinity-adapted community, while greater differences were found in the less saline and more diverse tributaries. The stressful habitat conditions of naturally saline rivers in arid regions are also indicated by generally low scores of the multimetric biotic indices IBMWP and IBGN (Kaczmarek et al., 2023). Inconsistent differences between less and more saline tributaries can be explained by the absence of sensitive taxa (e.g., sensitive Plecoptera, Ephemeroptera, and Trichoptera) associated with high index scores (Archaimbault & Dumont, 2010; Jáimez-Cuéllar et al., 2002). This indicates a macroinvertebrate community that largely consists of salt-tolerant generalist taxa (e.g., Oligochaeta), which can withstand increased salinity levels (Wolf et al., 2008). This is also reflected by a lower ratio of generally more salt-sensitive Ephemeroptera and Trichoptera to more salt-tolerant Diptera, Coleoptera, Odonata, and Hemiptera taxa (Kefford et al., 2016), which we observed for the more saline tributaries. However, low scores in the indices do not necessarily indicate poor environmental conditions due to anthropogenic activites, as aridity and salinity are largely induced by natural processes in the region (Warner et al., 2013) and, hence, largely describe the natural state of the river ecosystem (Velasco et al., 2006). To detect anthropogenic impacts (e.g., secondary salinization and pollution) in saline and intermittent rivers, specific indices should be developed and indicator organisms should be identified (Arias-Real et al., 2022; Gutiérrez-Cánovas et al., 2019).

Only around five dominant taxa per section made up more than 90 % of the total number of specimens of the whole community, mainly composed of generalist and dominant species that can withstand high salinity levels, such as the salt-tolerant ephemeropterans *Caenis luctuosa* and *Baetis pavidus*, the trichopteran *Hydropsyche* sp., or the Oligochaete (Arribas et al., 2019; Benlasri et al., 2023; Berezina, 2003; Kefford, 1998; Pond, 2012; Samraoui et al., 2021; Wolf et al., 2018). Saline ecosystems favor generalist and salinity specialist species that can survive in conditions of high salinity as resources are freed up by the loss of salt-sensitive species (Kefford et al., 2016; Velasco et al., 2006). In the saline tributaries, we observed proportionally more specimens of the abovementioned taxa, while salt-sensitive taxa (e.g., *Cloeon simile*, Tricladida, *Melanopsis cariosa* (Benlasri et al., 2023; Piscart et al., 2011; Velasco et al., 2006)) were absent or decreased proportionally.

Similar to Kaczmarek et al. (2021), our results suggest a loss of salt-sensitive taxa in the future, as they were not present in the more saline El Mellah and the confluence of Tissint, located in highly arid climate. The increasingly arid climate (Beck et al., 2018) and ongoing primary and secondary salinization will lead to increasingly harsh habitat conditions and highlight the importance of limiting global warming and of protecting aquatic ecosystems from the consequences of climate change and salinization (Cañedo-Argüelles et al., 2013; Schuler et al., 2019). Biodiversity loss can disrupt ecosystem functioning and resilience (Lecerf and Richardson, 2010; Peterson et al., 1998), and can result in a decrease in ecosystem health and human well-being (Kaczmarek et al., 2023). Specifically, salt-sensitive taxa with low abundances may be at risk. However, it is also important to consider protecting naturally saline ecosystems that harbor unique species adapted to high salinities (Velasco et al., 2006). These species' abilities to colonize impaired habitats (Kefford et al., 2016) can help to maintain ecosystem functions (e.g., decomposition; Wallace & Webster, 1996) and the health of salinized ecosystems in the future. Therefore, protecting saline ecosystems should be considered in future policies and action plans (Kaczmarek et al., 2023).

We found, in accordance with our second hypothesis, that the dissimilarities between macroinvertebrate communities (β-diversity) were lower between each tributary and the downstream section than between the two tributaries, indicating a combination of communities downstream from the confluence. However, again, differences were only small, not always congruent over seasons, and should, therefore, be treated with caution. The intermediate levels of salinity in the joint downstream section may have allowed for the coexistance of salt-tolerant and salt-sensitive species, as explained by Velasco et al. (2006). Another explanation for the lower β-diversity between the downstream section and each tributary is the immigration of species by macroinvertebrate drift, which could have led to a higher number of taxa being brought downstream with the current due to high salinity levels upstream (Beermann et al., 2018; Cellot, 1996). Given the higher β-diversity between the two tributaries, an immigration of taxa by drift from the tributaries would likely result in highest α -diversity after the confluence, which we did not observe. However, the study area was limited to just a few hundred meters around the confluence. Expanding the area up- and downstream could provide a better understanding of the transition and turn-over of macroinvertebrate communities around non-saline – saline confluences and allow for conclusions about the presence of macroinvertebrates due to drift or source-sink dynamics (Heino, 2013). Therefore, we expect that a confluence-based study design, with the extension of the study area, could provide further potential to study the effects of salinity and other stressors on macroinvertebrate communities, especially in terms of metacommunity concepts (Cunillera-Montcusí et al., 2022; Heino, 2013). Difficulties, however, include the identification of confluences that suit the study design (i.e., the stressor of interest) and differences in habitat conditions (e.g., flow and substrate) between the tributaries and between sites in each tributary.

Stronger adaptations for resistance and resilience to disturbances were observed for macroinvertebrate communities in the more saline El Mellah and the joint downstream section, compared to the less saline Iriri, which is in accordance with our third hypothesis. These adaptations included smaller body size and shorter life cycles, which are typical of r-strategists and promote survival in harsh environments (Díaz et al. 2008; Kaczmarek et al. 2021). The expected higher abundance of filter and deposit feeders in the more saline sections was only minimal in El Mellah compared to Iriri (Piscart et al., 2006). Differences in trait profiles were generally small, especially in the Tissint river sections. As EC here exceeds 5600 µS/cm in the less saline tributary, the community of all sections seems to show adaptations to salinity such as small life cycle duration, ovoviviparity and air breathing via plastron (Kaczmarek et al., 2021). The macroinvertebrate community of Dades showed more resistance and resilience adaptations compared to that of M'Goun, which might be related to low flow conditions at Dades. Low flow conditions also favor a higher number of cycles per year and air breathing, which support survival in arid conditions (Kaczmarek et al. 2021; Stubbington et al. 2017). For the creation of the community trait profiles, we had to aggregate traits for a large part of the taxa, as trait data for some taxa was not available in the database of Tachet et al. (2010). The availability of trait data for the species present in our arid study area could have resulted in larger differences of trait profiles between saline and non-saline tributaries. This highlights the need to complete databases on macroinvertebrate salinity tolerances and traits, especially in understudied regions (Cunillera-Montcusí et al. 2022; Schäfer et al. 2011).

Our study shows that the macroinvertebrate communities underwent seasonal changes during the hot and dry summer period, as it was observed in various studies (Dallas, 2003; Eriksen et al., 2021). It should be noted that not all observations described above were consistent across seasons. Seasonal dissimilarities can be explained by varying life history strategies such as the timing of hatching and emergence, which could lead to the presence (e.g., Ostracoda in Tissint) or absence (e.g., Hydracarina in Iriri / El Mellah) of seasonal species in the second sampling in September/October (Ferguson, 1944; Meyer, 1994). We observed a significant increase in the abundance of *Simulium* sp. (Iriri) and *Caenis luctuosa* (Tissint) during the dry summer period. These findings highlight the importance of considering seasonal variability in studies and biomonitoring of macroinvertebrate communities (Johnson et al., 2012).

We observed only small trends in α- and β-diversity in response to salinity, which, in addition to the overall low diversity of the community, is probably also due to the difficulty of excluding confounding factors and not necessarily to the absence of effects. It is difficult to completely exclude the influence of other environmental parameters in *in situ* studies, as described by Heino et al (2004) and Kefford (1998). To mitigate the impact of habitat conditions (Kefford, 1998), we covered different habitats by pooling three sites per section. However, we observed a large difference in community composition between Dades and M’Goun, which were similar in salinity levels, but differed in flow rate and velocity, caused by a prolonged drought in recent years and water abstractions upstream of the Dades site. Low flow conditions influence the macroinvertebrate community and cause higher drift propensities (Beermann et al., 2018; Heino et al., 2004). Although Dades showed the highest α-diversity due to generally good water quality in the region (Kaczmarek et al., 2023), its community exhibited higher dissimilarity compared to M’Goun and the joint downstream section, and nearly four-fifths of the whole specimens belonged to the generalist species *Caenis luctuosa*. Furthermore, both Dades and M'Goun dried up completely in August due to a drought. We also had to omit a fourth confluence with large differences in EC (3890 – 19330 µS/cm) from our study, as one of the tributaries was falling dry due to upstream water abstractions. These events caused issues for our study and highlight the increasing impact of climate change in the region, which will increase the pressure on water resources and compromise ecosystem health and human well-being (Kaczmarek et al., 2023).

3.5.1 Conclusion

Our study found only small differences between macroinvertebrate communities and their trait profiles from more and less saline tributaries, if any at all. However, larger differences were found between confluences on a large scale (e.g., Dades / M’Goun in higher altitude and Tissint towards the desert). Despite this, we believe that a confluence-based study design remains valuable for investigating the effects of specific stressors on macroinvertebrate community composition, as it enables the comparison of community responses while excluding these large-scale geographic patterns. The impact of salinity is likely more pronounced in river basins with more diverse communities that do not show any pre-adaptation to salinity and aridity. To build upon our findings, we suggest extending the study area up- and downstream to explore metacommunity concepts such as macroinvertebrate drift and source-sink dynamics. However, finding comparable rivers with similar habitat and flow characteristics may prove challenging. It is crucial to gain a better understanding of macroinvertebrate salinity tolerances and their resistance and resilience traits through the extension of global databases. This knowledge, coupled with efforts to limit future secondary salinization, will help to understand and efficiently protect river ecosystems worldwide.

3.6 References

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Chapter 4

Water quality, biological quality, and human well-being: Water salinity and scarcity in the Draa River basin, Morocco

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4.1 Abstract

River ecosystems are being threatened by rising temperatures, aridity, and salinity due to climate change and increased water abstractions. These threats also put human well-being at risk, as people and rivers are closely connected, particularly in water-scarce regions. We aimed to investigate the relationship between human well-being and biological and physico-chemical river water quality using the arid Draa River basin as a case study. Physico-chemical water measurements, biological monitoring of aquatic macroinvertebrates, and household surveys were used to assess the state of the river water, ecosystem, and human well-being, as well as the associations between them. Salinity levels exceeded maximum permissible values for drinking water in 35 % and irrigation water in 12 % of the sites. Salinity and low flow were associated with low biological quality. Human satisfaction with water quantity and quality, agriculture, the natural environment, and overall life satisfaction were low particularly in the Middle Draa, where 89 % of respondents reported emotional distress due to water salinity and scarcity. Drinking and irrigation water quality was generally rated lower in areas characterized by higher levels of water salinity and scarcity. The study found positive associations between the river water quality and biological quality indices, but no significant association between these factors and human satisfaction. These findings suggest that the relationship between human satisfaction and the biological and physicochemical river water quality is complex and that a more comprehensive approach to human well-being is likely needed to establish relationships.

4.2 Introduction

In the past 50 years, the framing of nature conservation developed from conserving nature for its own good, to conserving nature for the benefit of people, to a shared human-nature environment (Mace, 2014). In this social-ecological system perspective human well-being is linked directly to the health of the ecosystem and includes mental and physical health of individuals (Andrews and Duff, 2020), social bonds between them, but also the relationship between humans and nature (Gergen, 2009). This implies that human well-being is related to the quality of resources and ecosystem services and consists of the fulfillment of different interdependent categories of material and non-material needs (Gergen, 2009; Mace, 2014). The access to nature and the existence of biodiversity in the vicinity was shown to increase well-being (Hartig et al., 2014; Marselle et al., 2019). Understanding the direct and indirect connections between ecosystem health and human well-being and satisfaction can deliver crucial insights that may inform future conservation efforts.

River ecosystems play a vital role in human well-being by providing freshwater and food, regulating climate, and offering cultural services (Akinsete et al., 2019). However, human activities such as hydromorphological changes, pollution, as well as changes in climate conditions increase salinity levels and can threaten human well-being (Akinsete et al., 2019; Cunillera-Montcusí et al., 2022). River ecological health (i.e., river water quality, water quality influencing factors, status of the river ecosystem) and human well-being were decreasing from up- to downstream in a study using the Happy River Index in China, where water scarcity, degradation of the ecosystem, soil erosion, and pollution, and unguaranteed ecological flow were restricting human well-being and ecosystem health (Zuo et al., 2020). Nature and riverscapes can impact mental and physical health (Kaplan 2001; Russell et al., 2013; White et al., 2010), with studies reporting a positive correlation between river naturalness and human well-being (White et al., 2010). Disconnectedness from nature can have negative effects on psychological health (Frumkin et al., 2017; Kals and Maes, 2002; Sandifer et al., 2015). However, most studies have been conducted in developed countries and focused on large perennial rivers (Cruz-Garcia et al., 2017). It remains open to which extent this can be extrapolated to intermittent, ephemeral, and dry rivers in countries of the Global South (Ferreira et al., 2022; Messager et al., 2021; Nicolás-Ruiz et al., 2021). As climate change and anthropogenic pressures continue to increase, these systems and regions may be particularly threatened by a deteriorating ecological and human health (Liu et al., 2022; Zuo et al., 2020).

In the Draa River basin in the South of Morocco, people depend directly on the river ecosystem, as it is providing water for irrigation and domestic use, and thus helps to survive in the arid conditions of the northern Sahara (Mahjoubi et al., 2022). In the upper reaches of the Draa River basin, salinity is primarily caused by geological factors, with rocks and soils releasing ions into the water (Warner et al., 2013). Depending on the rock types, some streams have salinity levels as high as 20 mS/cm (e.g., El Mellah River; direct translation: Mellah = salt), almost half the level of sea water. Salinity further increases, especially in the Middle and Lower Draa basins, due to lower rainfall and increasingly arid climate (Beck et al., 2018; Williams, 1999), which leads to a lack of dilution of water and high evaporation, respectively (Warner et al., 2013). Secondary salinization, such as the use of saline freshwater for irrigation (Hssaisoune et al., 2020; Williams, 1999) in the large date palm oases along the Middle Draa

(Karmaoui, 2014), further increases salinity (Haj-Amor et al., 2016). The drying of intermittent streams during the summer and changes in the natural flow regime caused by the presence of a large dam between the Upper and Middle Draa impose additional stress to the river ecosystem (Karmaoui, 2014). The Draa River basin is characterized by several aridity and salinity gradients that allow to study associations between these gradients and potential responses of the river ecosystem and human well-being (Johannsen et al., 2016).

We assessed how river water quality and biological quality of rivers are associated with water salinity and scarcity in the Draa River basin and how these relate to human well-being. River water quality was assessed through physico-chemical water quality parameters to describe the state of rivers. Aquatic macroinvertebrate metrics were used to describe the biological quality, as macroinvertebrates fulfill important roles for the functioning of freshwater ecosystems and their presence in most aquatic habitats make them suitable to study the biological quality of rivers (Wallace and Webster, 1996; Covich et al., 1999). Human well-being was assessed through a standardized household survey targeting the topics of water and crop quality, people’s health status, and satisfaction.

Based on the processes of primary and secondary salinization and their effects on the river ecosystem, we propose the following hypotheses: High water salinity is associated with (1) poor river water quality and (2a) low biological quality of rivers. We also expect (2b) reduced flow rate as a measure of water scarcity to be associated with low biological quality. Additionally, we hypothesize (3) human satisfaction to be associated with low river water and biological quality, as we expect a direct link between the river ecosystem and human well-being. These hypotheses were tested by analyzing the relationships between river water quality, biological quality, and human well-being indices.

4.3 Materials and methods

4.3.1 Study area

A total of 17 sites in the Draa River basin were selected for the assessment of river water and biological quality and visited in October 2021 and March 2022 (Figure 4.1; Table C.1). 13 of those sites were in tributaries originating in the High and Anti-Atlas Mountains that drain into the El Mansour Eddahbi dam. From there the Draa River flows south-east, here referred to as Middle Draa, before turning as Lower Draa towards the Atlantic Ocean. However, the Middle and Lower Draa are dry for most of the year, leading water only after heavy rainfall events or dam releases. Only one site was selected in the Middle Draa, because the dry state of the river during the study period did not allow further ecological assessments of aquatic macroinvertebrate life stages. Four sites were located in the Lower Draa sub-basin at a tributary from the Anti-Atlas.

Surveys with residents were conducted in October and November 2021 and April 2022, interrupted by a nationwide lockdown. Sites were located in 11 localities close to the ecological sites and in three further localities along the Middle Draa, where no ecological sites were located due to the dry state of the river during the study period, which resulted from a two to three years long drought (Figure 4.1).

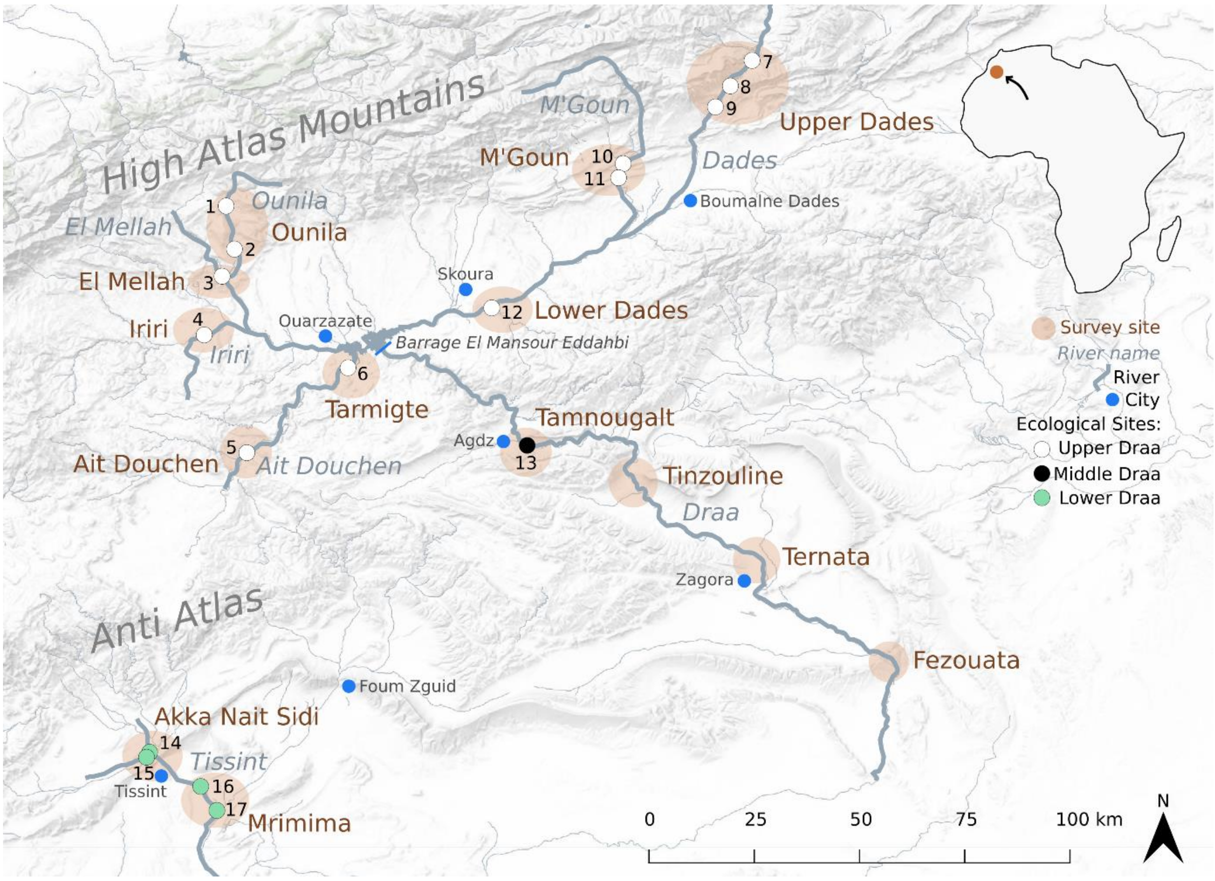

Figure 4.1. Map of Draa River basin showing the 17 ecological study sites and 14 survey sites. Ecological sites in ellipses were assigned to survey sites. (terrain-basemap: © EOX).

4.3.2 Physico-chemical parameters

Water temperature, pH, electrical conductivity, and dissolved oxygen were measured by using a multi-parameter (WTW MultiLine® Multi 3510 IDS) in the 17 ecological study sites (Figure 4.1). Furthermore, river width and depth were measured. Flow velocity was measured using a hydrological impeller (SEBA Hydrometrie) and subsequently combined with the area of the cross profile to calculate flow rate. The ion composition was measured in field by using the MACHEREY-NAGEL VISOCOLOR reagent case with the photometer PF-12Plus and VISOCOLOR Eco colorimetric test kits. Measurements covered chloride (Cl^-), sulfate (SO_4^{2-}), nitrate (NO_3^-), nitrite (NO_2^-), ammonium (NH_4^+), orthophosphate (PO_4^{3-}), potassium (K^+), total hardness (TH) and carbonate hardness (CH). Concentrations of nitrate, nitrite, ammonium, orthophosphate, and potassium lower than 4, 0.02, 0.01, 0.6, and 2 mg/l, respectively, were below detection level. Concentrations of chloride above 6,000 were set to 6,000 as this stands for the upper water quality standard boundary and we refrained from higher dilution of samples for measurements to avoid inaccuracies. To account for temporal variability and measurement errors in data analysis, the measurements from October and March were averaged (except for dissolved oxygen and nitrite which were only measured in October). If a value was under detection level, we used half of the detection level to calculate the mean, a method commonly used (Uh et al., 2008, but see Clarke, 1998). Although more advanced methods are available, in our case with only few non-detects and few sites, the bias was supposed to be low (Helsel, 2006; Helsel, 2010). In the case of sulfate, we excluded two outliers as they were more than 18 times higher than the values of all other sites including previous measurements in the same sites. We attributed these outliers to measurement errors. Values were compared to Moroccan water quality standards for drinking water (Royaume du Maroc, 2006) and irrigation water (SEEE, 2007) to evaluate exceedance of maximum admissible values.

4.3.3 Water quality index

A river water quality index, hereafter WQI, was calculated to determine river water quality using a modified version of the Moroccan water quality index (Royaume du Maroc, 2008). We did not quantify 5- day biochemical oxygen demand (BOD_5), dissolved organic carbon (DOC), total phosphorus, and fecal coliforms, which are used to evaluate water quality of rivers in Royaume du Maroc (2002), while quantifying water temperature, pH, electrical conductivity, chloride, sulfate, and nitrate, which are described in Royaume du Maroc (2002) for the assessment of water quality. Dissolved oxygen and ammonium were included as in the original index. All parameters were scaled to a range from 0 to 100 using the class boundaries and calculation as described in Royaume du Maroc (2002; 2008; Table 4.1). For sulfate, nitrate, and ammonium, the minimum values were set to half the detection level (sulfate < 20 = 10; nitrate < 4 = 2; ammonium < 0.1 = 0.05), other parameters had all values above the detection level.

Table 4.1. Moroccan water quality standards and intervals (Royaume du Maroc, 2002; 2008) for the used parameters water temperature (Temp), pH, electrical conductivity (Cond), dissolved oxygen (Oxygen), chloride, sulfate, nitrate, and ammonium.

Classification	WQI	Temp [°C]	pH	Cond [µS/cm]	Oxygen [mg/l]	Chloride [mg/l]	Sulfate [mg/l]	Nitrate [mg/l]	Ammonium [mg/l]
Excellent	100 - 80	0 - 20	6.5 - 8.5	100-750	7 - 10	0 - 200	0 - 100	0 - 10	0 - 0.1
Good	80 - 60	20 -25	-	750 - 1300	7 - 5	200 - 300	100 - 200	10-25	0.1 - 0.5
Moderate	60 - 40	25 - 30	8.5 - 9.2	1300 - 2700	5 - 3	300 - 750	200 - 250	25 - 50	0.5 - 2
Bad	40 - 20	30 - 35	3.5-6.5, 9.2-10	2700 - 3000	3 - 1	750 - 1000	250 - 400	> 50	2 - 8
Very bad	20 - 0	35 - 40	-	3000 - 7000	1 - 0	1000 - 6000	400 - 2000	-	8 - 50

4.3.4 Biological quality

4.3.4.1 Macroinvertebrates

At each ecological site, macroinvertebrates were sampled by using a 33 × 31 cm (0.1 m^2) Surber sampler (mesh size 500 µm) in October 2021. Quantitative samples were taken at ten spots per site which were selected to cover all microhabitats based on the proportion of microhabitats in a 100-m reach, resulting in a sample area of 1 m^2 per site. The samples were conserved with 95 % ethanol until sorting and identification of taxa in the laboratory. Taxa were identified to species level, except for Diptera (family or subfamily), Odonata (family or genus), Crustacea (order or species), Mollusca (genus or species), Annelida (subclass), and Tricladida (class).

Macroinvertebrate metrics describing biodiversity: taxon richness (number of taxa) and percentage of taxa of the orders EPT (%EPT; Ephemeroptera, Plecoptera and Trichoptera), and multi-metric biotic indices describing the biological water quality: IBMWP (Iberian biological monitoring working party, Jáimez-Cuéllar et al., 2002) and IBGN (Indice Biologique Global Normalis´e, Archaimbault & Dumont, 2010), were calculated to describe biological quality of the rivers. These metrics have already been used in Morocco before (Feio et al., 2021). However, sampling methods differed from the protocols used for IBMWP and IBGN.

4.3.4.2 Biological quality index

We created a biological quality index (BQI). Therefore, we normalized the macroinvertebrate metrics (taxon richness, %EPT, IBMWP, IBGN) to a scale from 0 to 100 to match the WQI and calculated the mean of the metrics per site, for the purpose of comparing it to the other indices and to analyzing the impact of physico-chemical parameters on the biological quality of rivers.

4.3.5 Human well-being

To compare people's perception of drinking and irrigation water quality, their health and satisfaction, 181 interviews using a structured standardized questionnaire were conducted with residents in the 14 survey sites (Figure 4.1), ranging from 7 to 23 interviews per site which lasted 5–12 min. Respondents were selected randomly. The survey used a mixed qualitative-quantitative research approach using categorical multiple choice questions to identify the water sources used for drinking and irrigation, single-answer multiple choice questions to cover the perceived quality of river water, groundwater, and the produced crops in relation to different sources of water (river water, groundwater, ONEE (The National Office of Electricity and Drinking Water) tap water or truck delivered water), and rating scales to assess the effect of water quality and quantity on people's health status, and six aspects of satisfaction (health care, quantity and quality of water resources, agricultural production possibilities, conditions of the natural environment, and life overall). We additionally asked for gender, occupation, and age category (Table C.2) to check for differences in responses between these categories.

To calculate a human satisfaction index (HSI) we used the values of the responses to the 4-point scale questions on satisfaction with health care, quantity and quality of water resources, agricultural production possibilities, and the conditions of the natural environment, ranging from very unsatisfied to very satisfied for the 14 survey sites applying equal-weights. Satisfaction with life overall was not used to calculate the index, as it represents already an aggregate measure of satisfaction. Individual respondent HSI values were taken to calculate a mean HSI per site (Figure 4.1). We normalized the index to a scale from zero (very unsatisfied) to 100 (very satisfied) for the purpose of comparing it to the other indices. We analyzed the impact of physico-chemical parameters on the mean HIS values per site to check for possible associations.

4.3.5 Data analysis

For all data analyses we used R v.4.0.4 (R Core Team, 2021) and RStudio (version 1.2.5019) with the packages "car" (Fox et al., 2007), "dplyr" (Wickham et al., 2015), "rstatix" (Kassambara, 2020), "caret" (Kuhn, 2012), and "beanplot" (Kampstra, 2008).

Before regression analysis, we excluded the predictors nitrite, ammonium, and carbonate hardness, as most values were either the same (i.e., very low variance) or below the detection limit. Sulfate was excluded because of two errors as mentioned above. We omitted chloride ($r = 0.93$), potassium ($r = 0.89$), and total hardness ($r = 0.82$) due to high bivariate correlation with electrical conductivity (Dormann et al., 2013). To analyze the associations between physico-chemical parameters (i.e., water quality) and biological quality, and human satisfaction, we employed the regularized regression method elastic net that simultaneously does variable selection and shrinkage of regression parameters. The elastic net can be viewed as a generalization of the lasso with a combination of the lasso and ridge penalty (Zou and

Hastie, 2005). This regression method can be used even if the ratio of observations (17 sites) to predictors (6; flow rate, water temperature, pH, electrical conductivity, dissolved oxygen, and orthophosphate) is low (Zou and Hastie, 2005). To check for significant differences of the survey responses between the survey sites and between demographic groups (i.e., gender, occupation, and age), we used the response values for the perceived quality of drinking water, irrigation water, and crop production, as well as mean satisfaction for each site. We used ANOVA for homogeneous and Welch's ANOVA for heterogeneous variances, followed by a Tukey's HSD or Games-Howell post-hoc test, respectively. Associations between WQI, BQI, overall satisfaction HSI as well as its elements were analyzed using Pearson's and Spearman's correlation coefficients. See Figure 4.1 for match between ecological and survey sites.

4.4 Results

4.4.1 River water quality

River water quality, as defined by the WQI, was good in 16 and moderate in one site (Table C.1). Water quality was lowest in the Lower Draa (Figure 4.2), and two tributaries in the Upper Draa. Low WQIs were mainly caused by very high electrical conductivity levels exceeding maximum admissible values by Moroccan water quality standards for drinking water (MAVDs) in six, and for irrigation water (MADIs) in two of those sites (Figure 4.2). Chloride exceeded MAVDs and MADIs in all sites, with highest values in the same abovementioned sites, while pH exceeded both standards in two sites (Figure 4.2). Sulfate exceeded MADI in one site. All other parameters met water quality standards, with values often close to or under detection level (Table C.1).

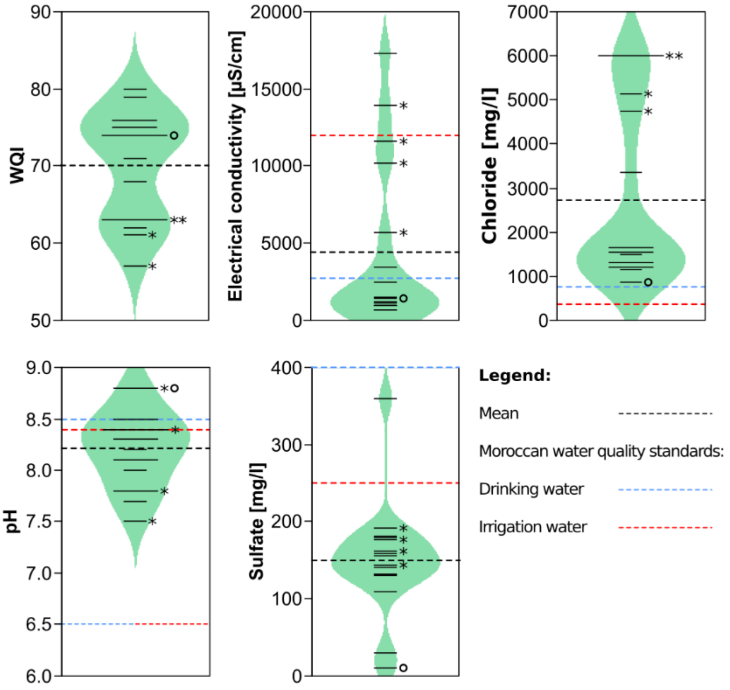

Figure 4.2. Beanplots (Kampstra, 2008) showing the distribution of values for the WQI and the parameters where water quality standards were exceeded (electrical conductivity, chloride, pH, and sulfate). The circle indicates the site located in the Middle Draa; asterisks indicate the four sites in the Lower Draa, remaining sites are in the Upper Draa.

4.4.2 Biological quality

4.4.2.1 Macroinvertebrates

Sites located in the Middle and Lower Draa showed low values for most metrics, as reflected in the BQI (Figure 4.3). Only for %EPT the value of the Middle Draa is located above the mean.

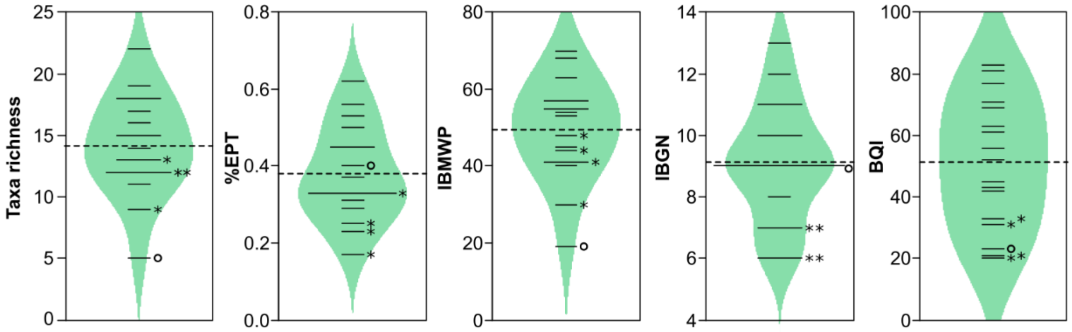

Figure 4.3. Beanplots showing the distribution of values for the biological quality metrics and the BQI. The dashed line shows the mean. The circle indicates the site located in the Middle Draa; asterisks indicate the four sites in the Lower Draa, remaining sites are in the Upper Draa. For abbreviations see section 4.3.4.

In the best-fit model as selected by the elastic net (lambda = 4.52, intercept 51.2), altitude and flow rate showed a positive, electrical conductivity negative association with the biological quality index (BQI), explaining 60 % of the variation (Table 4.2).

Table 4.2. Results of elastic net for the biological quality index (BQI) and human satisfaction index (HSI) showing parameter estimates of all included variables, lambda, and coefficient of determination (R^2).

Parameter	Estimate BQI	Estimate HSI
Intercept	51.2	53.4
Altitude	6.6	4.1
Flow rate	6.4	0
Water temperature	0	-0.8
pH	0	-5.2
Electrical Conductivity	-0.04	-1.8
Dissolved oxygen	0	0
Nitrate	0	3.5
Orthophosphate	0	0
lambda	4.52	5.3
R^2	0.6	0.75

4.4.3 Human well-being

Responses were similar across gender and occupation (Table C.3). Higher age was associated with a lower rating of drinking water quality, lower health status, and lower satisfaction, however, showing very low effect sizes for drinking water quality and satisfaction (Table C.3).

4.4.3.1 Water and crop quality

Water quality for drinking and irrigation as well as crop quality were rated generally good in the Upper Draa (Figure 4.4). In the Middle Draa, people were rating irrigation water and crop quality less good than in the Upper Draa. People using treated groundwater through taps rated drinking water quality 48 to 60 percent higher in the Middle and Lower Draa respectively compared to untreated groundwater, whereas the quality of truck delivered water was rated lower than untreated groundwater. There were no differences in the rating of irrigation water and crop quality between the use of groundwater and water from rivers and springs in the Upper and the Middle Draa (Table C.4). Clearer differences between the ratings were observed in the two villages of the Lower Draa (Table C.4).

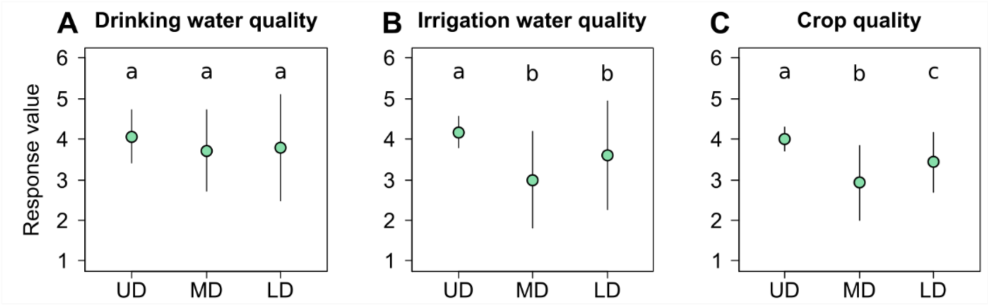

Figure 4.04. Response values from 1 (very bad) to 6 (excellent; see Table C.2) with SD for the Upper (UD, n = 101), Middle (MD, n = 56), and Lower Draa (LD, n = 24) for drinking water quality (A), irrigation water quality (B) and crop quality (C). Mean values of sub basins not sharing a lower-case letter are significantly different ($p < 0.05$).

Water was perceived by people to be sometimes salty in 27 % of the sites of the Upper Draa, whereas the others did not perceive water to be salty. In the Middle and Lower Draa, 59 and 50 %, respectively, perceived water to be salty, with in total 39 and 29 %, respectively, stating that they experience it to be salty often.

4.4.3.2 Health status

No differences were found in how people perceived their health status throughout the Draa River basin, with a total mean of 7.3 (SD = 1.4) on a scale from 1 to 10 (Table C.4). Of the respondents 8, 18 and 54 % in the Upper, Middle, and Lower Draa, respectively, indicated that the quality of water influences the health of people, of which 75, 89 and 46 % said that this effect is predominantly bad for the health status. Only four percent of people in the Upper Draa, but 25 and 54 % in the Middle and Lower Draa, respectively, reported physical diseases that they attributed to water salinity. While in the Upper Draa, physical diseases were only experienced sometimes, 14 and 54 % of those who experienced it in the Middle and Lower Draa stated that they occur often. 34 %, 89 % and 38 % reported emotional distress due to water salinity and/or scarcity in the Upper, Middle, and Lower Draa, respectively.

4.4.3.3. Human satisfaction

Except for satisfaction with health care, with which respondents were generally unsatisfied, all other aspects of satisfaction followed a similar pattern of between-subbasin differences (Figure 4.5, Table C.5), with differences being less strong in overall life satisfaction. The Upper Draa had the highest mean response values for people being predominantly satisfied, significantly higher compared to the Middle Draa where they are predominantly unsatisfied to very unsatisfied. Mean response values of the Lower Draa were in between the other subbasins, however showing a very high variance caused by highly different response values between the two survey sites of Akka and Mrimima. This is also reflected in the HSI values (Figure 4.6), with the people in the Upper Draa showing generally higher HSI values, except for the high variance in the Lower Draa (Figure C.1).

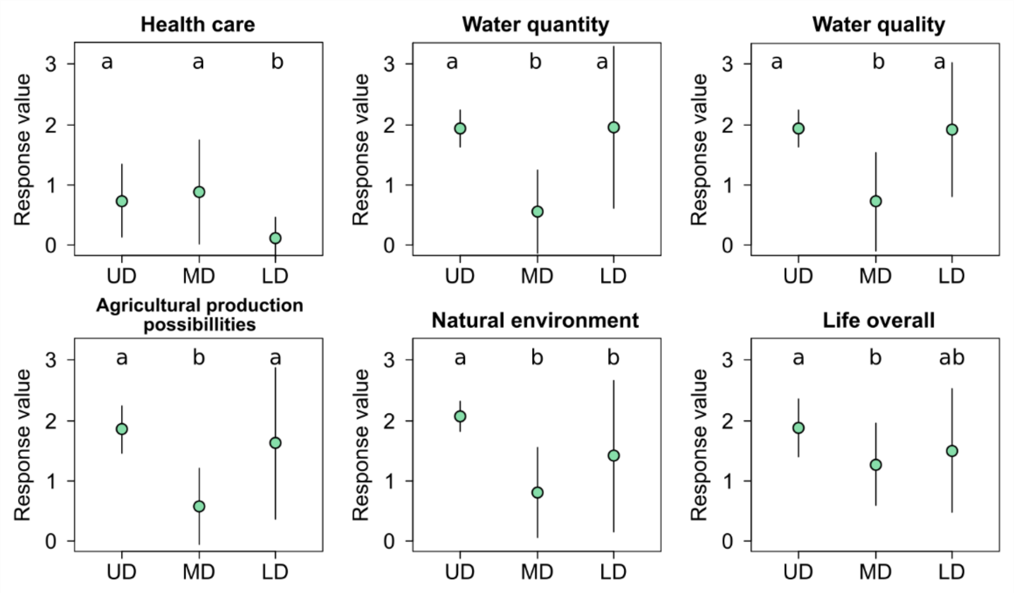

Figure 4.05. Response values from 0 (very unsatisfied) to 3 (very satisfied; see Table C.2) with SD for the Upper (UD, n = 101), Middle (MD, n = 56), and Lower Draa (LD, n = 24) for satisfaction with different aspects. Mean values of sub basins not sharing a lower-case letter are significantly different ($p < 0.05$).

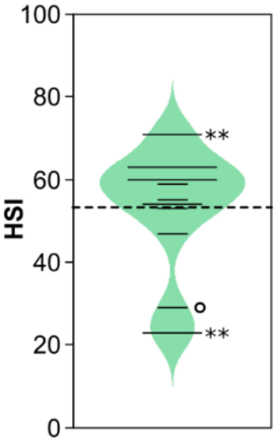

Figure 4.06. Beanplot showing the distribution of values for the mean HSI (Human Satisfaction Index) per site. The dashed line shows the mean overall. The circle indicates the site located in the Middle Draa; asterisks indicate the four sites in the Lower Draa, remaining sites are in the Upper Draa. Compare Figure C.1 for individual respondent HSI values.

In the best-fit model as selected by the elastic net (lambda = 5.3, intercept 53.4), altitude and nitrate showed a positive, water temperature, pH, and electrical conductivity a negative association with the human satisfaction index (HSI), explaining 75 % of the variation (Table 4.2).

4.4.4 Comparison of WQI, BQI, and HIS

The WQI was correlated with the BQI (Pearson's r(15) = 0.6, p = 0.01) in the 17 ecological sites (Figure 4.7). In the 11 survey sites, the HSI was only weakly, i.e., not significantly, correlated with BQI (Pearson's r (9) = 0.5, p = 0.11), and not with WQI (Pearson's r(9) = 0.25, p = 0.45). Values for the Upper Draa were generally high compared to the other sites (Figure 4.7). The individual components of satisfaction included (mean values per site) in the HSI were not significantly correlated to the WQI and BQI, either, except for satisfaction with the environment that correlated with BQI (Table C.5).

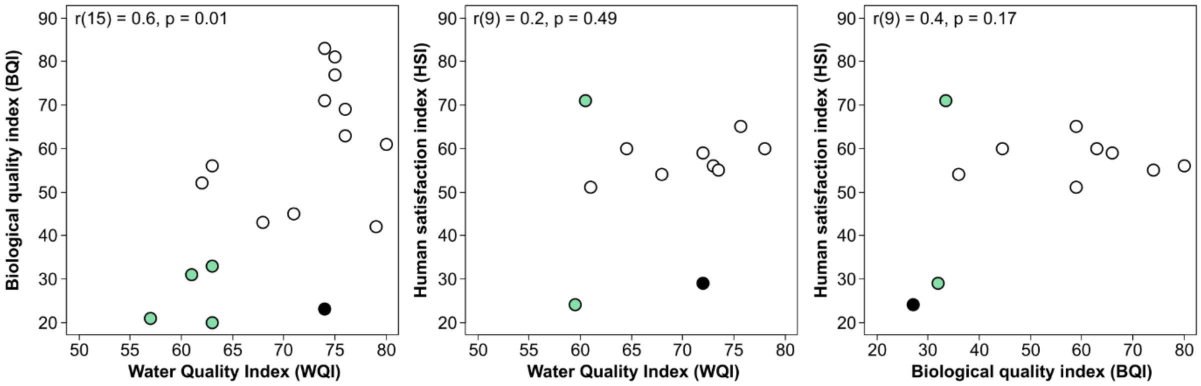

Figure 4.07. Scatter plots showing correlations of river water quality index (WQI), biological quality index (BQI, and human satisfaction index (HSI). Green points = Upper Draa, black point = Middle Draa, white points = Lower Draa.

4.5 Discussion

4.5.1 Water quality and quantity

We found that the water quality index of rivers in the Draa River basin is mainly determined by salinity. Sites with higher electrical conductivity and higher chloride concentrations scored lower in water quality index values and concentrations often exceeded maximum admissible values for human consumption (Royaume du Maroc, 2006) and irrigation (SEEE, 2007). This is in accordance with our first hypothesis. Low values of other parameters like phosphate indicate low pollution of the river water. This may be explained by fertilizers being rarely used in the mainly traditional farming that is conducted in the Draa River basin (Ou-Zine et al., 2021). This result should be interpreted with caution as other components of water quality that may indicate pollution such as BOD_5, DOC, total phosphorus, and fecal coliforms, were not determined. With further primary salinization due to increasing aridity (Beck et al., 2018; Williams, 1999) and ongoing secondary salinization, especially in the Middle and Lower Draa area (Warner et al., 2013), river water quality is likely to further degrade in the future.

The rating of the quality of water resources by respondents was largely consistent with the measured river water quality in terms of salinity, with most people in the Lower Draa region reporting poorer water quality and perceiving the water to be salty. Besides river water, groundwater can be affected by high and increasing salinity (Warner et al., 2013), limiting access to usable drinking and irrigation water. However, treatment of drinking water (e.g., ONEE tap water, mainly pumped from aquifers to water towers where it is treated) could explain the little differences of perceived drinking water quality in the three sub-basins. Perceived irrigation water quality was lower in the more saline and dry Middle and Lower Draa. Salinity levels well below the maximum admissible values for irrigation water of 12 mS/cm (SEEE, 2007) can already drastically reduce the growth and yield of salt-tolerant plants such as date palms (Tripler et al., 2011). While river water is used for irrigation in the Upper Draa, groundwater is mainly used in the Middle and Lower Draa, because river water is only available after dam releases or rain events or is too saline. Wells are deepened, or new ones are constructed (Berger et al., 2021), leading to increasing over-exploitation of aquifers

(Hssaisoune et al., 2020). The increased water salinity and scarcity, among other factors (Dessu et al., 2014), may explain the dissatisfaction with water quality and quantity in the Middle and Lower Draa, as we saw associations of the human satisfaction with altitude, electrical conductivity, and water temperature, though not with flow rate. However, as water quality was only investigated at one site in the Middle Draa and the other sites were dry during the sampling period, the transfer of this result to the entire sub-basin should be treated with caution. With increasingly dry climate (Beck et al., 2018; Tramblay et al., 2018), and intensive cultivation of water-demanding crops such as watermelons (Hssaisoune et al., 2020; Karmaoui et al., 2016), river ecosystem health and human well-being may be further compromised in the coming decades (Karmaoui et al., 2019).

4.5.2 Biological quality

Biological quality of rivers in the Draa River basin was positively correlated with river water quality, with a general decline from up- to downstream. Additionally, biological quality was, in accordance with our second hypothesis, negatively associated with high electrical conductivity and low flow rate. High salinity limits the survival of non-adapted species (Kaczmarek et al., 2021), with only saline specialist or generalist species surviving (Arribas et al., 2019; Samraoui et al., 2021). Consequently, sensitive taxa such as various ephemeropterans, plecopterans, and trichopterans (EPT) were absent in the saline sites of the Lower Draa, which is reflected in the IBGN (Archaimbault and Dumont, 2010). Low flow rate and the periodical drying of rivers further reduce macroinvertebrate richness (Beauchard et al., 2003), as many species are adapted to high flow velocities (Samraoui et al., 2021) and cannot tolerate stress caused by low flow or standing waters, cannot withstand desiccation, or are unable to complete their life cycles during shorter wet periods of the river (Stubbington et al., 2017). The Middle Draa is separated from the Upper Draa by the El Mansour Eddahbi dam. Because the Middle Draa only leads flowing water after dam releases or heavy rain events, adaptations to short reproductive cycles and stagnant flow are required (Kaczmarek et al., 2021; Samraoui et al., 2021). An increase in salinity and aridity in the coming decades (Hssaisoune et al., 2020, Terink et al., 2013) and the construction of dams (Zarfl et al., 2015) may lead to the loss of salt-sensitive or non-adapted species (Kaczmarek et al., 2021), compromising biological quality of rivers.

As a specific multimetric macroinvertebrate index for assessing river water quality, biological quality, or ecosystem health is lacking in most of Africa (Edegbene et al., 2019), we decided to combine several metrics. Overall, the biological quality index had the lowest values for the high salinity sites in the Lower Draa and the stagnant pool in the Middle Draa, suggesting that it is suitable for indicating generally poor conditions for human use in saline and arid sites. This is also reflected in the low scores for these sites in the IBMWP and IBGN, which were created to assess biological water quality using indicator organisms (Jáimez-Cuéllar et al., 2002; Archaimbault and Dumont, 2010). While measured river water quality in the site of the Middle Draa was better than in the Lower Draa, as also reflected in the IBGN, intermittency and stagnant flow resulted in poorer biological quality values compared to the saline sites. Overall, the IBMWP and the IBGN seemed to be useful to detect poor biological water quality in saline and low flow sites of the Draa River basin compared to the other sites of the Draa, though they do not account for the reference state in terms of the natural state of saline streams and their communities. Although we found a correlation between river water and biological quality, we did not achieve a differentiation between the impact of primary and secondary salinization. Naturally saline streams may be unsuitable for human use and score low in commonly used multimetric macroinvertebrate indices, still, they can harbor unique communities. This indicates the need of specific indices and indicator organisms for saline and intermittent streams (Arias-Real et al., 2022), especially to detect anthropogenic impacts in natural stressed ecosystems (Gutiérrez-Cánovas et al., 2019). However, more research is needed to define indicator organisms for yet less studied regions (Gutiérrez-Cánovas et al., 2019) and to further develop indices to monitor climate change and anthropogenic impacts on naturally saline streams (Gutiérrez-Cánovas et al., 2008).

Besides macroinvertebrates, other organisms such as riparian plant species (Mostakim et al., 2022) and vertebrates (Riesco et al., 2020) are affected by increasing primary and secondary salinization, as well as increasing aridity in the Draa River basin. A loss of species and a change of assemblage composition can disrupt ecosystem functioning (Lecerf and Richardson, 2010) and reduce ecosystem resilience to disturbance (Peterson et al., 1998). Conservation efforts should, however, not only focus on perennial freshwater rivers (Cañedo-Argüelles et al., 2016), but also take naturally saline and intermittent rivers and their adapted communities into account (Benamar et al., 2021; Velasco et al., 2006), as these species may have the potential to colonize anthropogenically salinized and intermittent rivers (Kefford et al., 2016). When important species are lost, other species, like invasive alien species, may proliferate (Clavero et al., 2015), potentially reducing human well-being (Jones, 2017) by for example an increase in species that transmit diseases to humans, such as mosquitoes (Ramasamy and Surendran, 2012) and pathogenic microorganisms (Keesing and Ostfeld, 2021). The aim to reduce the impact of secondary salinization on the river ecosystem and thereby safeguard human well-being may be compromised by future efforts to provide freshwater resources for drinking and irrigation water, like the cross-basin water transfers to other regions (El Moçayd, et al., 2020).

Asked about satisfaction with the natural environment, respondents were particularly dissatisfied along the mostly dry Middle Draa River. Other studies showed that healthy environments have a positive impact on satisfaction (Hartig et al., 2014). However, we found no correlation between human satisfaction overall and biological quality, which contradicts our third hypothesis. As the Middle Draa was mostly dry during the study period, we could not study water and biological quality in this area, where satisfaction was low. Data from more sites along the Middle Draa might have resulted in clearer trends. However, the missing differentiation between naturally saline and anthropogenically salinized rivers in biological quality indices, could have led to higher biological quality in natural high saline sites. Nevertheless, we found high levels of satisfaction mainly in the Upper Draa area where biological quality was typically good. While respondents in Akka in the Lower Draa showed highest satisfaction although living in an area showing low biological quality, we expect that this is related to their situation of high water availability with relatively low salinity levels for the Lower Draa region compared to their direct neighbors.

To maintain biological quality of rivers, measures are needed to limit increasing water demand and salinity. This can be achieved through water strategies, including improving irrigation efficiency (Hssaisoune et al., 2020; Jeddi et al., 2021) and reducing agricultural areas (Johannsen et al., 2016), especially for water-demanding crops such as watermelon (Karmaoui et al., 2016). Further intensive use of water resources would limit ecosystem functioning, leading to a loss of ecosystem services (Jakubínský et al., 2021) and thus may compromise river ecosystem health and human well-being.

4.5.3 Human health

Respondents reported generally good health conditions, while being unsatisfied with health care. Although differences in health status were low between sites in the whole basin and a clear association with biological quality was lacking, every tenth person reported negative effects from water, such as fecal-oral diseases and tooth discoloration. However, these effects are not necessarily caused by river water directly, as the bacteriological quality of water could be reduced between source and point-of-use (e.g., during central storage in water towers or storage in households; Wright et al., 2004). About half of the respondents from the Lower Draa reported physical diseases attributed to water salinity (e. g., kidney problems). Similarly, it was stated that salinity in drinking water might have a connection with kidney diseases like kidney stones and Rheumatism (SRTT (Sir Ratan Tata Trust Navajbai Ratan Tata Trust), 2011).

Besides physical diseases, nine out of ten respondents in the Middle Draa reported emotional distress caused by both water salinity and scarcity, whereas it was reported by about a third of respondents in the Upper and Lower Draa. Previous studies suggested that a low predictability of supply is a contributor to emotional distress (Stevenson et al., 2012, Wutich et al., 2016, Wutich and Ragsdale, 2008,). Several factors may explain the low predictability: natural factors include the decreased precipitation in the area, whereas the management-related ones mainly include flow regulation through the dam which is contributing to the intermittent characteristic of the Middle Draa. Other contributors to emotional distress could be caused by witnessing wetland degradation or destruction over the years (Larsen, 2012).

4.5.4 Human well-being

Aspects of human well-being covered in this analysis, namely water and crop quality, health status, and satisfaction (which includes satisfaction with health care, water quality and quantity, agriculture possibilities, environment, and life overall in the area) are partly provided by the river ecosystem in the three Draa sub-basins. However, we did not find a significant correlation of human satisfaction with the water and biological quality indices, with only the satisfaction with the conditions of the natural environment showing a positive correlation with the biological quality. River naturalness positively affects health and well-being among individuals, while a disconnection from nature may have detrimental effects on human satisfaction, as well as contributing to an unhealthy environment (Kaplan et al., 1989, Kaplan, 2001; Nasar, 2000; White et al., 2010). Similarly, our results indicate that respondents in the Upper Draa were predominantly satisfied with the natural environment, in contrast to the Middle Draa where respondents expressed missing the riverscape for years. While we found a correlation of the satisfaction with the conditions of the natural environment and aspects regarding water quantity and quality as well as agriculture, satisfaction with health care showed no correlation with those aspects. Other important intangible aspects of human well-being require further research for the Draa and other areas (e.g., spirituality, identity, cognition). When considered, these may provide stronger associations between the state of the ecosystem and human satisfaction and well-being. Our knowledge could be advanced by studies with a more comprehensive perspective that assesses how the different constituents of well-being benefit from nature.

4.5.5 Conclusion

Our findings indicate that high salinity levels and low water flow are reducing the water and biological quality of rivers in the Draa River basin. However, as current biological indices fail to discriminate between naturally saline and anthropogenically salinized rivers and, thus, potentially assigning a too low biological quality to naturally saline rivers, specific indices would be required for better assessment of their status. Our study suggests direct and indirect relationships between the state of the river ecosystem and human well-being, such as saline river water directly causing human emotional distress and decreasing satisfaction. However, several correlations were much weaker than hypothesized or non-existent. We suspect that the relationship can be masked by additional factors such as the cultural background or specific local needs or water usages so that more comprehensive surveys with more detailed and open interview questions and complex statistical tools may be required to find those associations. In addition, a larger sample size would increase the capacity to detect relationships. Targeting countries of the Global South is crucial, as these are particularly vulnerable to the effects of climate change on their nature, economy, and society, in particular on water supply for nature and humans. In this context, to improve human well-being, policies and action plans should consider the interdependence between ecosystems and their inhabitants.

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Chapter 5

5. Discussion and outlook

5.1. Environmental change in the Draa River basin

A significant portion of Northwest Africa's temperate climate areas is projected to become arid by the end of the century (Beck et al., 2018; Kaczmarek et al., 2021), while aridity in already highly arid regions like the Draa River basin is further increasing (Schilling et al., 2012; Terink et al., 2013). Consequently, an increase in water salinity and intermittency in freshwater ecosystems is anticipated (Bates et al., 2008; Williams, 1999). Human activities within the Draa River basin, such as the cultivation of unsustainable crops and alterations to natural water flow, will intensify these effects, resulting in reduced water quality and quantity in the basin (Kaczmarek et al., 2023; Karmaoui et al., 2016; Karmaoui et al., 2019). These changes will have adverse consequences for both the river ecosystem and the local population (Kaczmarek et al., 2023).

While the Upper Draa rivers, except for El Mellah, exhibit relatively low salinity, salinity levels increase in the Middle and Lower Draa due to secondary salinization processes (Kaczmarek et al., 2023; Warner et al., 2013). Several sites within the basin show high electrical conductivity and chloride concentrations that often exceed maximum permissible values for human consumption (Royaume du Maroc, 2006) and irrigation (SEEE, 2007), indicating poor water quality (Kaczmarek et al., 2023). Additionally, sulfate contributes to the salinity of saline rivers in arid regions (Millán et al., 2011). However, other parameters such as phosphate were found to be low, suggesting low pollution of the river water with fertilizers (Kaczmarek et al., 2023), as traditional farming practices, which are predominant in the Draa River basin, rarely employ fertilizers (Ou-Zine et al., 2021). Therefore, salinity can be considered the primary factor influencing water quality in the Draa River basin (Kaczmarek et al., 2023; Kaczmarek et al., submitted). However, since we did not assess other components of water quality, such as BOD5, DOC, total phosphorus, and fecal coliforms, it is possible that other entries of pollution may be present, particularly in close proximity to urban areas.

Increased water salinity, intermittency, and chronic disturbances can affect river ecosystems, altering their metabolism and functioning (Millán et al., 2011). Saline and intermittent river ecosystems are predominantly composed of highly adapted organisms capable of withstanding harsh environmental conditions and extreme changes (Millán et al., 2011). Salinity and intermittency have been shown to influence the composition of benthic diatom and macroinvertebrate communities in the Draa River basin (Benlasri et al., 2023; Kaczmarek et al., 2021; Kaczmarek et al., submitted; Lazrak et al., 2022). While water salinity directly affects the human population of the Draa River basin through restricted use of saline water for irrigation and potential mental and physical health issues, it can also impact human well-being by depleting ecosystem services (Kaczmarek et al., 2023; Mahjoubi et al., 2022).

5.2. Macroinvertebrate richness in response to environmental change

We found, on average, 37 % fewer insect families in arid sites compared to temperate sites in Northwest Africa (Kaczmarek et al., 2021). Desert and saline ecosystems favor generalist and salinity specialist species capable of surviving in harsh conditions. These species can thrive due to the availability of resources freed up by the absence of salt-sensitive species (Kefford et al., 2016; Velasco et al., 2006). Consequently, the macroinvertebrate community in the Draa River basin primarily consists of species that can withstand arid and saline conditions (Kaczmarek et al., submitted). Approximately 90 % of the total number of specimens in the community belong to only five dominant taxa, primarily generalist species, such as the salt-tolerant ephemeropterans *Caenis luctuosa* and *Baetis pavidus* (i.e., in contrast to generally rather sensitive Ephemeroptera), the trichopteran *Hydropsyche* sp., and the Oligochaete (Benlasri et al., 2023; Kaczmarek et al., submitted). Sensitive taxa such as *Cloeon simile*, Tricladida, and *Melanopsis cariosa* are either absent or significantly reduced in saline sites (Kaczmarek et al., submitted). This results in a lower ratio of generally salt-sensitive Ephemeroptera, Trichoptera, and Plecoptera to more salt-tolerant Diptera, Coleoptera, Odonata, and Hemiptera taxa (Kaczmarek et al., submitted; Kefford et al., 2016; Millán et al., 2011), as the former taxa prefer low saline and pristine habitats (Díaz et al., 2008; Kaczmarek et al., 2021).

The anticipated increase in arid and saline environmental conditions in the future will result in the expansion of habitats that are unsuitable for species not adapted to these conditions (Domisch et al., 2011; Domisch et al., 2013; Kaczmarek et al., 2021). Consequently, species are expected to migrate poleward or to higher altitudes to follow favorable habitat conditions (Domisch et al., 2013; Walther et al., 2009). While this may contribute to increased diversity in temperate Europe through the immigration of the highly diverse Mediterranean fauna (Bonada et al., 2007), the Draa River basin and Northwest Africa as a whole are likely to experience a loss of diversity in the coming decades (Beauchard et al., 2003; Benlasri et al., 2023; Kaczmarek et al., 2021). The invasion of other families adapted to arid environments might not sufficiently compensate for the loss, resulting in a decline in overall taxon richness (Dornelas et al., 2019; Morghad et al., 2019). The decline in diversity will primarily be driven by the loss of taxa associated with temperate climates, while only a few adapted species, such as *Micronectidae*, may expand their ranges due to reduced competition (Bonada et al., 2007; Kaczmarek et al., 2021).

5.3 Resistance and resilience adaptations

To ensure survival in the saline and intermittent streams of the arid Draa River basin it is crucial for species to possess resistance traits against high salinity, elevated water temperatures, and the periodic drying of the river (Leigh et al., 2016; Stubbington et al., 2017). These environmental variables act as filters, shaping the insect communities and their trait profiles (Díaz et al., 2008; Statzner et al., 2001). In line with the concept of r-strategists (MacArthur & Wilson, 1967), smaller body size and an increased number of reproductive cycles per year have been linked to salinity and aridity, suggesting that these traits promote survival in arid environments (Díaz et al., 2008; Kaczmarek et al., 2021; Kaczmarek et al., submitted; Stubbington et al., 2017). The ability to swim and respiratory adaptations for air-breathing were associated with aridity and higher conductivity (Kaczmarek et al., 2021). Swimming enables species to reach food sources quickly as the flow recedes (Datry et al., 2017). Adaptations for air-breathing, such as plastron and spiracles, aid in coping with rapid ion uptake in saline water and lower oxygen levels in stagnant or slow-running water (Chessman, 2015; Datry et al., 2017; Kefford et al., 2016).

While adaptations against desiccation and the presence of terrestrial clutches are known to support survival in dry conditions (Datry et al., 2017; Díaz et al., 2008; Vidal-Abarca et al., 2013), we did not find evidence of these associations in our study (Kaczmarek et al., 2021; Kaczmarek et al., submitted). The same was the case for changes in functional feeding groups, where a proportional increase of gathering-collectors, scrapers, and predators was expected (Millán et al., 2011). Overall, the differences in trait profiles of the Tissint tributaries with salinity levels exceeding 5,000 µS/cm were minimal. However, comparing the less saline Iriri with the more saline El Mellah showed similar associations of traits as observed when comparing trait profiles for Northwest Africa as a whole (Kaczmarek et al., 2021; Kaczmarek et al., submitted). With salinity levels of 2,440 µS/cm in El Mellah, we observed a higher proportion of resistance adaptations compared to Iriri with 810 µS/cm. This suggests that adaptations to salinity are necessary at levels of conductivity that are exceeded (i.e., above around 1,000-2,000 µS/cm) in many rivers within the Draa River basin (Kaczmarek et al., 2023). Dramatic changes in the macroinvertebrate communities have been reported to occur around 1,000 µS/cm (Horrigan et al., 2005), whereas a critical salinity level of about 75 g/L (~ 100,000 µS/cm) was found to lead to an aprubt change in community composition in hypersaline streams (Velasco et al., 2006). Hence, this finding can also explain the limited differences in trait profiles between sites in Tissint, where salinity levels ranged from around 5,610 µS/cm to 10,180 µS/cm (Kaczmarek et al., submitted). An increase of salinity levels of yet low saline rivers beyond such a threshold could therefore lead to drastic changes in community composition. A macroinvertebrate community adapted to salinity levels above this threshold might therefore only show minor changes in community composition, as it is largely adapted to the environment (Kaczmarek et al., submitted; Velasco et al., 2006)

We observed resistance adaptations in the Dades River associated with intermittent drying (Kaczmarek et al., submitted). Although the Dades River is mostly permanent, short periods of drying caused by water abstractions can significantly impact the macroinvertebrate community as it excludes species that cannot cope with drying (Bonada et al., 2007). Low-flow conditions favor a higher number of reproductive cycles per year and air-breathing, both of which enhance survival in arid environments (Kaczmarek et al., 2021; Stubbington et al., 2017). The strong intermittent flow in the Middle Draa valley, resulting from the El Mansour Eddahbi dam, can be seen as the cause of low diversity in this area (Kaczmarek et al., 2023). The projected increase in salinity and aridity in the coming decades, (Hssaisoune et al., 2020; Terink et al., 2013) and the construction of dams (Zarfl et al., 2015) may further accelerate the loss of species (Kaczmarek et al., 2021).

Resilience traits such as the capacity for active aerial dispersal, play a crucial role in facilitating recolonization following prolonged droughts and contribute to the maintenance of local populations (Bogan et al., 2017; Leigh et al., 2016; Stubbington et al., 2017). These traits were associated with aridity, high water temperatures, and conductivity (Kaczmarek et al., 2021). However, when comparing tributaries at confluences, we did not observe significant differences in the proportion of organisms with aerial dispersal traits (Kaczmarek et al., submitted).

5.4 Macroinvertebrate communities in salinizing ecosystems

Low diversity can have detrimental effects on ecosystems leading to the loss of important functions and reduced resilience to disturbances such as prolonged droughts (Lecerf and Richardson, 2010; Peterson et al., 1998). In the Draa River basin we found that the biological quality of the river ecosystem, as assessed by measures of diversity and multimetric macroinvertebrate indices, was lower in the more arid regions of the Middle and Lower Draa, which were characterized by lower water quality due to higher salinity (Kaczmarek et al., 2023). Additionally, we observed that macroinvertebrate diversity is further diminished when water temperatures exceed approximately 20 °C (Kaczmarek et al., 2021). To safeguard the integrity of the ecosystem, it is crucial to protect freshwater ecosystems with low salinity levels, such as the rivers Dades, M'Goun, and Iriri. Low-saline rivers can serve as a refuge for species in increasingly saline environments (Kaczmarek et al., submitted). Furthermore, preserving the natural state of ecosystems in the higher altitudes of the High Atlas Mountains is important, as these areas may serve as refuges for more sensitive species with increasing arid climate during climate change (Domisch et al., 2013).

However, the low diversity of macroinvertebrate communities in highly saline streams within the Draa River basin does not necessarily indicate poor environmental conditions as it is indicated by the multimetric indices IBGN and IBMWP (Kaczmarek et al., 2023; Kaczmarek et al., submitted). While salinity levels can increase due to secondary salinization, they are primarily induced by natural processes in the region (Warner et al., 2013). Additionally, saline rivers often show high primary productivity based on autotrophic biomass and consequently high abundances of adapted macroinvertebrate species (Benamar et al., 2021; Millán et al., 2011). Therefore, the less diverse but adapted communities can largely represent the natural state of the river ecosystem (Velasco et al., 2006). Protecting saline habitats becomes significant not only for their own conservation value but also to safeguard macroinvertebrate species that have adapted to harsh conditions (Benamar et al., 2021; Velasco et al., 2006). Adapted species may play crucial roles in fulfilling ecosystem functions within increasingly salinized ecosystems and may have the potential to colonize anthropogenically salinized and intermittent rivers (Kefford et al., 2016).

Our findings revealed that the macroinvertebrate communities in the highly saline El Mellah River exhibited fewer salt-sensitive species compared to the less saline Iriri River (Kaczmarek et al., submitted). Moreover, there were higher similarities in community composition (lower β-diversity) between these rivers and the joint downstream section following their confluence suggesting a combination of species downstream of the confluence (Kaczmarek et al., submitted). The intermediate salinity levels in the downstream section may have facilitated the coexistence of both salt-tolerant and salt-sensitive species (Kaczmarek et al., submitted; Velasco et al., 2006). Furthermore, the immigration of species through macroinvertebrate drift (Beermann et al., 2018; Cellot, 1996) or source-sink dynamics (Heino, 2013) could contribute to the higher similarities observed in the joint downstream section (Kaczmarek et al., submitted). The availability of suitable habitats or a source population in close proximity may aid in maintaining a viable population within the basin (Bonada et al., 2006). Therefore, the conservation of both more and less saline rivers is crucial for preserving the respective macroinvertebrate communities.

In addition to the climate change induced increased intermittency, human activities, such as extensive regulation of waterways, can further contribute to the reduction of macroinvertebrate richness. These human-induced factors include deteriorating water quality, fragmentation of river sections, and alterations in flow regimes (Kaczmarek et al., 2021; Martínez et al., 2013; McAllister et al., 2001; Navarro-Llácer et al., 2010). The global trend of increasing river regulation (Zarfl et al., 2015), driven by increasing water demands, poses a significant risk to freshwater biodiversity (Ayt Ougougdal et al., 2020; Kefford et al., 2016). Moreover, the expansion of anthropogenic land use for agriculture and urbanization has been found to have particularly negative effects on endemic species (Genito et al., 2002; Hepp et al., 2010; Kietzka et al., 2018). However, it is worth noting that the input of nutrient-rich sources from surrounding croplands (MacFarlane, 1983) and favorable conditions in human settlement areas can potentially benefit overall insect richness, provided pesticide use remains low (Kaczmarek et al., 2021). As generalist species are generally more adaptable to environmental changes (Domisch et al., 2013), these human-induced alterations may result in an increased abundance of disease-transmitting species such as the vector mosquito *Culex pipiens* (Farajollahi et al., 2011). These disease vectors are capable of transmitting illnesses such as malaria, West Nile virus, and Zika virus (Farajollahi et al., 2011; Ramasamy and Surendran, 2012).

In our studies, the use of macroinvertebrates to study the ecosystem, assess biological quality, and understand the impact of stressors in the Draa River basin faced several challenges. While well-developed multimetric macroinvertebrate indices for evaluating river biological quality and ecosystem health exist for extensively studied regions in Europe and North America, such indices are lacking for most of Africa (Cunillera-Montcusí et al., 2022; Edegbene et al., 2019). In the Draa River basin, the IBGN (Archaimbault and Dumont, 2010) and IBMWP (Jáimez-Cuéllar et al., 2002) indices helped to detect poor biological quality in saline and low flow sites compared to other sites within the Draa River basin (Kaczmarek et al., 2023). However, these indices do not consider, as described above, the reference state concerning the natural salinity in streams and their associated communities. As a result, distinguishing between the impacts of primary and secondary salinization was not possible. Further research is necessary to identify indicator organisms for less-studied regions and saline and intermittent streams and to enhance the development of indices capable of monitoring climate change and anthropogenic impacts on naturally saline streams (Arias-Real et al., 2022; Cunillera-Montcusí et al., 2022; Gutiérrez-Cánovas et al., 2008). Additionally, efforts are needed to improve the literature for identifying taxa at lower taxonomical levels and expanding trait databases, especially for under-studied regions such as Africa (Cunillera-Montcusí et al., 2022). As a result of incomplete databases, the analysis of traits in our study often had to be limited to lower taxonomical levels, potentially overlooking certain effects (Kaczmarek et al., 2021; Kaczmarek et al., submitted). Finally, while metabarcoding is rapidly advancing as a quick and cost-effective monitoring tool (Elbrecht et al., 2017), its application in Africa is currently often constrained by logistical challenges and the absence of comprehensive barcode databases for African species. This has prevented us from using metabarcoding in our studies.

5.5 Relationship between the ecosystem and human well-being

The naturalness of rivers has been shown to have a positive impact on the health and well-being of individuals (Kaplan et al., 1989; Kaplan, 2001; Nasar, 2000; White et al., 2010), and healthy environments have been linked to higher satisfaction levels (Hartig et al., 2014). Therefore, we hypothesized lower levels of human well-being and satisfaction in the southern region, where the Draa River shows limited water flow due to the El Mansour Eddahbi dam as well as higher salinity levels (Kaczmarek et al., 2023). However, our findings only indicated a significant correlation between satisfaction with the natural environment and biological quality, but not with overall satisfaction (Kaczmarek et al., 2023). Nevertheless, we observed high levels of overall satisfaction, (i.e., satisfaction with water quality and quantity, agricultural possibilities, environment, health care, and life overall) primarily in the Upper Draa area where water and biological quality were generally good. Additionally, most of the arid and saline Middle and Lower Draa sites exhibited the lowest levels of satisfaction (Kaczmarek et al., 2023). These results suggest that indirect effects, such as the treatment of drinking water, may have overshadowed the correlation between water and biological quality and overall human satisfaction. Further interdisciplinary research is necessary to detect possible associations in this regard.

Our study revealed negative effects of saline river water resources on the local population of the Draa River basin. Although drinking water can undergo treatment to improve its quality, water used for irrigation often remains saline, leading to significant reductions in the growth and yield of salt-tolerant crops such as date palms (Kaczmarek et al., 2023; Tripler et al., 2011). Consequently, groundwater resources are being over-exploited, exacerbating secondary salinization as saline groundwater is utilized for irrigation purposes (Hssaisoune et al., 2020). This, coupled with the cultivation of water-demanding crops such as watermelons (Hssaisoune et al., 2020; Karmaoui et al., 2016), contributes to increasing water scarcity and salinity in the region. These factors not only promote physical diseases but also contribute to emotional distress and have an overall negative impact on human well-being (Kaczmarek et al., 2023).

5.6 Future and conservation

The projected extension of aridity and salinity in the Draa River basin over the coming decades presents significant challenges for the entire basin, including its river and adjacent ecosystems, as well as the human population dependent on it. Maintaining water quality and natural flow regimes of the rivers is crucial for protecting the ecosystem, but it is likely that the increasing water demand to sustain livelihoods in the valley will continue (Karmaoui et al., 2016). However, further intensive use of water resources would limit ecosystem functioning leading to a loss of essential ecosystem services (Jakubínský et al., 2021), thereby compromising river ecosystem health and human well-being (Kaczmarek et al., 2023). Therefore, it is necessary to implement measures that effectively address the increasing water demand and secondary salinization. Water strategies, such as improving irrigation efficiency (Hssaisoune et al., 2020; Jeddi et al., 2021) and reducing agricultural areas (Johannsen et al., 2016), particularly for water-demanding crops like watermelon (Karmaoui et al., 2016), can play a crucial role in limiting the impact. By implementing these strategies adverse effects on water resources can be mitigated and the ecological balance can be preserved. Additionally, maintaining flow in normally perennial rivers would help to support species that are not adapted to drying. As described above, conservation efforts should not only focus on less saline rivers in the High Atlas Mountains but take saline rivers and their adapted communities into account. It is important to note that the challenges faced in the Draa River basin are not solely caused by local processes and activities. Climate change, predominantly caused by the Global North (Harlan et al., 2015), significantly contributes to the increasing droughts experienced in the Draa River basin (Schilling et al., 2012; Schilling et al., 2020), highlighting the consequences of climate change faced by the Global South. Therefore, global efforts to limit global warming and address the impacts of climate change need to be accelerated. A collaborative approach is necessary to ensure the sustainable management of water resources and the protection of ecosystems and human well-being not only in the Draa River basin but also in similar regions worldwide.

5.7 Overall conclusion

The Draa River basin in Northwest Africa is expected to face the expansion of hot and arid climate conditions. Our study demonstrates that the projected rise in temperature, salinity, and intermittency of aquatic ecosystems will result in a decline in macroinvertebrate diversity and the loss of species that are not adapted to these changes. This negative impact will extend to the entire ecosystem and, consequently, the inhabitants of the Draa River basin. To safeguard the integrity of the ecosystem amidst ongoing climate change, it is crucial to protect freshwater environments from additional anthropogenic stressors such as secondary salinization and excessive water abstractions. Promoting sustainable water use for irrigation and cultivating crops that require less water can help alleviate pressure on water resources. Furthermore, it is essential to safeguard both more and less saline rivers, preserve natural water flow, and maintain connectivity between habitats to protect the biotic community of the Draa River basin. Our study revealed direct and indirect relationships between the river ecosystem and human well-being, such as the adverse effects of saline river water on human emotional well-being and overall satisfaction. Protecting the ecosystem, therefore, also benefits the inhabitants through valuable ecosystem services. Future policies and action plans should consider the interdependence between ecosystems and human inhabitants to enhance well-being. However, global efforts to mitigate the impacts of climate change should be intensified, as increasing aridity is caused by global actions. The establishment of barcode and trait databases, the development of multimetric indices capable of identifying poor conditions in naturally saline and intermittent rivers, and the utilization of innovative assessment methods such as metabarcoding can contribute to assessing ecosystem health and better predict future climate change threats.

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Chapter 6

6. Appendix

6.1. Supplementary Material

6.1.1. A: Supplementary Material for Chapter 2: Environmental Change Threatens Freshwater Insect Communities in Northwest Africa: A Meta-Analysis

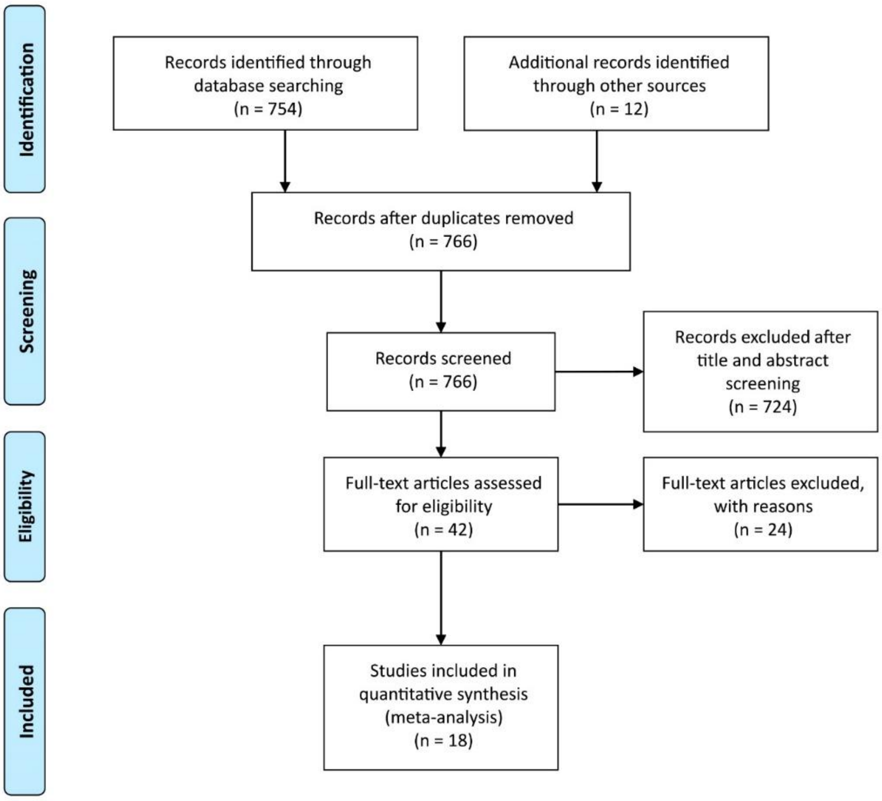

Figure A.1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses; Moher et al. 2009) flow chart presenting the selection of studies for the metaanalysis of associations between climate-related environmental variables and aquatic insects in Northwest Africa.

Chapter 6: Appendix

Table A.1. Publications used in analyses with number of sites, and mean values for number of families (Fam), altitude (Alt, m), water temperature (Temp, [°C]), EC ([µS/cm]), river size (Size, [m²]), Global Aridity Index (GAI), degree of regulation (Reg [%]), cropland extent (Crop, [%]), urban extent (Urb, [%]) and number of samplings taken per site (Samp). In the case of "Bonada", the data was obtained from MacroMED (Blanco-Garrido et al., 2013).

Publication	Sites	Fam	Alt	Temp	EC	Size	GAI	Reg	Crop	Urb	Samp
Benzina, I., Bachir, A. S., Ghazi, C., Santoul, F., Céréghino, R. (2019). How altitudinal gradient affects the diversity and composition of benthic insects in arid areas streams of northern East Algeria?. Biologia 75, 567-577. doi: 10.2478/s11756-019-00326-8	23	8.2	1330	14.2	577	0.5	38	0	0	10	3
Berger, E., Bossenbroek, L., Beermann, A. J., Schäfer, R. B., Znari, M., Riethmüller, S., et al. (2021). Social-ecological interactions in the Draa River Basin, southern Morocco: Towards nature conservation and human well-being using the IPBES framework. Sci. Total. Environ. 769:144492. doi: 10.1016/j.scitotenv.2020.144492	14	12.2	720	29.6	4462	17	8	98	5	14	1
Berrahou, A., Cellot, B., Richoux, P. (2001). Distribution longitudinale des macroinvertébrés benthiques de la Moulouya et de ses principaux affluents (Maroc). Ann. Limnol. - Int. J. Lim. 37(3), 223-235. doi: 10.1051/limn/2001020	10	10.4	624	23.5	1172	8.7	19	33	10	6	2
Bonada, N., Dolédec, S., Statzner, B. (2007). Taxonomic and biological trait differences of stream macroinvertebrate communities between mediterranean and temperate regions: implications for future climatic scenarios. Glo. Change Biol. 13(8), 1658-1671. doi: 10.1111/j.1365-2486.2007.01375.x	3	5	1150	9.9	472	5.5	90	0	1	0	1
Ghougali, F., Bachir, A. S., Chaabane, N., Brik, I., Medjber, R. A., Rouabah, A. (2019). Diversity and distribution patterns of benthic insects in streams of the Aurès arid region (NE Algeria). Oceanol. Hydrobiol. St. 48(1), 31-42. doi: 10.1515/ohs-2019-0004	6	9.7	1264	19.5	654	0.5	40	0	0	5	1
Giudicelli, J., and Dakki, M. (1984). Les Sources du Moyen Atlas et de Rif (Maroc): Faunistique (Description de Deux Espèces Nouvelles de Trichoptères), Écologie, Intérêt Biogéographique. Bijdr. Dierkd. 54, 83-100. doi: 10.1163/26660644-05401007	1	5	1910	9.5	400	1.7	55	0	1	0	7
Gutiérrez-Cánovas, C., Arribas, P., Naselli-Flores, L., Bennas, N., Finocchiaro, M., Millán, A., et al. (2019). Evaluating anthropogenic impacts on naturally stressed ecosystems: Revisiting river classifications and biomonitoring metrics along salinity gradients. Sci. Total. Environ. 658, 912-921. doi: 10.1016/j.scitotenv.2018.12.253	28	15.4	217	18.3	24496	3.8	33	9	10	2	1
Haouchine, N. (2010) Evaluation de la qualité hydrobiologique du réseau hydrographique de l'oued El Harrach (w.de Blida et d'Alger). [dissertation]. [Bab Ezzouar (Algeria)]: Université des sciences et de la technologie Houari-Boumédiène	15	23.7	98	18.7	1530	9.5	63	0	64	55	12
Hinchi, I., Bouayad, K., Fadil, F. (2020). Hydrobiological study of the source Tadout (Middle Atlas, Morocco): Physical chemistry, microbiology and benthic fauna. Global Scient. J. 8(1), 1451-1473.	1	10	1300	18.8	651	3.7	28	0	2	0	8
Karrouch, L., Chahlaoui, A., Essahale, A. (2017). Anthropogenic Impacts on the Distribution and Biodiversity of Benthic Macroinvertebrates and Water Quality of the Boufekrane River, Meknes, Morocco. J. Geosci. Environ. Protect. 5(7), 173-195. doi: 10.4236/gep.2017.57014	6	21	628	19.4	974	7.7	42	0	67	32	12
Maamri, A., Pattee, E., Dolédec, S., Chergui, H. (2005). The benthic macroinvertebrate assemblages in the Zegzel-Cherraa, a partly-temporary river system, Eastern Morocco. Ann. Limnol. - Int. J. Lim. 41(4), 247-257. doi: 10.1051/limn/2005017	5	21.6	265	22.2	366	1	26	0	89	22	12
Mabrouki, Y., Taybi, A. F., El Alami, M., Berrahou, A. (2019). Biotypology of stream macroinvertebrates from North African and semi arid catchment: Oued Za (Morocco). Knowl. Manag. Aquat. Ecosyst. 420:17. doi: 10.1051/kmae/2019009	11	25.7	731	19.9	944	8.8	21	0	1	4	3
Nechad, I., and Fadil, F. (2016). Taxonomic diversity of benthic stands of the Tataw source (Imouzer Marmoucha, Middle Atlas - Morocco). Int. J. Scient. Eng. Res. 7(8), 592-608.	1	10	1710	11.4	353	1.5	20	0	0	0	12

Table A.1. (continued)

Publication	Sites	Fam	Alt	Temp	EC	Size	GAI	Reg	Crop	Urb	Samp
Sellam, N., Viñolas, A., Zouggaghe, F., Moulaï, R. (2019). Assesment of the physico-chemical and biological quality of surface waters in arid and semi-arid regions of Algeria (North-Africa). B. Soc. Zool. Fr. 144(4): 157-178.	2	22	1036	20.9	2957	2.3	20	0	16	0	3
Souilmi, F., Ghedda, K., Fahde, A., Fihri, F. Z. E., Tahraoui, S., Elasri, F., et al. (2019). Taxonomic diversity of benthic macroinvertebrates along the Oum Er Rbia River (Morocco): implications for water quality biomonitoring using indicator species. W. Afr. J. Appl. Ecol. 27(1), 137-149.	10	19.3	709	20.1	2270	6	41	197	57	12	4
Touabay, M., Aouad, N., Mathieu, J. (2002). Etude hydrobiologique d'un cours d'eau du Moyen-Atlas : l'oued Tizguit (Maroc). Ann. Limnol. - Int. J. Lim. 38(1), 65-80. doi: 10.1051/limn/2002007	11	20.5	1654	13.3	382	1.9	67	0	45	12	12
Khebiza, M. Y., Boughrous, A. A., Gabbanini, C., Messouli, M., Messana, G. (2006). Impact of waste discharges on the water quality and interstitial community structure of two Mediterranean rivers. Ital. J. Zool. 73(2), 153-166. doi: 10.1080/11250000600679462	5	13.4	1192	17.1	263	7.8	38	0	41	11	12
Yasri, N. (2009). Diversite, Ecologie et Biogeographie des Macroinvertebres de Quelques Affluents du Mazafran. [dissertation]. [Bab Ezzouar (Algeria)]: Université des sciences et de la technologie Houari-Boumédiène	13	15.3	182	20.3	1257	9.7	67	644	48	37	11

Table A.2. Biological traits used in the study and their different categories, based on Tachet et al. (2000).

Variable	Trait	Category
1	Size	a: ≤ .25 cm; b: > .25-.5 cm; c: > .5-1 cm; d: > 1-2 cm; e: > 2-4 cm; f: > 4-8 cm
2	Life cycle duration	a: ≤ 1 year; b: > 1 year
3	Potential number of cycles / year	a: < 1; b: 1, c: > 1
4	Aquatic stages	a: egg; b: larva; c: nymph; d: adult
5	Reproduction	a: ovoviviparity; b: isolated eggs, free; c: isolated eggs, cemented; d: clutches, cemented or fixed; e: clutches, free; f: clutches, in vegetation; g: clutches, terrestrial
6	Dispersal	a: aquatic passive; b: aquatic active; c: aerial passive; d: aerial active
7	Resistance form	a: eggs, statoblasts; b: cocoons; c: housings against desiccation; d: diapause or dormancy; e: none
8	Respiration	a: tegument; b: gill; c: plastron; d: spiracle; e: hydrostatic vesicle
9	Locomotion and substrate	a: flier; b: surface swimmer; c: full water swimmer; d: crawler; e: burrower; f: interstitial; g: temporarily attached; h: permanently attached
10	Food	a: microorganisms; b: detritus (< 1mm); c: dead plant (≥ 1mm); d: living microphytes; e: living macrophytes; f: dead animal (≥ 1mm); g: living microinvertebrates; h: living macroinvertebrates; i: vertebrates
11	Feeding habits	b: deposit feeder; c: shredder; d: scraper; e: filter-feeder; f: piercer; g: predator; h: parasite

6.1.2. B: Supplementary Material for Chapter 3: Macroinvertebrate community responses to salinity around non-saline – saline confluences in the Draa River basin, Morocco

Table B.1. Full table showing macroinvertebrate community trait profiles for 11 biological traits with 62 modalities for sections and sites for both samplings.

Site	Size							Life cycle duration		Potential number of cycles per year		
	≤ .25 cm	> .25-.5 cm	> .5-1 cm	> 1-2 cm	> 2-4 cm	> 4-8 cm	> 8 cm	≤ 1 year	> 1 year	< 1	1	> 1
Sections												
Tissint												
A1	0.054	0.156	0.356	0.255	0.171	0.008	0.000	0.851	0.149	0.048	0.413	0.539
A2	0.044	0.129	0.366	0.283	0.168	0.010	0.000	0.884	0.116	0.035	0.428	0.538
A3	0.039	0.147	0.404	0.258	0.149	0.003	0.000	0.887	0.113	0.041	0.419	0.540
Iriri / El Mellah												
B1 (Iriri)	0.004	0.162	0.409	0.268	0.129	0.021	0.006	0.694	0.306	0.014	0.506	0.480
B2 (El Mellah)	0.048	0.213	0.431	0.197	0.074	0.028	0.009	0.806	0.194	0.017	0.386	0.597
B3	0.058	0.215	0.402	0.186	0.103	0.027	0.008	0.795	0.205	0.027	0.363	0.610
Dades / M'Goun												
C1 (Dades)	0.035	0.224	0.434	0.206	0.068	0.025	0.006	0.800	0.200	0.009	0.433	0.557
C2 (M'Goun)	0.003	0.228	0.419	0.221	0.090	0.036	0.004	0.848	0.152	0.022	0.457	0.521
C3	0.036	0.278	0.444	0.194	0.045	0.003	0.000	0.956	0.044	0.007	0.400	0.593

Table B.1. (continued)

Site	Aquatic stages				Reproduction								Dispersal			
	egg	larva	nymph	adult	ovoviviparity	isolated eggs, free	isolated eggs, cemented	clutches, cemented or fixed	clutches, free	clutches, in vegetation	clutches, terrestrial	asexual reproduction	aquatic passive	aquatic active	aerial passive	aerial active
Sections																
Tissint																
A1	0.365	0.365	0.146	0.124	0.113	0.089	0.166	0.483	0.054	0.038	0.057	0.000	0.382	0.251	0.113	0.254
A2	0.384	0.349	0.128	0.138	0.116	0.080	0.161	0.533	0.030	0.023	0.058	0.000	0.407	0.257	0.103	0.233
A3	0.365	0.374	0.152	0.108	0.104	0.091	0.200	0.481	0.064	0.010	0.050	0.000	0.376	0.250	0.120	0.254
Iriri / El Mellah																
B1 (Iriri)	0.370	0.400	0.135	0.096	0.074	0.118	0.150	0.476	0.041	0.049	0.063	0.029	0.294	0.309	0.137	0.260
B2 (El Mellah)	0.348	0.414	0.172	0.065	0.029	0.112	0.183	0.483	0.056	0.018	0.072	0.047	0.379	0.223	0.152	0.246
B3	0.358	0.407	0.163	0.072	0.055	0.117	0.180	0.470	0.042	0.024	0.068	0.043	0.364	0.222	0.151	0.263
Dades / M'Goun																
C1 (Dades)	0.333	0.423	0.183	0.061	0.027	0.116	0.189	0.411	0.083	0.060	0.081	0.034	0.348	0.210	0.152	0.290
C2 (M'Goun)	0.321	0.411	0.233	0.036	0.011	0.136	0.152	0.488	0.099	0.025	0.070	0.019	0.317	0.210	0.203	0.270
C3	0.355	0.409	0.209	0.028	0.000	0.095	0.225	0.562	0.056	0.000	0.062	0.000	0.348	0.206	0.191	0.256

Table B.1. (continued)

Site	Resistance forms					Respiration				Locomotion and substrate relation					
	eggs, statoblasts	cocoons	housings against desiccation	diapause or dormancy	none	tegument	gill	plastron	spiracle	flier	surface swimmer	full water swimmer	crawler	burrower	interstitial
Sections															
Tissint															
A1	0.168	0.000	0.023	0.162	0.648	0.366	0.554	0.021	0.060	0.003	0.046	0.265	0.464	0.051	0.060
A2	0.170	0.000	0.023	0.184	0.623	0.359	0.567	0.020	0.055	0.000	0.047	0.232	0.506	0.052	0.059
A3	0.212	0.000	0.027	0.136	0.625	0.380	0.573	0.013	0.034	0.000	0.047	0.274	0.459	0.052	0.063
Iriri / El Mellah															
B1 (Iriri)	0.222	0.079	0.000	0.113	0.587	0.474	0.378	0.000	0.148	0.008	0.014	0.193	0.461	0.107	0.089
B2 (El Mellah)	0.169	0.077	0.000	0.158	0.597	0.473	0.386	0.016	0.125	0.003	0.021	0.182	0.416	0.101	0.115
B3	0.155	0.065	0.000	0.148	0.632	0.482	0.394	0.019	0.105	0.004	0.008	0.212	0.412	0.092	0.107
Dades / M'Goun															
C1 (Dades)	0.169	0.052	0.000	0.130	0.649	0.454	0.395	0.017	0.133	0.014	0.014	0.192	0.429	0.102	0.117
C2 (M'Goun)	0.178	0.062	0.000	0.101	0.659	0.478	0.447	0.000	0.075	0.004	0.011	0.131	0.485	0.123	0.106
C3	0.230	0.000	0.000	0.156	0.614	0.460	0.475	0.013	0.052	0.000	0.021	0.148	0.514	0.057	0.090

Table B.1. (continued)

Site	Locomotion and substrate relation (continued)		Food								
	temporarily attached	permanently attached	microorganisms	detritus (< 1mm)	dead plant (>= 1mm)	living microphytes	living macrophytes	dead animal (>= 1mm)	living microinvertebrates	living macroinvertebrates	vertebrates
Sections											
Tissint											
A1	0.111	0.000	0.008	0.174	0.133	0.274	0.124	0.037	0.114	0.114	0.022
A2	0.104	0.000	0.010	0.184	0.151	0.289	0.124	0.041	0.112	0.080	0.008
A3	0.105	0.000	0.010	0.188	0.139	0.293	0.113	0.041	0.105	0.107	0.004
Iriri / El Mellah											
B1 (Iriri)	0.127	0.001	0.022	0.245	0.103	0.234	0.079	0.022	0.082	0.172	0.041
B2 (El Mellah)	0.159	0.001	0.029	0.277	0.071	0.268	0.105	0.027	0.110	0.097	0.016
B3	0.163	0.001	0.025	0.272	0.075	0.260	0.120	0.023	0.106	0.098	0.021
Dades / M'Goun											
C1 (Dades)	0.132	0.001	0.028	0.255	0.095	0.256	0.090	0.034	0.105	0.090	0.047
C2 (M'Goun)	0.140	0.001	0.034	0.263	0.121	0.271	0.111	0.036	0.087	0.055	0.022
C3	0.171	0.000	0.023	0.246	0.110	0.292	0.154	0.040	0.096	0.039	0.000

Table B.1. (continued)

Site	Feeding habits							
	absorber	deposit feeder	shredder	scraper	filter-feeder	piercer	predator	parasite
Sections								
Tissint								
A1	0.000	0.167	0.166	0.321	0.102	0.074	0.153	0.016
A2	0.000	0.177	0.166	0.372	0.126	0.040	0.104	0.015
A3	0.000	0.196	0.148	0.336	0.098	0.045	0.161	0.015
Iriri / El Mellah								
B1 (Iriri)	0.009	0.236	0.131	0.244	0.138	0.073	0.153	0.016
B2 (El Mellah)	0.014	0.277	0.098	0.218	0.162	0.099	0.114	0.019
B3	0.013	0.259	0.108	0.242	0.148	0.119	0.092	0.019
Dades / M'Goun								
C1 (Dades)	0.010	0.283	0.128	0.219	0.133	0.093	0.114	0.020
C2 (M'Goun)	0.006	0.286	0.141	0.252	0.134	0.059	0.102	0.020
C3	0.000	0.264	0.112	0.286	0.132	0.117	0.068	0.021

Table B.2. Full table describing all nine sites per confluence and sampling, with time, location, physico-chemical parameters, ion composition, substrate, abundance list of macroinvertebrates, and metrics/indices (%EPT = Percentage of Ephemeroptera, Plecoptera, and Trichoptera; IBMWP = Iberian biological monitoring working party; IBGN = Indice Biologique Global Normalisé).

Site	**Time**		**Location**		
	Date	Time	Latitude	Longitude	Alt
Tissint					
Sampling 1 (June)					
A1 US	20/06/2022	15:00	29.90921700	-7.33197200	591
A1 MS	20/06/2022	13:00	29.909434	-7.330968	588
A1 DS	20/06/2022	16:00	29.90984100	-7.33021400	583
A2 US	20/06/2022	12:50	29.91284200	-7.33193400	583
A2 MS	20/06/2022	11:50	29.91113800	-7.33102000	585
A2 DS	20/06/2022	13:10	29.91056000	-7.33053500	581
A3 US	21/06/2022	10:07	29.91022980	-7.32886020	580
A3 MS	20/06/2022	17:00	29.910016	-7.327408	580
A3 DS	21/06/2022	10:30	29.9100450	-7.3262417	579
Sampling 2 (Sept.)					
A1 US	30/09/2022	12:30	29.90921700	-7.33197200	591
A1 MS	30/09/2022	12:00	29.909434	-7.330968	588
A1 DS	30/09/2022	14:00	29.90984100	-7.33021400	583
A2 US	30/09/2022	11:00	29.91284200	-7.33193400	583
A2 MS	30/09/2022	10:30	29.91113800	-7.33102000	585
A2 DS	30/09/2022	11:30	29.91056000	-7.33053500	581
A3 US	30/09/2022	14:30	29.91022980	-7.32886020	580
A3 MS	30/09/2022	15:00	29.910016	-7.327408	580
A3 DS	30/09/2022	15:30	29.9100450	-7.3262417	579
Iriri / El Mellah					
Sampling 1 (June)					
B1 (Iriri) US	28/06/2022	13:45	30.9579224	-7.090268	1191
B1 (Iriri) MS	28/06/2022	13:20	30.9589146	-7.0889463	1190
B1 (Iriri) DS	28/06/2022	12:50	30.959032	-7.08839	1190
B2 (El Mellah) US	28/06/2022	15:00	30.9602303	-7.0895465	1191
B2 (El Mellah) MS	28/06/2022	14:40	30.9595178	-7.0885554	1190
B2 (El Mellah) DS	28/06/2022	14:10	30.9591202	-7.08762	1191
B3 US	28/06/2022	15:30	30.958977	-7.0867754	1194
B3 MS	28/06/2022	16:00	30.9586429	-7.0859879	1193
B3 DS	28/06/2022	16:20	30.9580711	-7.0854108	1191
Sampling 2 (Oct.)					
B1 (Iriri) US	03/10/2022	13:15	30.9579224	-7.090268	1191
B1 (Iriri) MS	03/10/2022	13:00	30.9589146	-7.0889463	1190
B1 (Iriri) DS	03/10/2022	12:30	30.959032	-7.08839	1190
B2 (El Mellah) US	03/10/2022	12:15	30.9602303	-7.0895465	1191
B2 (El Mellah) MS	03/10/2022	12:00	30.9595178	-7.0885554	1190
B2 (El Mellah) DS	03/10/2022	11:30	30.9591202	-7.08762	1191
B3 US	03/10/2022	10:30	30.958977	-7.0867754	1194
B3 MS	03/10/2022	11:00	30.9586429	-7.0859879	1193
B3 DS	03/10/2022	10:00	30.9580711	-7.0854108	1191
Dades / M'Goun					
C1 (Dades) US	26/06/2022	13:30	31.1832496	-6.1851207	1359
C1 (Dades) MS	26/06/2022	12:30	31.1828202	-6.18627	1358
C1 (Dades) DS	26/06/2022	11:45	31.182843	-6.18787	1359
C2 (M'Goun) US	26/06/2022	15:00	31.1855551	-6.1895296	1358
C2 (M'Goun) MS	26/06/2022	14:45	31.1841806	-6.1895379	1358
C2 (M'Goun) DS	26/06/2022	14:10	31.1833629	-6.1888215	1357
C3 US	26/06/2022	16:30	31.1834601	-6.1893944	1357
C3 MS	26/06/2022	16:00	31.1837128	-6.1913833	1358
C3 DS	26/06/2022	15:30	31.1833129	-6.1945436	1353

Table B.2. (continued)

Site	Physico-chemical parameters									Ion composition								
	Water Temperature [°C]	pH	Conductivity [µS/cm]	Oxygen [mg/L]	Oxygen [%]	Width [m]	Depth [cm]	Flow velocity [m/s]	Flow rate [m³/s]	Ammonium NH_4^+ (mg/l)	Nitrate NO_3^- (mg/l)	Nitrite NO_2^- (mg/l)	Phosphate PO_4 (mg/l)	Chloride Cl^- (mg/l)	Potassium K^+ (mg/l)	Sulfate SO_4^{2-} (mg/L)	Total hardness (°d)	Carbonate hardness (°d)
A1 US	29.6	7.52	5620	12.9	181.1	3	12.67	0.28	0.03	NA	NA	NA	NA	NA	NA	NA	NA	NA
A1 MS	30.8	7.79	5590	15.48	>200	5.5	12	0.14	0.04	<0.1	8.5	0.03	3.8	3300	18	132	200	100
A1 DS	31.2	7.90	5590	11.35	163.8	13.5	16.33	0.16	0.08	NA	NA	NA	NA	NA	NA	NA	NA	NA
A2 US	28.3	7.45	10750	9.53	130.3	20	38	0.02	0.03	NA	NA	NA	NA	NA	NA	NA	NA	NA
A2 MS	28.2	7.66	10790	11.02	150.5	5.2	24	0.09	0.03	<0.1	7.8	0.07	3.1	53000	27	157	200	100
A2 DS	27.7	7.20	8420	8.18	111	12	48	0.03	0.04	NA	NA	NA	NA	NA	NA	NA	NA	NA
A3 US	26.7	7.50	7240	8.21	109.7	7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
A3 MS	30.8	7.45	7490	10.55	152	17.5	66	0.05	0.11	<0.1	13	0.05	3.4	6500	23	141	200	100
A3 DS	27.2	7.73	7370	8.71	117.7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
A1 US	26.2	7.51	5640	10.36	137.3	1.7	14.67	0.31	0.02	NA	NA	NA	NA	NA	NA	NA	NA	NA
A1 MS	26.6	7.73	5630	13.4	184.3	5.5	12.33	0.15	0.02	<0.1	NA	0.03	3.3	4900	19	NA	600	200
A1 DS	28.2	7.91	5610	10.57	145.5	5.7	10	0.37	0.04	NA	NA	NA	NA	NA	NA	NA	NA	NA
A2 US	25.7	7.58	11210	7.32	96	8.7	37.67	0.03	0.02	NA	NA	NA	NA	NA	NA	NA	NA	NA
A2 MS	24.8	7.71	11150	8.7	112.8	3.7	19.67	0.18	0.03	<0.1	NA	0.07	2.5	20000	26	NA	400	200
A2 DS	26.2	7.31	8740	7.74	103.4	7.5	50.33	0.04	0.04	NA	NA	NA	NA	NA	NA	NA	NA	NA
A3 US	28.1	7.54	7400	9.51	131.2	9.4	14.67	0.14	0.05	NA	NA	NA	NA	NA	NA	NA	NA	NA
A3 MS	28.7	7.58	7280	9.31	131.3	8.4	68	0.06	0.09	<0.1	NA	0.05	3.7	6400	22	NA	400	200
A3 DS	29	7.74	7380	9.41	132	8.3	16.67	0.29	0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA
B1 US	20.6	7.69	845	4.52	57.9	1.1	37	0.02	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA
B1 MS	20.2	7.69	764	4.35	55.1	1.6	18.33	0.48	0.02	<0.1	<4.0	<0.02	2.3	53	4	62	100	10
B1 DS	21.2	7.82	792	4.25	54.7	4.6	7.3	0.61	0.04	NA	NA	NA	NA	NA	NA	NA	NA	NA
B2 US	24.7	7.81	2800	6.79	93.8	4.8	11.67	0.28	0.03	NA	NA	NA	NA	NA	NA	NA	NA	NA
B2 MS	24.2	7.72	2740	5.75	78.4	5.2	27.5	0.03	0.01	<0.1	<4.0	<0.02	1	3300	8	209	100	20
B2 DS	23.8	7.65	2560	5.24	71.1	4.1	7.5	0.45	0.03	NA	NA	NA	NA	NA	NA	NA	NA	NA
B3 US	24.8	7.83	2270	6.17	85.2	6.9	9.5	0.53	0.08	NA	NA	NA	NA	NA	NA	NA	NA	NA
B3 MS	24.6	7.83	1955	6.21	85.8	6.4	18.33	0.24	0.06	<0.1	<4.0	0.03	<0.6	150	6	162	40	20
B3 DS	25.1	7.82	1961	6.61	91.7	8.3	8	0.47	0.09	NA	NA	NA	NA	NA	NA	NA	NA	NA
B1 US	21.1	7.60	774	2.21	28.1	1	49.67	0.04	0.00	NA	NA	NA	NA	NA	NA	NA	NA	NA
B1 MS	21.1	7.65	751	4.33	55.4	2.8	21.67	0.20	0.02	<0.1	NA	<0.02	<0.6	1600	6	NA	400	200
B1 DS	21.4	7.57	918	4.15	53.2	4.75	10.33	0.22	0.03	NA	NA	NA	NA	NA	NA	NA	NA	NA
B2 US	22	7.63	2050	5.74	74.4	3.5	10.67	0.31	0.03	NA	NA	NA	NA	NA	NA	NA	NA	NA
B2 MS	21.8	7.66	2200	5.6	72.3	3.5	29	0.08	0.02	<0.1	NA	<0.02	<0.6	3000	7	NA	400	200
B2 DS	21.6	7.77	2300	7.07	91	2.2	10	0.61	0.03	NA	NA	NA	NA	NA	NA	NA	NA	NA
B3 US	20.7	7.77	1988	6.62	83.7	4.2	13.17	0.49	0.06	NA	NA	NA	NA	NA	NA	NA	NA	NA
B3 MS	21	7.79	1795	6.77	86	5.8	27.33	0.11	0.05	<0.1	NA	<0.02	<0.6	1700	7	NA	500	200
B3 DS	20.2	7.82	1812	7.06	88.3	6.9	11	0.36	0.07	NA	NA	NA	NA	NA	NA	NA	NA	NA
C1 US	23	8.35	882	7.02	100.1	2.2	17	0.37	0.01	NA	NA	NA	NA	NA	NA	NA	NA	NA
C1 MS	23.5	8.27	1295	8.46	116.9	4.12	11.67	0.13	0.01	<0.1	<4.0	<0.02	1.9	400	3	159	200	100
C1 DS	22.4	8.28	1304	8.61	121.2	4.1	8.83	0.25	0.02	NA	NA	NA	NA	NA	NA	NA	NA	NA
C2 US	25.2	8.18	1303	8.77	125.4	7.2	16	0.44	0.14	NA	NA	NA	NA	NA	NA	NA	NA	NA
C2 MS	29.1	8.23	1263	8.85	136.1	9.1	16.67	0.75	0.27	<0.1	<4.0	<0.02	<0.6	500	<2	113	100	10
C2 DS	28.7	8.30	1267	9.33	142.2	7	12	0.71	0.16	NA	NA	NA	NA	NA	NA	NA	NA	NA
C3 US	28.2	8.23	1285	9.02	136.4	8.4	17.83	0.83	0.33	NA	NA	NA	NA	NA	NA	NA	NA	NA
C3 MS	33.1	7.93	1659	7.77	127.6	7.3	25	0.60	0.24	<0.1	<4.0	<0.02	<0.6	300	2	127	100	11
C3 DS	29	7.79	1590	6.52	98.9	22.95	15.17	0.43	0.38	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table B.2. (continued)

Site	Substrate										Macroinvertebrates						
	Mega-lithal	Macro-lithal	Meso-lithal	Micro-lithal	Akal	Psammal/ psammopelal	Algae	Submerged macrophytes	Emergent macrophytes	Living parts of terrestrial plants	*Caenis pusilla*	*Caenis luctuosa*	*Baetis pavidus*	*Procloeon stagnicola*	*Cheleocloeon dimorphicum*	*Cloeon simile*	*Ecdyonurus rothschildi*
A1 US	0.00	3.57	3.57	3.57	3.57	7.14	3.57	3.57	64.29	7.14	0	9	108	0	0	12	0
A1 MS	0.00	11.11	11.11	11.11	11.11	11.11	5.56	5.56	33.33	0.00	0	10	56	0	0	47	0
A1 DS	45.45	4.55	4.55	4.55	4.55	4.55	13.64	4.55	13.64	0.00	0	168	83	0	0	98	0
A2 US	0.00	0.00	0.00	4.17	8.33	50.00	0.00	4.17	33.33	0.00	0	20	20	0	0	38	0
A2 MS	3.57	3.57	21.43	21.43	10.71	3.57	3.57	3.57	28.57	0.00	0	70	9	0	0	47	0
A2 DS	0.00	0.00	0.00	4.55	4.55	59.09	0.00	4.55	27.27	0.00	0	41	1206	0	0	3	0
A3 US	0.00	0.00	17.39	17.39	17.39	8.70	4.35	4.35	26.09	4.35	0	227	275	6	0	0	0
A3 MS	0.00	0.00	11.11	11.11	22.22	22.22	0.00	5.56	22.22	5.56	0	16	2	0	0	52	0
A3 DS	10.53	10.53	21.05	10.53	10.53	10.53	5.26	5.26	10.53	5.26	0	118	92	14	0	7	0
A1 US	0.00	3.57	3.57	3.57	3.57	7.14	3.57	3.57	64.29	7.14	0	4	18	1	0	0	0
A1 MS	0.00	11.11	11.11	11.11	11.11	11.11	5.56	5.56	33.33	0.00	0	158	281	0	0	13	0
A1 DS	45.45	4.55	4.55	4.55	4.55	4.55	13.64	4.55	13.64	0.00	0	28	23	0	0	0	0
A2 US	0.00	0.00	0.00	4.17	8.33	50.00	0.00	4.17	33.33	0.00	0	240	78	0	0	8	0
A2 MS	3.57	3.57	21.43	21.43	10.71	3.57	3.57	3.57	28.57	0.00	0	360	620	0	0	0	0
A2 DS	0.00	0.00	0.00	4.55	4.55	59.09	0.00	4.55	27.27	0.00	0	125	0	0	0	52	0
A3 US	0.00	0.00	17.39	17.39	17.39	8.70	4.35	4.35	26.09	4.35	0	102	96	0	0	0	0
A3 MS	0.00	0.00	11.11	11.11	22.22	22.22	0.00	5.56	22.22	5.56	0	390	436	0	0	14	0
A3 DS	10.53	10.53	21.05	10.53	10.53	10.53	5.26	5.26	10.53	5.26	0	13	3	0	0	8	0
B1 US	0.00	7.14	10.71	10.71	3.57	0.00	3.57	14.29	35.71	14.29	0	364	2	2	0	57	0
B1 MS	5.56	16.67	16.67	5.56	0.00	0.00	11.11	22.22	16.67	5.56	0	215	23	1	0	14	0
B1 DS	0.00	11.11	16.67	11.11	5.56	0.00	5.56	33.33	11.11	5.56	0	392	145	0	0	2	0
B2 US	0.00	5.26	10.53	10.53	21.05	21.05	5.26	10.53	5.26	10.53	0	289	92	0	0	2	0
B2 MS	0.00	4.55	13.64	9.09	9.09	18.18	9.09	13.64	4.55	18.18	0	161	0	0	0	8	0
B2 DS	0.00	10.53	15.79	10.53	10.53	10.53	5.26	21.05	5.26	10.53	0	272	19	0	0	0	0
B3 US	10.53	15.79	21.05	10.53	10.53	10.53	5.26	5.26	5.26	5.26	0	111	227	0	0	0	0
B3 MS	23.53	17.65	11.76	11.76	5.88	5.88	5.88	5.88	5.88	5.88	0	163	11	0	0	0	0
B3 DS	18.18	22.73	13.64	9.09	9.09	4.55	4.55	9.09	4.55	4.55	0	67	140	0	0	0	0
B1 US	0.00	7.14	10.71	10.71	3.57	0.00	3.57	14.29	35.71	14.29	0	11	0	0	0	2	0
B1 MS	5.56	16.67	16.67	5.56	0.00	0.00	11.11	22.22	16.67	5.56	0	34	8	1	1	0	0
B1 DS	0.00	11.11	16.67	11.11	5.56	0.00	5.56	33.33	11.11	5.56	0	222	57	0	2	0	0
B2 US	0.00	5.26	10.53	10.53	21.05	21.05	5.26	10.53	5.26	10.53	0	49	40	0	0	0	0
B2 MS	0.00	4.55	13.64	9.09	9.09	18.18	9.09	13.64	4.55	18.18	0	6	4	0	0	0	0
B2 DS	0.00	10.53	15.79	10.53	10.53	10.53	5.26	21.05	5.26	10.53	0	57	53	0	0	0	0
B3 US	10.53	15.79	21.05	10.53	10.53	10.53	5.26	5.26	5.26	5.26	0	80	185	0	0	0	0
B3 MS	23.53	17.65	11.76	11.76	5.88	5.88	5.88	5.88	5.88	5.88	0	300	0	0	14	90	0
B3 DS	18.18	22.73	13.64	9.09	9.09	4.55	4.55	9.09	4.55	4.55	0	33	180	0	2	0	0
C1 US	0.00	14.29	21.43	28.57	14.29	0.00	7.14	0.00	14.29	0.00	0	446	19	0	0	0	0
C1 MS	0.00	15.38	30.77	30.77	15.38	0.00	7.69	0.00	0.00	0.00	0	320	45	0	0	5	0
C1 DS	0.00	7.69	23.08	30.77	30.77	0.00	7.69	0.00	0.00	0.00	0	154	0	0	0	0	0
C2 US	0.00	10.00	15.00	30.00	5.00	5.00	5.00	25.00	5.00	0.00	0	104	76	0	0	0	0
C2 MS	0.00	21.05	21.05	21.05	5.26	0.00	5.26	21.05	5.26	0.00	0	144	114	0	0	0	2
C2 DS	6.67	26.67	26.67	13.33	6.67	0.00	6.67	6.67	6.67	0.00	5	61	136	0	0	0	2
C3 US	10.53	5.26	10.53	42.11	15.79	0.00	5.26	0.00	10.53	0.00	0	47	83	2	0	0	0
C3 MS	5.56	5.56	16.67	44.44	16.67	0.00	5.56	0.00	5.56	0.00	0	47	71	0	0	0	0
C3 DS	0.00	5.00	10.00	40.00	15.00	0.00	5.00	5.00	20.00	0.00	5	127	91	0	0	0	2

Table B.2. (continued)

Site	Macroinvertebrates (continued)																
	Hydropsyche	*Oxyethira sp.*	*Orthotrichia sp.*	*Hydroptila vectis*	*Polycentropodidae*	*Orthocladiinae*	*Tanytarsini*	*Tanypodinae*	*Simulium sp.*	*Anthomyiidae*	*Tabanidae*	*Ceratopogonidae*	*Dixidae*	*Limoniidae*	*Tipulidae*	*Stratiomyidae*	*Bidessus minutissimus*
A1 US	5	3	0	0	0	649	0	2	9	0	0	0	0	0	0	0	1
A1 MS	20	2	0	0	0	196	0	0	16	0	0	23	0	0	0	0	0
A1 DS	3	0	3	0	0	65	0	7	10	0	0	2	0	0	0	0	2
A2 US	3	0	0	0	0	56	0	0	0	0	0	0	0	0	0	0	0
A2 MS	0	0	0	0	0	17	0	0	0	0	0	1	0	0	0	0	0
A2 DS	238	0	0	3	0	230	0	0	12	0	0	21	0	0	0	0	0
A3 US	30	8	0	0	0	290	0	0	15	0	0	25	0	0	0	0	0
A3 MS	0	3	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0
A3 DS	2	4	0	0	0	22	0	0	3	0	0	11	0	0	0	0	0
A1 US	1	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0
A1 MS	33	2	0	0	0	94	0	0	21	0	0	48	0	0	0	0	0
A1 DS	0	0	0	0	0	34	0	0	0	0	0	0	0	0	0	0	0
A2 US	88	0	0	0	0	86	0	0	0	0	0	24	0	0	0	0	0
A2 MS	119	0	0	0	0	69	0	0	42	0	1	0	0	0	0	0	0
A2 DS	0	0	0	0	0	23	0	0	0	0	0	6	0	0	0	0	0
A3 US	7	0	0	0	0	32	0	0	4	0	0	10	0	0	0	0	0
A3 MS	12	0	0	0	0	76	0	24	8	0	0	48	0	0	0	0	0
A3 DS	0	0	0	0	1	13	0	3	0	0	0	3	0	0	0	0	0
B1 US	0	0	0	0	0	56	0	0	0	0	0	0	0	0	0	0	0
B1 MS	7	0	0	8	0	88	0	0	30	0	0	2	0	0	0	0	0
B1 DS	46	0	0	11	0	79	0	0	7	0	4	5	0	0	0	0	0
B2 US	68	0	0	12	0	34	0	0	3	0	0	0	0	0	0	0	0
B2 MS	0	2	0	0	0	19	0	0	0	0	0	0	0	0	0	0	0
B2 DS	6	0	0	7	0	10	0	2	0	0	2	2	0	0	0	0	0
B3 US	72	0	0	43	0	52	0	0	0	0	4	0	0	0	0	0	0
B3 MS	10	0	0	15	0	11	0	1	1	0	0	3	0	0	0	0	0
B3 DS	29	0	0	16	0	23	0	0	0	0	0	0	0	0	0	0	0
B1 US	0	0	0	0	0	19	0	0	2	0	0	0	0	0	0	0	0
B1 MS	3	0	0	4	0	56	0	0	346	0	0	0	0	0	0	0	0
B1 DS	46	0	0	6	0	108	0	0	131	0	0	0	0	17	0	0	0
B2 US	13	0	0	4	0	52	0	0	30	0	1	2	0	0	0	0	0
B2 MS	0	0	0	0	0	8	0	0	0	0	0	0	4	0	0	0	0
B2 DS	37	0	0	0	0	23	0	0	8	0	0	0	0	0	0	0	0
B3 US	84	6	0	10	0	86	0	0	67	0	1	0	0	0	0	0	0
B3 MS	0	0	0	0	0	198	0	0	2	0	0	0	0	0	0	0	0
B3 DS	115	0	0	11	0	130	0	0	86	0	0	0	0	0	0	0	0
C1 US	8	1	0	3	0	36	0	1	17	0	0	0	0	0	0	1	0
C1 MS	13	0	0	1	0	38	0	8	0	1	1	3	0	0	0	0	0
C1 DS	2	0	0	0	0	11	0	3	0	0	0	0	0	0	0	0	0
C2 US	0	0	0	0	0	18	12	0	0	0	0	0	0	0	0	0	0
C2 MS	61	0	0	31	0	119	0	7	3	0	0	5	0	0	6	0	0
C2 DS	25	0	0	20	0	49	0	0	4	0	0	7	0	0	12	0	0
C3 US	6	1	0	2	0	19	0	0	1	0	0	1	0	0	0	0	0
C3 MS	4	0	0	6	0	18	0	1	0	0	0	0	0	0	0	1	0
C3 DS	26	1	3	14	0	68	0	1	4	0	0	4	0	0	0	0	0

Table B.2. (continued)

Site	Macroinvertebrates (continued)														
	Bidessus minutissimus	*Nebrioporus clarki*	*Pomatinus substriatus*	Ostracoda	*Atyaephyra desmaresti*	*Brachythemis leucosticta*	Odonata	*Melanopsis cariosa*	*Radix balthica*	*Physella acuta*	*Planorbis metidjensis*	*Micronecta*	Oligochaeta	Hydracarina	Tricladida
A1 US	1	0	0	0	0	0	16	687	0	0	4	34	0	0	0
A1 MS	0	0	0	0	1	0	14	710	0	0	7	24	0	0	0
A1 DS	2	0	0	0	2	0	9	300	0	0	0	12	0	0	0
A2 US	0	0	0	0	104	0	8	602	0	0	0	6	0	0	0
A2 MS	0	0	0	0	2	0	11	214	0	0	0	7	0	0	0
A2 DS	0	0	0	0	1	0	0	57	0	0	2	0	0	0	0
A3 US	0	0	0	0	6	0	1	74	0	0	4	5	0	0	0
A3 MS	0	0	0	0	13	0	2	21	0	0	0	0	0	0	0
A3 DS	0	0	0	0	11	0	1	266	0	0	1	2	0	0	0
A1 US	0	0	0	2	15	10	0	562	0	0	6	3	0	0	0
A1 MS	0	0	0	7	26	10	0	0	0	0	0	15	0	0	0
A1 DS	0	0	0	0	108	0	0	396	0	0	0	0	0	0	0
A2 US	0	0	0	16	22	0	0	280	0	0	0	18	0	0	0
A2 MS	0	0	0	0	0	2	0	245	0	0	14	0	0	0	0
A2 DS	0	0	0	0	4	0	18	240	0	14	0	23	0	0	0
A3 US	0	0	0	0	2	2	0	236	0	0	22	0	0	0	0
A3 MS	0	0	0	10	38	23	0	34	0	0	0	6	0	0	0
A3 DS	0	0	0	0	13	11	0	186	0	0	0	0	0	0	0
B1 US	0	9	0	0	0	3	0	0	0	0	0	0	2	0	9
B1 MS	0	7	0	6	5	0	0	0	0	0	0	0	3	8	124
B1 DS	0	22	0	10	2	0	0	0	8	0	0	0	68	0	132
B2 US	0	2	0	0	0	1	0	0	0	0	0	0	0	24	0
B2 MS	0	0	0	4	0	1	0	0	0	0	0	10	35	0	0
B2 DS	0	0	0	14	0	0	0	0	0	0	0	0	214	3	0
B3 US	0	1	0	0	0	0	0	0	0	0	0	1	227	1	0
B3 MS	0	0	0	0	0	0	0	0	0	0	0	0	38	14	0
B3 DS	0	0	0	0	0	0	0	0	0	0	0	0	437	0	0
B1 US	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0
B1 MS	0	2	0	0	0	0	0	0	0	0	0	0	4	0	63
B1 DS	0	7	0	8	0	0	0	0	0	0	0	0	44	0	7
B2 US	0	0	0	3	0	0	0	0	0	0	0	0	16	0	1
B2 MS	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
B2 DS	0	0	0	0	0	0	0	0	0	0	0	0	84	0	0
B3 US	0	2	0	0	0	0	0	0	0	0	0	0	38	0	0
B3 MS	0	0	0	0	1	21	0	0	1	0	0	34	14	0	0
B3 DS	0	2	0	0	0	0	0	0	0	0	0	0	13	0	0
C1 US	0	8	0	0	0	1	0	0	0	0	0	3	0	0	0
C1 MS	0	5	1	0	0	0	0	0	0	0	0	0	20	0	0
C1 DS	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0
C2 US	0	2	0	0	0	0	0	0	2	0	0	0	8	0	0
C2 MS	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
C2 DS	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
C3 US	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
C3 MS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C3 DS	0	0	0	0	0	0	0	0	1	0	0	2	0	0	0

Table B.2. (continued)

Site						
	Specimens	Taxa	%EPT (Abundance)	%EPT (Presence)	IBMWP	IBGN
A1 US	1539	13	8.9	38.5	43	9
A1 MS	1126	13	12.0	38.5	50	7
A1 DS	764	14	46.5	35.7	50	9
A2 US	857	9	9.5	44.4	32	5
A2 MS	378	9	33.3	33.3	31	4
A2 DS	1814	11	82.2	45.5	39	8
A3 US	966	13	56.5	38.5	50	9
A3 MS	117	8	62.4	50.0	30	7
A3 DS	554	14	42.8	42.9	50	9
A1 US	628	11	3.8	36.4	35	5
A1 MS	708	12	68.8	41.7	50	6
A1 DS	589	5	8.7	40.0	16	3
A2 US	860	10	48.1	40.0	31	6
A2 MS	1472	9	74.7	33.3	32	5
A2 DS	505	9	35.0	22.2	37	5
A3 US	513	10	40.0	30.0	38	5
A3 MS	1119	13	76.1	30.8	44	7
A3 DS	254	10	9.8	40.0	38	5
B1 US	504	9	84.3	44.4	27	4
B1 MS	541	15	49.5	40.0	52	9
B1 DS	933	15	63.9	33.3	55	9
B2 US	527	10	87.9	50.0	41	8
B2 MS	240	8		37.5	31	4
B2 DS	551	11	55.2	36.4	37	8
B3 US	739	10	61.3	40.0	36	8
B3 MS	267	10	74.5	40.0	35	8
B3 DS	712	6	35.4	66.7	22	6
B1 US	38	6	34.2	33.3	29	3
B1 MS	522	11	9.8	54.5	35	8
B1 DS	655	12	50.8	41.7	42	8
B2 US	211	11	50.2	36.4	43	8
B2 MS	24	5	41.7	40.0	22	2
B2 DS	262	6	56.1	50.0	21	5
B3 US	559	10	65.3	50.0	34	8
B3 MS	675	10	59.9	30.0	36	5
B3 DS	572	9	59.6	55.6	30	7
C1 US	544	12	87.7	41.7	44	8
C1 MS	461	13	83.3	38.5	38	7
C1 DS	179	5	87.2	40.0	16	3
C2 US	222	7	81.1	28.6	17	4
C2 MS	493	11	71.4	45.5	48	8
C2 DS	322	11	77.3	54.5	49	8
C3 US	164	11	86.0	54.5	36	6
C3 MS	148	7	86.5	57.1	25	7
C3 DS	349	14	77.1	57.1	46	9

Table B.3. Table describing sites with up- mid-, and downstream sites per tributary and the joint downstream section summarized with physico-chemical parameters, ion composition, abundance list of macroinvertebrates, and metrics/indices (%EPT = Percentage of Ephemeroptera, Plecoptera, and Trichoptera; %DCOH = Percentage of Diptera, Coleoptera, Odonata, Hemiptera; EPT/DCOH = ratio of EPT to DCOH; IBMWP = Iberian biological monitoring working party; IBGN = Indice Biologique Global Normalisé).

Site	**Physico-chemical parameters**						**Ion composition**								
	Water Temperature [°C]	pH	Conductivity [µS/cm]	Oxygen [mg/L]	Oxygen [%]	Flow rate [m³/s]	Ammonium NH_4^+ (mg/l)	Nitrate NO_3^- (mg/l)	Nitrite NO_2^- (mg/l)	Phosphate PO_4 (mg/l)	Chloride Cl^- (mg/l)	Potassium K^+ (mg/l)	Sulfate SO_4^{2-} (mg/L)	Total hardness (°d)	Carbonate hardness (°d)
Tissint															
Sampling 1 (June)															
A1	30.5	7.7	5600.0	13.24	172.45	0.05	0.05	8.5	0.03	3.8	3300	18	132	200	100
A2	28.1	7.4	9986.7	9.58	130.60	0.03	0.05	7.8	0.07	3.1	53000	27	157	200	100
A3	28.2	7.6	7366.7	9.16	126.47	0.11	0.05	13	0.05	3.4	6500	23	141	200	100
Sampling 2 (Sept)															
A1	27.0	7.7	5626.7	11.44	155.70	0.03	0.05	NA	0.03	3.3	4900	19	NA	600	200
A2	25.6	7.5	10366.7	7.92	104.07	0.03	0.05	NA	0.07	2.5	20000	26	NA	400	200
A3	28.6	7.6	7353.3	9.41	131.50	0.09	0.05	NA	0.05	3.7	6400	22	NA	400	200
Sum															
A1	28.8	7.7	5613.3	12.34	164.08	0.04	0.05	8.5	0.03	3.55	4100	18.5	132	400	150
A2	26.8	7.5	10176.7	8.75	117.33	0.03	0.05	7.8	0.07	2.8	36500	26.5	157	300	150
A3	28.4	7.6	7360.0	9.28	128.98	0.10	0.05	13	0.05	3.55	6450	22.5	141	300	150
Iriri / El Mellah															
Sampling 1 (June)															
B1 (Iriri)	20.7	7.7	800.3	4.37	55.90	0.02	0.05	2	0.01	2.3	53	4	62	100	10
B2 (El Mellah)	24.2	7.7	2700.0	5.93	81.10	0.02	0.05	2	0.01	1	3300	8	209	100	20
B3	24.8	7.8	2062.0	6.33	87.57	0.08	0.05	2	0.03	0.3	150	6	162	40	20
Sampling 2 (Oct)															
B1 (Iriri)	21.2	7.6	814.3	3.56	45.57	0.02	0.05	NA	0.01	0.3	1600	6	NA	400	200
B2 (El Mellah)	21.8	7.7	2183.3	6.14	79.23	0.03	0.05	NA	0.01	0.3	3000	7	NA	400	200
B3	20.6	7.8	1865.0	6.82	86.00	0.06	0.05	NA	0.01	0.3	1700	7	NA	500	200
Sum															
B1 (Iriri)	20.9	7.7	807.3	3.97	50.73	0.02	0.05	2	0.01	1.3	826.5	5	62	250	105
B2 (El Mellah)	23.0	7.7	2441.7	6.03	80.17	0.03	0.05	2	0.01	0.65	3150	7.5	209	250	110
B3	22.7	7.8	1963.5	6.57	86.78	0.07	0.05	2	0.02	0.3	925	6.5	162	270	110
Dades / M'Goun															
C1 (Dades)	23.0	8.3	1160.3	8.03	112.73	0.01	0.05	2	0.01	1.9	400	3	159	200	100
C2 (M'Goun)	27.7	8.2	1277.7	8.98	134.57	0.19	0.05	2	0.01	0.3	500	1	113	100	10
C3	30.1	8.0	1511.3	7.77	120.97	0.31	0.05	2	0.01	0.3	300	2	127	100	11

Table B.3. (continued)

Site	**Macroinvertebrates**												
	Caenis pusilla	*Caenis luctuosa*	*Baetis pavidus*	*Procloeon stagnicola*	*Cheleocloeon dimorphicum*	*Cloeon simile*	*Ecdyonurus rothschildi*	*Hydropsyche*	*Oxyethira* sp.	*Orthotrichia* sp.	*Hydroptila vectis*	*Polycentropodidae*	Orthocladiinae
Tissint													
Sampling 1 (June)													
A1	0	187	247	0	0	157	0	28	5	3	0	0	910
A2	0	131	1235	0	0	88	0	241	0	0	3	0	303
A3	0	361	369	20	0	59	0	32	15	0	0	0	320
Sampling 2 (Sept)													
A1	0	190	322	1	0	13	0	34	2	0	0	0	134
A2	0	725	698	0	0	60	0	207	0	0	0	0	178
A3	0	505	535	0	0	22	0	19	0	0	0	1	121
Sum													
A1	0	377	569	1	0	170	0	62	7	3	0	0	1044
A2	0	856	1933	0	0	148	0	448	0	0	3	0	481
A3	0	866	904	20	0	81	0	51	15	0	0	1	441
Iriri / El Mellah													
Sampling 1 (June)													
B1 (Iriri)	0	971	170	3	0	73	0	53	0	0	19	0	223
B2 (El Mellah)	0	722	111	0	0	10	0	74	2	0	19	0	63
B3	0	341	378	0	0	0	0	111	0	0	74	0	86
Sampling 2 (Oct)													
B1 (Iriri)	0	267	65	1	3	2	0	49	0	0	10	0	183
B2 (El Mellah)	0	112	97	0	0	0	0	50	0	0	4	0	83
B3	0	413	365	0	16	90	0	199	6	0	21	0	414
Sum													
B1 (Iriri)	0	1238	235	4	3	75	0	102	0	0	29	0	406
B2 (El Mellah)	0	834	208	0	0	10	0	124	2	0	23	0	146
B3	0	754	743	0	16	90	0	310	6	0	95	0	500
Dades / M'Goun													
C1 (Dades)	0	920	64	0	0	5	0	23	1	0	4	0	85
C2 (M'Goun)	5	309	326	0	0	0	4	86	0	0	51	0	186
C3	5	221	245	2	0	0	2	36	2	3	22	0	105

Table B.3. (continued)

Site	**Macroinvertebrates (continued)**												
	Tanytarsini	*Tanypodinae*	*Simulium* sp.	*Anthomyiidae*	*Tabanidae*	*Ceratopogonidae*	*Dixidae*	*Limoniidae*	*Tipulidae*	*Stratiomyidae*	*Bidessus minutissimus*	*Nebrioporus clarki*	*Pomatinus substriatus*
Tissint													
Sampling 1 (June)													
A1	0	9	35	0	0	25	0	0	0	0	3	0	0
A2	0	0	12	0	0	22	0	0	0	0	0	0	0
A3	0	0	18	0	0	36	0	0	0	0	0	0	0
Sampling 2 (Sept)													
A1	0	0	21	0	0	48	0	0	0	0	0	0	0
A2	0	0	42	0	1	30	0	0	0	0	0	0	0
A3	0	27	12	0	0	61	0	0	0	0	0	0	0
Sum													
A1	0	9	56	0	0	73	0	0	0	0	3	0	0
A2	0	0	54	0	1	52	0	0	0	0	0	0	0
A3	0	27	30	0	0	97	0	0	0	0	0	0	0
Iriri / El Mellah													
Sampling 1 (June)													
B1 (Iriri)	0	0	37	0	4	7	0	0	0	0	0	38	0
B2 (El Mellah)	0	2	3	0	2	2	0	0	0	0	0	2	0
B3	0	1	1	0	4	3	0	0	0	0	0	1	0
Sampling 2 (Oct)													
B1 (Iriri)	0	0	479	0	0	0	0	17	0	0	0	9	0
B2 (El Mellah)	0	0	38	0	1	2	4	0	0	0	0	0	0
B3	0	0	155	0	1	0	0	0	0	0	0	4	0
Sum													
B1 (Iriri)	0	0	516	0	4	7	0	17	0	0	0	47	0
B2 (El Mellah)	0	2	41	0	3	4	4	0	0	0	0	2	0
B3	0	1	156	0	5	3	0	0	0	0	0	5	0
Dades / M'Goun													
C1 (Dades)	0	12	17	1	1	3	0	0	0	1	0	13	1
C2 (M'Goun)	12	7	7	0	0	12	0	0	18	0	0	3	0
C3	0	2	5	0	0	5	0	0	0	1	0	0	0

Table B.3. (continued)

Site	Macroinvertebrates (continued)											
	Ostracoda	*Atyaephyra desmaresti*	*Brachythemis leucosticta*	Odonata	*Melanopsis cariosa*	*Radix balthica*	*Physella acuta*	*Planorbis metidjensis*	*Micronecta*	Oligochaeta	Hydracarina	Tricladida
Tissint												
Sampling 1 (June)												
A1	0	3	0	39	1697	0	0	11	70	0	0	0
A2	0	107	0	19	873	0	0	2	13	0	0	0
A3	0	30	0	4	361	0	0	5	7	0	0	0
Sampling 2 (Sept)												
A1	9	149	20	0	958	0	0	6	18	0	0	0
A2	16	26	2	18	765	0	14	14	41	0	0	0
A3	10	53	36	0	456	0	0	22	6	0	0	0
Sum												
A1	9	152	20	39	2655	0	0	17	88	0	0	0
A2	16	133	2	37	1638	0	14	16	54	0	0	0
A3	10	83	36	4	817	0	0	27	13	0	0	0
Iriri / El Mellah												
Sampling 1 (June)												
B1 (Iriri)	16	7	3	0	0	8	0	0	0	73	8	265
B2 (El Mellah)	18	0	2	0	0	0	0	0	10	249	27	0
B3	0	0	0	0	0	0	0	0	1	702	15	0
Sampling 2 (Oct)												
B1 (Iriri)	8	2	2	0	0	0	0	0	0	48	0	70
B2 (El Mellah)	3	0	2	0	0	0	0	0	0	100	0	1
B3	0	1	21	0	0	1	0	0	34	65	0	0
Sum												
B1 (Iriri)	24	9	5	0	0	8	0	0	0	121	8	335
B2 (El Mellah)	21	0	4	0	0	0	0	0	10	349	27	1
B3	0	1	21	0	0	1	0	0	35	767	15	0
Dades / M'Goun												
C1 (Dades)	0	0	1	0	0	0	0	0	3	29	0	0
C2 (M'Goun)	0	0	0	0	0	2	0	0	0	8	1	0
C3	0	0	0	0	0	2	0	0	3	0	0	0

Table B.3. (continued)

Site	Specimens	Taxa	%EPT (Abundance)	%EPT (Presence)	%DCOH (Presence)	EPT/DCOH	IBMWP	IBGN
Tissint								
Sampling 1 (June)								
A1	3429	16	18.29	37.50	43.75	0.86	53	9
A2	3049	13	55.69	38.46	38.46	1.00	50	9
A3	1637	14	52.29	42.86	35.71	1.20	50	9
Sampling 2 (Sept)								
A1	1925	15	29.19	40.00	33.33	1.20	50	7
A2	2837	16	59.57	25.00	43.75	0.57	54	7
A3	1886	15	57.37	33.33	40.00	0.83	54	7
Sum								
A1	5354	19	22.21	36.84	42.11	0.875	56	10
A2	5886	17	57.56	29.41	41.18	0.71	60	10
A3	3523	18	55.01	38.89	38.89	1.00	63	10
Iriri / El Mellah								
Sampling 1 (June)								
B1 (Iriri)	1978	18	65.17	33.33	33.33	1.00	67	10
B2 (El Mellah)	1318	17	71.17	35.29	47.06	0.75	56	10
B3	1718	13	52.62	30.77	53.85	0.57	45	9
Sampling 2 (Oct)								
B1 (Iriri)	1215	16	32.67	43.75	31.25	1.40	56	7
B2 (El Mellah)	497	13	52.92	30.77	46.15	0.67	55	9
B3	1806	16	61.46	43.75	37.50	1.17	54	9
Sum								
B1 (Iriri)	3193	20	52.80	35.00	35.00	1.00	71	10
B2 (El Mellah)	1815	19	66.17	31.58	47.37	0.67	65	10
B3	3524	19	57.15	36.84	42.11	0.88	62	10
Dades / M'Goun								
C1 (Dades)	1184	18	85.90	33.33	61.11	0.55	58	10
C2 (M'Goun)	1037	16	75.31	37.50	43.75	0.86	56	9
C3	661	16	81.39	56.25	37.50	1.50	50	9

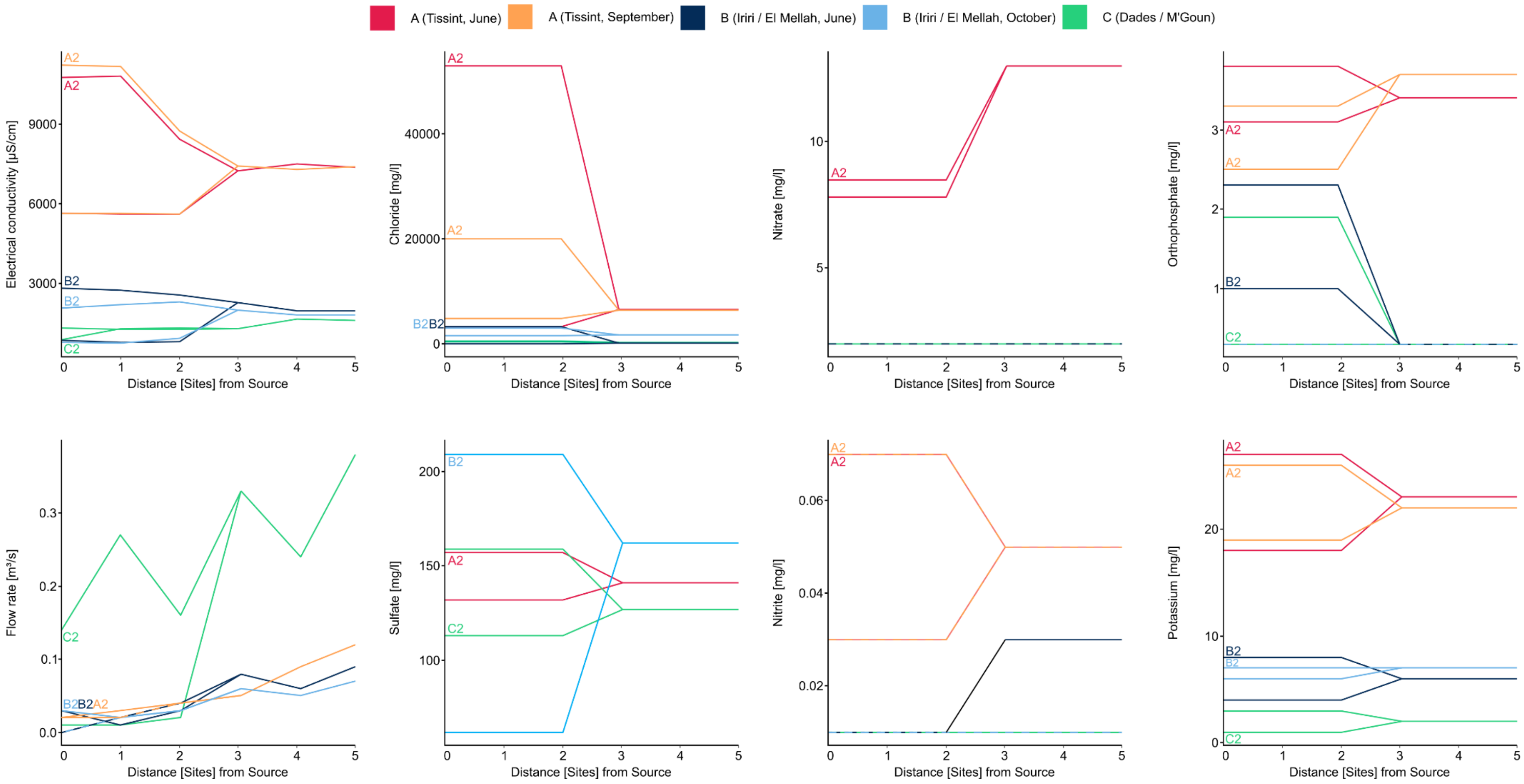

Figure 0B.1. Environmental parameters for the three confluences (seasons separated). Lines are connecting values measured at sites; values between sites may vary. A2, B2, and C2 indicates saltier tributary.

Figure B.02. Proportion of traits for the two tributaries and the joint downstream section at the three confluences.

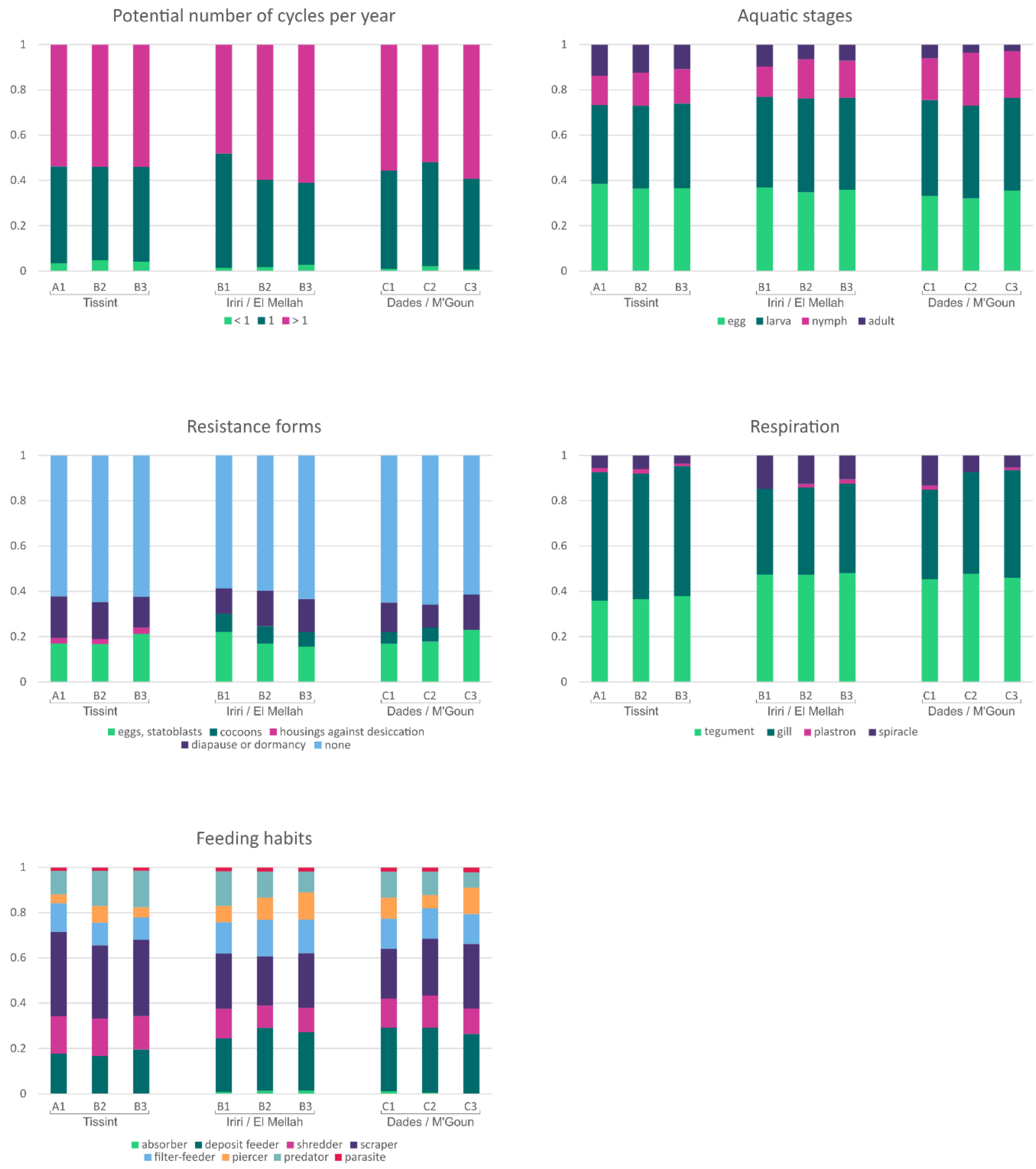

Figure B.2. (continued)

6.1.3. C: Supplementary Material for Chapter 4: Water quality, biological quality, and human well-being: Water salinity and scarcity in the Draa River basin, Morocco

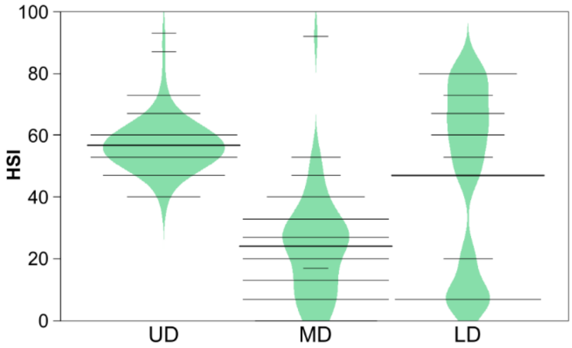

Figure C.1. Beanplot showing the distribution of values for all individual HSI (Human Satisfaction Index) values for the Upper (UD), Middle (MD), and Lower Draa (LD). The bold lines show the mean.

Table C.1. Location, river characteristics and physico-chemical parameters (for October 2021, March 2022, and the used mean values), ecosystem health metrics, and the indices: water quality index (WQI), biological quality index (BQI), and human satisfaction index (HIS), all with their range, mean and SD for all study sites, sorted by Upper, Middle, and Lower Draa (bold names). Red values were excluded from the analysis or set to a maximum level (in case of chloride >6000), as they represent measurement failures due to dilution or calibration problems. MAVD is the Maximum Admissible Value by Moroccan water quality standards for drinking water (Royaume du Maroc 2006), MAVI the Maximum Admissible Value (SEEE, 2007) for irrigation water.

N°	Name	Lat	Long	Alt	Width [m] '21	Width [m] '22	Width [m] Mean	Depth [cm] '21	Depth [cm] '22	Depth [cm] Mean	Flow velocity [m/s] '21	Flow velocity [m/s] '22	Flow velocity [m/s] Mean
	Upper Draa												
1	Ounila US	31.2617547	-7.1542015	1747	7.9	3.85	5.9	0.1	0.18	0.14	0.3	0.33	0.315
2	Ounila MS	31.146719	-7.140803	1412	8	6.7	7.4	0.2	0.16	0.18	0.44	0.3	0.37
3	El Mellah US	31.09406	-7.148652	1318	4	5	4.5	0	0.04	0.02	0.14	0.17	0.155
4	Iriri DS	30.945731	-7.199225	1252	8	8.2	8.1	0.3	0.15	0.225	0.07	0.07	0.07
5	Ait Douchen US	30.656967	-7.094667	1336	4	5.8	4.9	0.1	0.2	0.15	0	0.02	0.01
6	Ait Douchen DS	30.8652278	-6.84642778	1114	5	5	5.0	0.6	0.1	0.35	0.01	0.08	0.045
7	Dades High US	31.618608	-5.855497	1818	5.4	8.4	6.9	0.1	0.15	0.125	0.15	0.55	0.35
8	Dades (Gorges)	31.556222	-5.908688	1753	6	9.7	7.9	0.3	0.4	0.35	0.09	0.15	0.12
9	Dades MS	31.50473	-5.94536	1657	2	4.9	3.5	0.1	0.17	0.135	0.34	0.64	0.49
10	M'Goun US	31.365555	-6.171667	1547	16.6	11.5	14.1	0.3	0.3	0.3	0.47	0.55	0.51
11	M'Goun DS	31.330998	-6.182975	1511	5	12	8.5	0.2	0.23	0.215	0.18	0.56	0.37
12	Dades DS	31.01195	-6.49404	1188	13	8	10.5	0.2	0.5	0.35	0.02	0.52	0.27
	Middle Draa												
13	Tamnougalt	30.674778	-6.407056	904	-	-	-	-	-	-	0	0	0
	Lower Draa												
14	Akka Nait Sidi 1	29.911138	-7.33102	564	4	6	5.0	0.2	0.23	0.215	0.12	0.13	0.125
15	Akka Nait Sidi 2	29.9098167	-7.33021944	588	4	5.3	4.7	0.1	0.15	0.125	0.17	0.14	0.155
16	Tissint	29.822129	-7.196371	491	6	9.5	7.8	0.2	0.14	0.17	0.17	0.12	0.145
17	Mrimima	29.779739	-7.168112	461	11	6.5	8.8	0.2	0.16	0.18	0.08	0.16	0.12
Min				461	2.0	3.9	3.5	0.0	0.0	0.0	0.0	0.0	0.0
Max				1818	16.6	12.0	14.1	0.6	0.5	0.5	0.5	0.6	0.5
Mean				1198	6.9	7.3	7.1	0.2	0.2	0.2	0.2	0.3	0.2
SD				423	3.7	2.4	2.6	0.1	0.1	0.2	0.1	0.2	0.2
MAVD													
MAVI													

Table C.1. (Continued)

N°	Flow rate [m³/s] '21	Flow rate [m³/s] '22	Flow rate [m³/s] Mean	Temp [°C] '21	Temp [°C] '22	Temp [°C] Mean	pH '21	pH '22	pH Mean	Cond [µS/cm] '21	Cond [µS/cm] '22	Cond [µS/cm] Mean	Oxygen [mg/l] '21	Oxygen [mg/l] '22	Oxygen [mg/l] Mean
1	0.07	0.05	0.06	21.6	18.5	20.1	7.1	8.3	7.7	2810	2150	2480	7.99	2.7	8.0
2	0.14	0.06	0.1	20.7	18.3	19.5	7.9	8.3	8.1	3820	3080	3450	8.1	**2.9**	8.1
3	0	0.01	0.005	23.7	22.3	23.0	8.4	8.1	8.3	15370	19330	17350	11.59	**3.3**	11.6
4	0.03	0.02	0.025	19.8	16.1	18.0	7.8	8.5	8.1	649	613	631	8.44	3.3	8.4
5	0	0.01	0.005	22.4	20.1	21.3	7.7	7.8	7.8	1134	1137	1136	5.6	5.95	5.6
6	0.01	0.01	0.01	25.5	20.7	23.1	7.5	8.4	8.0	1239	1175	1207	14.02	3.3	14.0
7	0.02	0.15	0.085	12.5	8.7	10.6	8.2	8.5	8.4	626	677	652	12.45	3.4	12.5
8	0.04	0.13	0.085	17.5	14.2	15.9	8.5	8.4	8.5	1163	792	978	10.6	4.3	10.6
9	0.02	0.09	0.055	16.5	13.1	14.8	8.5	8.5	8.5	1077	779	928	9.09	3.5	9.1
10	0.45	0.54	0.495	19.5	15.1	17.3	8.4	8.4	8.4	1030	883	957	8.76	2.7	8.8
11	0.4	0.35	0.375	19.9	15.2	17.6	8.2	8.5	8.3	1087	861	974	8.7	3.1	8.7
12	0.01	0.49	0.25	21.3	13.2	17.3	8.0	8.4	8.2	1792	1182	1487	15.83	2.6	15.8
13	0	0	0	25.2	23	24.1	8.1	9.5	8.8	2500	260	1380	17.23	3.7	17.2
14	0.02	0.05	0.035	23.6	23.9	23.8	7.7	7.9	7.8	10220	10210	10215	9.6	10.12	9.6
15	0.02	0.02	0.02	25.6	20.9	23.3	7.3	7.8	7.5	5680	5620	5650	12.4	14.84	12.4
16	0.04	0.04	0.04	24.3	15.1	19.7	8.2	8.5	8.4	11210	11970	11590	11.16	NA	11.2
17	0.04	0.03	0.035	18.8	21.7	20.3	8.9	8.6	8.8	14240	13680	13960	8.72	NA	8.7
Min	0	0	0	12.5	8.7	10.6	7.1	7.8	7.5	626	260	631	5.6	-	5.6
Max	0.5	0.54	0.495	25.6	23.9	24.1	8.9	9.5	8.8	15370	19330	17350	17.2	-	17.2
Mean	0.08	0.12	0.10	21.1	17.7	19.4	8.0	8.4	8.2	4450	4376	4413	10.6	-	10.6
SD	0.13	0.17	0.14	3.4	4.1	3.5	0.5	0.4	0.3	4882	5616	5229	2.9	-	2.9
MAVD						-			6.5 - 8.5			2700			<5
MAVI						35			6.5 - 8.4			12000			-

Table C.1. (Continued)

N°	Cl^- [mg/l] '21	Cl^- [mg/l] '21	Cl^- [mg/l] '22	Cl^- [mg/l] Mean	SO_4^{2-} [mg/l] '21	SO_4^{2-} [mg/l] '22	SO_4^{2-} [mg/l] Mean	NO_3^- [mg/l] '21	NO_3^- [mg/l] '22	NO_3^- [mg/l] Mean	NO_2^- [mg/l] '21	NO_2^- [mg/l] '22	NO_2^- [mg/l] Mean
		Ion Chromatography											
1	1300		2000	1650	177	183	180	4.8	<4	3.4	<0.02	NA	0.01
2	5100		1600	3350	190	530	360	<4	<4	2	<0.02	NA	0.01
3	540000000	1756	73000	>6000	177	186	181.5	<4	<4	2	<0.02	NA	0.01
4	2400		200	1300	30	30	30	<4	<4	2	<0.02	NA	0.01
5	2100		300	1200	128	136	132	8	13.3	10.65	0.02	NA	0.02
6	2500		600	1550	148	139	143.5	<4	<4	2	<0.02	NA	0.01
7	2200		200	1200	117	102	109.5	5.1	6.6	5.85	0.02	NA	0.02
8	2800		300	1550	145	118	131.5	6.7	<4	4.35	<0.02	NA	0.01
9	2100		200	1150	143	118	130.5	<4	5.8	3.9	<0.02	NA	0.01
10	2400		200	1300	140	141	140.5	<4	5.5	3.75	<0.02	NA	0.01
11	2800		200	1500	173	144	158.5	<4	5.2	3.6	<0.02	NA	0.01
12	3200	113	100	1650	187	123	155	<4	5.8	4.8	0.07	NA	0.07
13	1500		200	850	4000	<20	10	<4	<4	2	0.02	NA	0.02
14	5600		3900	4750	172	180	176	9.7	13.9	11.8	0.05	NA	0.05
15	7300		3000	5150	216	166	191	12.8	11.2	12	0.05	NA	0.05
16	230000	1434	1500	>6000	168	154	161	<4	<4	2	<0.02	NA	0.01
17	105100000	1377	3000	>6000	8900	143	143	<4	<4	2	<0.02	NA	0.01
Min	1300	113	100	850	30.0	<20	10	<4	<4	2	<0.02	-	0.01
Max	540000000	1756	73000	>6000	8900	530	360	12.8	13.9	11.8	0.1	-	0.07
Mean	37963135	1170	5324	-	895	-	149	-	-	-	-	-	-
SD	127912118	627	16960	-	2196	-	71	-	-	-	-	-	-
MAVD				750			400			50			0.5
MAVI				350			250			-			-

Table C.1. (Continued)

N°	NH_4^+ [mg/l] '21	NH_4^+ [mg/l] '22	NH_4^+ [mg/l] Mean	$PO_4$3- [mg/l] '21	PO_4 [mg/l] '22	PO_4 [mg/l] Mean	K^+ [mg/l] '21	K^+ [mg/l] '22	K^+ [mg/l] Mean	TH [°d] '21	TH [°d] '22	TH [°d] Mean	CH [°d] '21	CH [°d] '22	CH [°d] Mean
1	<0.1	<0.1	0.05	1.1	<0.6	0.7	5	3	4	400	100	250	200	100	150
2	<0.1	<0.1	0.05	<0.6	<0.6	0.3	7	5	6	500	100	300	200	100	150
3	<0.1	<0.1	0.05	1.5	<0.6	0.9	28	40	34	800	600	700	200	100	150
4	<0.1	<0.1	0.05	1.1	<0.6	0.7	4	4	4	-	100	100	8	100	54
5	0.1	0.2	0.15	1.1	0.9	1.0	8	7	7.5	500	200	350	300	100	200
6	<0.1	<0.1	0.05	<0.6	<0.6	0.3	10	7	8.5	500	100	300	200	100	150
7	<0.1	<0.1	0.05	<0.6	<0.6	0.3	3	3	3	500	100	300	200	100	150
8	<0.1	<0.1	0.05	<0.6	<0.6	0.3	4	2	3	500	100	300	200	100	150
9	<0.1	<0.1	0.05	<0.6	<0.6	0.3	3	3	3	400	100	250	200	100	150
10	<0.1	<0.1	0.05	<0.6	<0.6	0.3	<2	<2	1	600	300	450	200	100	150
11	<0.1	<0.1	0.05	<0.6	<0.6	0.3	<2	<2	1	500	200	350	200	100	150
12	<0.1	<0.1	0.05	4.6	<0.6	2.5	6	3	4.5	600	200	400	200	100	150
13	<0.1	<0.1	0.05	1	<0.6	0.8	11	3	7	600	100	350	200	100	150
14	<0.1	<0.1	0.05	3.5	2.1	2.8	28	21	24.5	600	200	400	300	100	200
15	<0.1	<0.1	0.05	5.4	2.5	4.0	23	40	31.5	700	300	500	300	100	200
16	0.2	<0.1	0.125	0.9	<0.6	0.6	50	40	45	600	400	500	200	100	150
17	0.3	0.1	0.3	1.9	1.8	1.9	70	50	60	800	400	600	200	100	150
Min	<0.1	<0.1	0.05	<0.6	<0.6	<0.6	<2	<2	1	400	100	100	8	100	54
Max	0.3	0.2	0.3	5.4	2.5	4.0	70	50	60	800	600	700	300	100	200
Mean	-	-	-	-	-	-	-	-	-	569	212	376	206	100	153
SD	-	-	-	-	-	-	-	-	-	116	141	138	62	0	31
MAVD			0.5			-			-			-			-
MAVI			-			-			-			-			-

Table C.1. (Continued)

N°	Taxa richness	%EPT	IBMWP	IBGN	WQI	BQI	HSI
1	16	0.31	41	9	71	45	60
2	17	0.29	53	9	62	52	60
3	15	0.33	55	10	63	56	47
4	18	0.33	57	10	80	61	60
5	12	0.33	45	9	68	43	55
6	19	0.37	63	11	74	71	59
7	11	0.45	41	8	79	42	63
8	18	0.56	55	9	76	69	63
9	15	0.53	54	9	76	63	63
10	13	0.62	57	12	75	77	54
11	14	0.5	68	13	75	81	54
12	22	0.45	70	11	74	83	53
13	5	0.4	19	9	74	23	29
14	12	0.25	44	7	61	31	71
15	13	0.23	48	7	63	33	71
16	9	0.33	30	6	63	20	23
17	12	0.17	40	6	57	21	23
Min	5	0.17	19	6	78	20.0	23.0
Max	22	0.62	70	13	57	83.0	71.0
Mean	14.2	0.38	49	9.1	69	51.3	52.7
SD	3.9	0.12	13	1.9	6.7	20.5	14.4
MAVD							
MAVI							

Table C.2 Questions and possible answer options used in the questionnaire.

Questions	Answer options
Water and crop quality	
1. What sources of water do you use for drinking?	- River water - Groundwater of the commune - ONEE tap water - ONEE truck delivered water
2. What source of water do you use for irrigation?	- River water - Groundwater - Other sources
3. How do you qualify the quality of the water you drink?	- Very bad - Bad - Neither good nor bad - Good - Very good - Excellent
4. How do you qualify the quality of the water you use for irrigation?	- Very bad - Bad - Neither good nor bad - Good - Very good - Excellent
5. How do you qualify the quality of the crops you produce?	- Very bad - Bad - Neither good nor bad - Good - Very good - Excellent
Health status	
6. On a scale of 1 (very bad) to 10 (excellent), how do you qualify your general health status?	- 1 – 10
7. Do you think the quality of water used in this village has some effects on the health of people?	- Yes - No
8. If yes, is this effect:	- Predominantly positive - Predominantly negative
9. Do you perceive the water to be salty?	- Yes, often - Yes, sometimes - No
10. How often do you experience physical diseases from the water salinity?	- Often - Sometimes - Never
11. How often do you experience emotional distress due to water salinity and/or scarcity?	- Often - Sometimes - Never
Satisfaction	
12. How satisfied are you with the following aspects in your area? Please use the categories (very unsatisfied, predominantly unsatisfied, predominantly satisfied, very satisfied) for your answer:	- The health care - The quantity of water resources - The quality of water resources - Your agricultural production possibilities - The conditions of the natural environment
13. Considering all these elements, how satisfied are you overall currently with your life?	- Very unsatisfied - Predominantly unsatisfied - Predominantly satisfied - Very satisfied
Demographic questions	
14. Gender	- Male - Female
15. Occupation	- Farming - Other services
16. Age category	- 10 to 20 years old - 20 to 40 years old - 40 to 70 years old - Over 70 years old

Table C.3. Results of comparisons of response values for demographic groups, showing mean values and standard deviation (SD) for each group, F-statistic (F), degrees of freedom (df), p-value and Eta². Significant differences between groups are indicated by lower-case letters, with significant differences if letters are different.

Comparisons of demographic groups	Mean/SD Group 1	Mean/SD Group 2	Mean/SD Group 3	Mean/SD Group 4	F	df	p-value	Eta²
Gender	**Male**	**Female**	**-**	**-**				
Drinking water	3.94/0.94	3.89/0.79			0.1	1	0.75	
Irrigation water	3.78/0.96	3.64/1.13			0.76	1	0.38	
Crop quality	3.62/0.8	3.56/0.74			0.29	1	0.59	
Health status	7.42/1.53	7.02/1.18			3.25	1	0.07	
Satisfaction	1.44/0.58	1.35/0.6			0.91	1	0.34	
Occupation	**Farming**	**Other services**	**-**	**-**				
Drinking water ~ Occupation	3.97/0.85	3.88/0.94			0.45	1	0.5	
Irrigation water ~ Occupation	3.86/0.91	3.59/1.11			3.11	1	0.08	
Crop quality ~ Occupation	3.61/0.79	3.57/0.79			0.13	1	0.71	
Health status ~ Occupation	7.26/1.47	7.38/1.45			0.27	1	0.61	
Satisfaction ~ Occupation	1.38/0.55	1.42/0.64			0.97	1	0.33	
Age	**10-20 years**	**20-40 years**	**40-70 years**	**over 70 years**				
Drinking water ~ Age	3/1.22	3.94/0.89	3.87/0.77	4.23/1.07	2.83	3	0.04*	0.01
Irrigation water ~ Age	3/1	3.8/0.98	3.9/0.87	3.18/1.33	2.69	3	0.08	
Crop quality ~ Age	3.2/0.84	3.69/0.66	3.57/0.84	3.45/1.01	1.14	3	0.33	
Health status ~ Age	8.4/1.67 (ab)	7.72/1.19 (a)	7/1.45 (b)	6.4/1.64 (b)	7.46	3	0.0001*	0.12
Satisfaction ~ Age	1.2/0.45 (ab)	1.5/0.57 (a)	1.47/0.52 (a)	0.95/0.69 (b)	7.22	3	0.0001*	0.05

Table C.4. Responses to questionnaires sorted by survey sites and subbasins (SB) showing gender (G; M = male, F = female), occupation (O; 1 = Farming, 0 = Other services), age category (A; 1 = 10-20 years old, 2 = 20-40, 3 = 40-70, 4 = over 70), source of drinking (SDr) and irrigation water (SIr; R = river water, G = groundwater, Tr = truck delivered water, Ta = tap water, O = other sources), quality of drinking water (Wdr), irrigation water (WIr) and crops (Crop; 1 = very bad, 2 = bad, 3 = neither good nor bad, 4 = good, 5 = very good, 6 = excellent), health status (Health) on a scale from 1 (very bad) to 10 (excellent), perceived saltiness of water (Salty; 0 = no, 1 = yes sometimes, 2 = yes often), physical and emotional distress by salinity and scarcity (0 = never, 1 = sometimes, 2 = often), and satisfaction with health care, quantity and quality of water resources, agricultural production possibilities, conditions of the natural environment and life overall (0 = very unsatisfied, 1 = predominantly unsatisfied, 2 = predominantly satisfied, 3 = very satisfied).

Site	SB	G	O	A	SDr	SIr	WDr	WIr	Crop	Health	Salty	Physical	Emotional	SatHealth	SatQuantity	SatQuality	SatAgriculture	SatEnvironment	SatLife
OunilaUS	UD	M	1	3	TrO	R	5	4	5	6	0	0	0	1	2	2	2	2	0
OunilaUS	UD	M	1	2	TrO	R	5	4	5	8	0	0	0	1	2	2	2	2	1
OunilaUS	UD	M	1	3	TrO	R	5	4	5	6	0	0	0	1	2	2	2	2	1
OunilaUS	UD	M	1	2	TrO	R	5	4	5	9	0	0	0	1	2	2	2	2	2
OunilaUS	UD	M	1	2	TrO	R	5	4	4	8	0	0	0	1	2	2	2	2	2
OunilaUS	UD	M	1	2	TrO	R	5	4	4	7	0	0	0	1	2	2	2	2	2
OunilaUS	UD	M	1	2	TrO	R	4	4	4	9	0	0	0	1	2	2	2	2	2
OunilaUS	UD	F	0	2	TrO	R	4	4	4	5	0	0	0	1	2	2	2	2	2
OunilaUS	UD	M	0	3	TrO	R	5	5	4	6	0	0	0	1	2	2	2	2	2
OunilaUS	UD	M	0	2	TrO	R	4	4	4	6	0	0	0	1	2	2	2	2	2
OunilaUS	UD	M	1	2	TrO	R	5	4	4	8	0	0	0	1	2	2	2	2	2
OunilaUS	UD	M	1	3	TrO	R	4	5	5	8	0	0	0	1	2	2	2	2	2
OunilaUS	UD	F	0	2	TrO	R	4	4	4	7	0	0	0	1	2	2	2	2	2
OunilaUS	UD	M	0	2	TrO	R	5	5	4	7	0	0	0	1	2	2	2	2	2
OunilaUS	UD	M	1	2	TrO	R	5	4	4	8	0	0	0	1	2	2	2	2	2
Ounila	UD	F	1	3	Tr	R	4	4	3	7	0	0	1	1	2	2	1	2	2
Ounila	UD	M	1	3	Tr	R	3	4	4	5	0	0	1	1	1	2	2	2	2
Ounila	UD	M	1	4	Tr	R	4	4	3	4	0	0	2	1	1	1	2	2	2
Ounila	UD	M	1	3	Tr	R	4	4	4	5	0	0	1	1	1	1	2	2	2
Ounila	UD	M	1	3	Tr	R	3	4	3	NA	0	0	1	1	1	1	2	2	2
Ounila	UD	M	1	2	Tr	R	3	4	4	7	0	0	1	1	2	2	1	2	2
Ounila	UD	M	1	3	Tr	R	3	4	4	7	0	0	1	1	1	1	1	2	2
Ounila	UD	F	1	3	Tr	R	4	4	3	6	0	1	2	1	2	2	1	2	2
Ounila	UD	F	1	3	Tr	R	4	4	4	9	1	0	1	1	1	1	1	2	2
Ounila	UD	F	1	2	Tr	R	4	4	4	9	1	0	1	1	1	1	1	2	2
Ounila	UD	M	1	3	Tr	R	3	4	4	8	1	0	1	1	1	1	2	2	2
Iriri	UD	M	1	2	G	RO	5	5	4	10	0	0	0	1	2	2	2	2	1
Iriri	UD	F	1	3	G	RO	5	5	4	6	0	0	0	1	2	2	2	2	2
Iriri	UD	F	0	4	G	RO	5	5	4	5	0	0	NA	1	2	2	2	2	1
Iriri	UD	M	1	2	G	RO	5	5	4	7	0	0	NA	1	2	2	2	2	2
Iriri	UD	M	1	2	G	RO	5	5	4	8	0	0	0	1	2	2	2	2	2
Iriri	UD	F	NA	3	G	RO	5	5	4	7	0	0	0	1	2	2	2	2	2
Iriri	UD	M	1	2	G	RO	5	5	4	8	0	0	0	1	2	2	2	2	2
Iriri	UD	M	1	2	G	RO	5	5	4	9	0	0	0	1	2	2	2	2	2
Iriri	UD	M	0	3	G	RO	5	5	4	10	0	0	0	1	2	2	2	2	2
Iriri	UD	M	1	2	G	RO	5	5	4	9	0	0	0	1	2	2	2	2	2

Table C.4. (continued)

Site	SB	G	O	A	SDr	SIr	WDr	WIr	Crop	Health	Salty	Physical	Emotional	SatHealth	SatQuantity	SatQuality	SatAgriculture	SatEnvironment	SatLife
Iriri	UD	F	1	2	G	RO	5	5	4	9	0	0	0	1	2	2	2	2	2
Iriri	UD	M	0	2	G	RO	5	5	4	7	0	0	0	1	2	2	2	2	2
AitDouchen	UD	M	0	3	G	O	4	4	4	9	0	0	0	0	2	2	2	2	1
AitDouchen	UD	M	1	2	G	O	4	4	4	8	0	0	0	0	2	2	2	2	1
AitDouchen	UD	M	0	2	G	O	4	4	4	7	0	0	0	0	2	2	2	2	1
AitDouchen	UD	M	1	2	G	O	4	4	4	9	0	0	0	1	2	2	2	2	1
AitDouchen	UD	F	0	3	G	O	4	4	4	6	0	0	0	1	2	2	2	2	2
AitDouchen	UD	M	0	3	G	O	4	4	4	5	0	0	0	0	2	2	2	2	1
AitDouchen	UD	M	0	2	G	O	4	4	4	6	0	0	0	0	2	2	2	2	2
AitDouchen	UD	M	0	3	G	O	4	4	4	NA	0	0	0	0	2	2	2	2	2
AitDouchen	UD	F	0	3	G	O	4	4	4	5	0	0	0	1	2	2	2	2	2
AitDouchen	UD	M	0	1	G	O	4	4	4	8	0	0	0	0	2	2	2	2	1
AitDouchen	UD	M	1	2	G	O	4	4	4	8	0	0	0	0	2	2	2	2	2
Tarmigte	UD	M	1	2	Ta	G	4	4	4	9	0	0	0	1	2	2	2	2	2
Tarmigte	UD	M	1	2	Ta	G	4	4	4	8	0	0	1	0	2	2	2	2	2
Tarmigte	UD	M	0	3	Ta	G	4	4	4	7	0	0	1	1	2	2	2	2	1
Tarmigte	UD	M	0	2	Ta	G	4	4	4	7	0	0	0	1	2	2	2	2	1
Tarmigte	UD	M	0	2	Ta	G	4	4	4	9	0	0	0	1	2	2	2	2	2
Tarmigte	UD	M	1	2	Ta	G	4	4	4	7	0	0	1	1	2	2	2	2	2
Tarmigte	UD	M	1	3	Ta	G	4	4	4	6	0	0	1	1	2	2	2	2	2
Tarmigte	UD	M	0	2	Ta	G	4	4	4	8	0	0	0	1	2	2	2	2	2
Tarmigte	UD	M	1	2	Ta	G	4	4	4	9	0	0	1	1	2	2	2	2	2
Tarmigte	UD	M	0	3	Ta	G	4	4	4	6	0	0	0	1	2	2	2	2	2
Dades	UD	M	1	3	G	R	3	4	4	5	0	0	1	1	2	1	1	2	2
Dades	UD	M	1	3	G	R	3	4	4	8	0	0	1	1	2	2	1	2	2
Dades	UD	F	1	2	G	R	3	4	4	8	0	0	1	1	2	2	1	2	2
Dades	UD	M	1	3	G	R	3	4	4	7	0	1	1	1	2	2	1	2	2
Dades	UD	M	0	2	G	R	3	4	4	7	0	1	1	3	2	2	1	2	2
Dades	UD	M	1	2	G	R	4	4	4	9	0	0	1	1	2	2	1	2	2
Dades	UD	M	1	3	G	R	4	4	4	6	0	0	1	1	2	2	1	2	2
Dades	UD	F	0	2	G	R	4	4	4	6	0	0	0	1	2	2	1	2	2
Dades	UD	M	1	2	G	R	4	4	4	7	0	0	1	1	2	2	1	2	2
Dades	UD	M	1	2	G	R	4	4	4	6	0	0	1	1	2	2	1	2	2
Dades	UD	M	1	4	RG	R	5	4	4	NA	0	1	1	1	2	2	2	3	2
Dades	UD	F	1	2	G	R	4	4	4	9	NA	0	1	2	3	3	3	3	3
Dades	UD	F	1	4	G	R	4	4	4	7	0	0	1	2	2	2	2	3	2
Dades	UD	M	0	2	G	R	4	5	4	9	0	0	1	2	3	3	2	3	3
Dades	UD	M	1	3	GTr	R	5	5	4	8	0	0	0	2	2	2	2	3	3
Dades	UD	M	0	2	GTr	R	5	5	4	7	0	0	0	2	2	2	2	3	3
Dades	UD	M	NA	2	G	R	3	4	4	6	0	0	1	1	2	2	2	3	2
Mgoun	UD	F	0	2	G	R	4	4	4	6	0	0	0	1	2	2	2	2	3
Mgoun	UD	M	0	3	G	R	4	NA	4	7	0	0	0	0	2	2	2	2	2
Mgoun	UD	M	1	3	G	R	4	4	4	6	0	0	0	0	2	2	2	2	1

Table C.4. (continued)

Site	SB	G	O	A	SDr	SIr	WDr	WIr	Crop	Health	Salty	Physical	Emotional	SatHealth	SatQuantity	SatQuality	SatAgriculture	SatEnvironment	SatLife
Mgoun	UD	F	NA	2	G	R	4	4	4	6	0	0	0	0	2	2	2	2	2
Mgoun	UD	M	0	2	G	R	4	4	4	7	0	0	1	0	2	2	2	2	1
Mgoun	UD	F	0	2	G	R	3	4	4	6	0	0	1	0	2	2	2	2	2
Mgoun	UD	F	0	2	G	R	4	4	4	8	0	0	0	0	2	2	2	2	2
Mgoun	UD	M	1	3	G	R	3	4	4	5	0	0	1	0	2	2	2	2	2
Mgoun	UD	F	0	2	G	R	3	4	4	8	0	0	1	0	2	2	2	2	2
Mgoun	UD	M	1	2	G	R	3	4	4	6	0	0	1	0	2	2	2	2	2
Mgoun	UD	M	1	3	G	R	3	4	4	7	0	0	0	0	2	2	2	2	2
Mgoun	UD	M	0	2	G	R	3	4	4	8	0	0	0	0	2	2	2	2	2
Mgoun	UD	F	0	1	G	R	3	4	4	6	0	0	1	0	2	2	2	2	1
Skoura	UD	F	0	3	G	RG	4	4	4	6	0	0	0	0	2	2	2	2	2
Skoura	UD	F	NA	3	G	RG	4	4	4	7	0	0	1	0	2	2	2	2	2
Skoura	UD	F	0	2	G	RG	4	4	4	8	0	0	0	0	2	2	2	2	2
Skoura	UD	F	0	3	G	RG	4	4	4	6	0	0	0	0	2	2	2	2	2
Skoura	UD	F	0	2	G	RG	4	4	4	7	0	0	0	0	2	2	2	2	2
Skoura	UD	F	0	3	G	RG	4	4	4	7	0	0	0	0	2	2	2	2	2
Skoura	UD	F	0	3	G	RG	4	4	4	6	0	0	0	0	2	2	2	2	2
Skoura	UD	F	0	2	G	RG	4	4	4	8	0	0	0	0	2	2	2	2	2
Skoura	UD	F	NA	3	G	RG	4	4	4	8	0	0	0	0	2	2	2	2	2
Skoura	UD	F	0	3	G	RG	4	4	4	7	0	0	0	0	2	2	2	2	2
Skoura	UD	F	0	3	G	RG	4	4	4	8	0	0	0	0	2	2	2	2	2
Skoura	UD	F	0	2	G	RG	4	4	4	8	0	0	0	0	2	2	2	2	2
Tamnougalt	MD	M	1	2	G	RG	3	4	3	6	2	0	2	1	1	1	1	1	1
Tamnougalt	MD	F	1	3	G	RG	3	4	3	8	1	NA	0	1	1	1	1	1	1
Tamnougalt	MD	M	1	3	G	RG	3	4	3	6	2	0	2	0	1	1	1	1	1
Tamnougalt	MD	M	1	2	G	RG	3	4	3	8	2	0	2	0	1	1	1	1	1
Tamnougalt	MD	M	1	2	G	RG	3	4	3	8	2	0	2	0	1	1	1	1	1
Tamnougalt	MD	M	1	3	G	RG	3	4	3	6	2	0	2	0	1	1	1	1	1
Tamnougalt	MD	M	1	3	G	RG	3	4	3	5	2	0	2	0	1	1	1	1	1
Tinzouline	MD	M	1	3	G	G	3	3.5	3	5	1	1	2	0	0	0	0	2	1
Tinzouline	MD	M	0	4	G	R	6	1	5	10	0	0	0	0	0	0	0	0	0
Tinzouline	MD	F	1	2	G	G	4	3	3	8	1	1	2	0	1	0	1	2	1
Tinzouline	MD	F	1	3	G	G	4	3	3	8	1	1	2	0	1	0	1	2	1
Tinzouline	MD	F	1	4	G	G	4	3	3	8	1	1	2	0	1	0	1	2	1
Tinzouline	MD	F	1	3	G	RG	6	6	2	10	1	0	2	2	0	1	0	0	1
Tinzouline	MD	M	1	2	G	G	3	1	2	9	1	0	2	0	0	0	0	2	2
Tinzouline	MD	M	1	3	G	RG	3	2	3	10	1	0	2	0	0	0	0	0	2
Tinzouline	MD	M	0	1	G	G	3	2	2	10	1	0	2	2	1	1	0	0	2
Tinzouline	MD	M	1	3	G	RG	4	3	4	9	0	0	0	2	1	2	2	1	2
Tinzouline	MD	M	1	3	G	G	4	4	4	NA	0	0	2	2	0	1	1	0	2
Ternata	MD	M	1	3	G	G	3	4	2	7	2	0	2	2	0	0	0	1	1
Ternata	MD	M	1	3	G	G	3	4	2	7	2	0	2	2	0	0	0	1	1

Table C.4. (continued)

Site	SB	G	O	A	SDr	SIr	WDr	WIr	Crop	Health	Salty	Physical	Emotional	SatHealth	SatQuantity	SatQuality	SatAgriculture	SatEnvironment	SatLife
Ternata	MD	M	1	3	G	G	3	4	2	7	2	0	2	2	0	0	0	1	1
Ternata	MD	M	1	3	G	G	3	4	2	7	2	0	2	2	0	0	0	1	1
Ternata	MD	F	0	2	G	G	2	2	4	6	2	1	2	2	0	0	0	1	0
Ternata	MD	F	0	2	G	G	4	4	4	NA	0	0	2	2	1	1	1	1	1
Ternata	MD	M	1	3	G	G	4	4	4	5	0	0	2	1	0	0	0	0	2
Ternata	MD	M	1	4	G	G	4	4	4	5	0	0	2	1	0	0	0	0	2
Ternata	MD	M	1	4	G	G	4	4	4	6	0	0	2	1	0	0	0	0	2
Ternata	MD	M	1	4	G	G	4	4	4	6	0	0	2	1	0	0	0	0	2
Ternata	MD	M	0	4	G	G	4	4	4	7	0	0	2	1	0	0	0	0	2
Ternata	MD	M	0	4	G	G	4	4	4	7	0	0	2	1	0	0	0	0	2
Ternata	MD	F	1	4	G	G	3	4	4	NA	0	0	2	0	0	2	0	NA	NA
Ternata	MD	M	0	2	G	G	4	4	4	8	0	0	2	1	1	0	0	2	2
Ternata	MD	F	1	3	G	G	4	5	3	7	0	0	2	0	0	2	0	0	2
Fezouata	MD	F	0	2	G	RG	3	3	3	6	0	0	1	2	1	1	1	2	2
Fezouata	MD	M	0	3	Ta	G	5	3	3	9	0	0	0	3	3	3	2	NA	0
Fezouata	MD	M	0	2	G	G	2	2	1	10	2	0	2	1	0	1	1	1	1
Fezouata	MD	M	0	2	G	G	2	1	2	7	0	2	2	NA	NA	NA	NA	NA	1
Fezouata	MD	M	0	3	G	G	3	3	3	5	2	1	1	2	1	0	1	1	1
Fezouata	MD	M	0	4	G	RG	3	3	2	5	2	1	1	1	1	1	1	1	1
Fezouata	MD	M	1	4	G	RG	4	2	2	5	2	0	1	2	1	1	1	1	2
Fezouata	MD	F	0	3	G	RG	3	1	NA	7	2	1	2	2	1	2	1	1	2
Fezouata	MD	F	1	3	G	RG	3	1	1	6	2	1	2	1	0	2	0	2	2
Fezouata	MD	M	0	2	G	RG	4	2	3	8	2	1	2	1	0	0	0	1	0
Fezouata	MD	M	0	1	G	RG	4	2	3	8	2	1	2	1	0	0	0	1	1
Fezouata	MD	F	0	2	G	G	4	2	2	6	2	0	2	0	0	0	1	1	2
Fezouata	MD	M	0	3	G	G	3	1	1	10	2	1	2	0	0	1	0	0	0
Fezouata	MD	M	1	4	G	G	3	2	2	6	2	2	2	0	0	0	0	0	0
Fezouata	MD	F	0	4	G	G	4	2	1	7	1	0	0	0	0	0	0	0	1
Fezouata	MD	M	0	2	Ta	G	6	3	3	10	1	0	2	0	1	2	1	0	1
Fezouata	MD	M	1	4	Ta	G	6	1	3	5	0	0	2	0	2	2	1	0	2
Fezouata	MD	M	0	2	Ta	G	6	3	3	10	0	0	2	0	2	2	2	0	1
Fezouata	MD	F	1	4	Ta	G	6	1	3	6	0	0	2	1	1	1	1	0	1
Fezouata	MD	M	0	2	Ta	G	4	3.5	4	9	0	0	2	1	1	2	1	1	0
Fezouata	MD	M	1	4	Ta	G	4	3	4	8	0	0	0	1	2	1	2	2	2
Fezouata	MD	M	1	3	Ta	G	4	3	3	9	0	0	1	1	0	1	1	2	2
Fezouata	MD	M	1	4	GTa	G	4	2	3	10	0	0	1	0	0	0	0	0	2
Akka	LD	M	0	3	Ta	RG	4	4	3	9	0	1	1	0	3	3	2	2	2
Akka	LD	M	0	3	Ta	RG	4	4	3	9	0	1	1	0	3	3	2	2	2
Akka	LD	M	0	3	Ta	RG	5	5	4	9	0	0	0	0	3	3	3	3	2
Akka	LD	M	0	2	Ta	RG	4	4	4	NA	0	0	0	1	2	2	2	2	2
Akka	LD	M	0	2	Ta	RG	5	3	3	6	0	1	0	0	2	3	2	2	1
Akka	LD	M	0	2	Ta	RG	4	5	NA	9	0	1	0	0	3	3	2	3	3
Akka	LD	M	0	2	Ta	RG	4	4	3	8	0	0	0	0	3	3	2	2	3

Table C.4. (continued)

Site	SB	G	O	A	SDr	SIr	WDr	WIr	Crop	Health	Salty	Physical	Emotional	SatHealth	SatQuantity	SatQuality	SatAgriculture	SatEnvironment	SatLife
Akka	LD	M	0	3	Ta	RG	4	3.5	3	7	0	0	0	1	3	3	2	3	2
Akka	LD	M	0	2	Ta	RG	5	4	3	8	0	0	0	1	2	2	2	2	2
Akka	LD	M	1	3	Ta	RG	6	5	5	6	0	0	0	0	3	3	3	3	3
Akka	LD	M	0	4	Ta	RG	6	6	5	5	0	0	0	0	3	3	3	3	2
Akka	LD	M	0	3	Ta	R	5	3	4	8	0	0	1	0	3	3	3	2	2
Mrimima	LD	M	0	4	G	O	2	3	4	6	2	0	1	0	2	1	0	0	2
Mrimima	LD	M	0	2	G	G	2	6	4	9	1	0	2	0	3	0	3	1	2
Mrimima	LD	M	0	1	G	G	1	3	3	10	1	2	2	0	3	1	3	0	2
Mrimima	LD	M	0	2	G	G	3	3	4	7	1	0	1	0	3	1	3	1	2
Mrimima	LD	M	0	2	G	G	3	3	2	9	1	1	1	0	3	0	0	0	1
Mrimima	LD	M	0	2	G	G	3	2	3	NA	2	2	0	0	0	1	0	0	0
Mrimima	LD	F	0	2	G	G	3	2	3	NA	2	2	0	0	0	1	0	0	0
Mrimima	LD	F	0	2	G	G	3	2	3	NA	2	2	0	0	0	1	0	0	0
Mrimima	LD	F	0	2	G	G	3	2	3	NA	2	2	0	0	0	1	0	0	0
Mrimima	LD	F	0	2	G	G	3	2	3	NA	2	2	0	0	0	1	0	0	0
Mrimima	LD	F	0	2	G	G	3	2	3	NA	2	2	0	0	0	1	0	0	0
Mrimima	LD	F	0	2	G	G	6	6	4	7	1	1	2	0	0	3	2	3	1

Table C.5. Pearson/Spearman correlation table showing correlation coefficients with significance values (*** p<0.001, ** p<0.01, * p<0.05, ° p<0.1). WQI = Water Quality Index, BQI = Biological Quality Index, HSI = Human Satisfaction Index, Sat categories are for satisfaction with health care, quality and quantity of water resources, agricultural production possibilities, conditions of the natural environment and life overall for all 17 sites (mean values per site).

Pearson	WQI	BQI	HSI	SatHealth	SaQuality	SatQuantity	SatAgriculture	SatEnvironment	SatLife
WQI	1	0.6*	0.25	0.3	0.13	0.14	0	0.41	0.4
BQI		1	0.5	0.24	0.38	0.36	0.53°	0.6°	0.66°
HSI			1	0.43	0.94***	0.92***	0.88***	0.95***	0.87***
SatHealth				1	0.13	0.12	0.04	0.46	0.48
SaQuality					1	0.99***	0.91***	0.84**	0.76**
SatQuantity						1	0.88***	0.8**	0.73*
SatAgriculture							1	0.79**	0.68*
SatEnvironment								1	0.93***
SatLife									1

Spearman	WQI	BQI	HSI	SatHealth	SaQuality	SatQuantity	SatAgriculture	SatEnvironment	SatLife
WQI	1	0.56*	0.27	0.36	0.27	0.24	0.13	0.18	0.29
BQI		1	0.21	0.1	0.35	0.34	0.4	0.32	0.48
HSI			1	0.47	0.92***	0.91***	0.71*	0.87***	0.59*
SatHealth				1	0.21	0.18	-0.09	0.35	0.32
SaQuality					1	1***	0.77**	0.94***	0.71*
SatQuantity						1	0.76**	0.93***	0.71*
SatAgriculture							1	0.67*	0.39
SatEnvironment								1	0.85***
SatLife									1

6.1.4. References - Appendix

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6.2 Author contributions

Article 1:

Kaczmarek, N., R. B. Schäfer, & E. Berger, 2021. Environmental Change Threatens Freshwater Insect Communities in Northwest Africa: A Meta-Analysis. Frontiers in Environmental Science 9: 671715. https://doi.org/10.3389/fenvs.2021.671715

Contributions: *Nils Kaczmarek*: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing - Original Draft, Visualization. *Ralf B. Schäfer*: Conceptualization, Methodology, Validation, Formal analysis, Writing - Original Draft, Supervision, Funding acquisition. *Elisabeth Berger*: Conceptualization, Methodology, Validation, Formal analysis, Resources, Writing - Original Draft, Supervision, Project administration, Funding acquisition.

Article 2:

Kaczmarek, N., M. Benlasri, R. B. Schäfer, A. Aabid, M. Nothof, K. Lazrak, M. Ghamizi, E. Berger, submitted. Macroinvertebrate community responses to salinity around non-saline – saline confluences in the Draa River basin, Morocco.

Contributions: *Nils Kaczmarek*: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing - Original Draft, Visualization. *Mokhtar Benlasri*: Methodology, Investigation, Formal analysis. *Ralf B. Schäfer*: Conceptualization, Methodology, Validation, Formal analysis, Writing - Original Draft, Supervision, Funding acquisition. *Abdelghani Aabid*: Conceptualization, Investigation. *Maren Nothof*: Methodology, Validation, Investigation. *Mohamed Ghamizi*: Resources, Supervision. *Khawla Lazrak*: Investigation. *Elisabeth Berger*: Conceptualization, Methodology, Validation, Formal analysis, Resources, Writing - Original Draft, Supervision, Project administration, Funding acquisition.

Article 3:

Kaczmarek, N., I. Mahjoubi, M. Benlasri, M. Nothof, R. B. Schäfer, O. Frör, & E. Berger, 2023. Water quality, biological quality, and human well-being: Water salinity and scarcity in the Draa River basin, Morocco. Ecological Indicators Elsevier 148: 110050. https://doi.org/10.1016/j.ecolind.2023.110050

Nils Kaczmarek: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing - Original Draft, Writing - Review & Editing, Visualization. *Imane Mahjoubi*: Conceptualization, Methodology, Validation, Investigation, Writing - Original Draft, Writing - Review & Editing. *Mokhtar Benlasri*: Investigation. *Maren Nothof*: Methodology, Validation, Formal analysis, Investigation. *Ralf B. Schäfer*: Methodology, Validation, Formal analysis, Writing - Review & Editing, Supervision, Funding acquisition. *Oliver Frör*: Methodology, Validation, Writing - Review & Editing, Supervision, Funding acquisition. *Elisabeth Berger*: Conceptualization, Methodology, Validation, Writing - Original Draft, Writing - Review & Editing, Supervision, Project administration, Funding acquisition.

AI tools such as DeepL, Grammarly and ChatGPT were used to improve the language of the dissertation.

6.3 Declaration

I, the author of this dissertation, declare herewith, that I wrote the submitted dissertation "Macroinvertebrate community composition and ecosystem health in response to salinity and environmental change in the Draa River basin, Morocco" independently and clearly indicated all aids and sources used for the dissertation, as well as the contributions of any collaborators and other authors.

I did not seek any paid assistance of intermediary or advisory services. I did not use this dissertation in the same or a similar form as an examination paper for a state or other academic examination in Germany or abroad. I did not submit this or a different dissertation to this or another department or another academic institution.

I declare that I am aware that a violation of one of the above-mentioned points could result in the withdrawal of the doctoral title and, if applicable, may also have further legal consequences.

Landau in der Pfalz, ________________________

02.11.2023 Nils Kaczmarek

6.4 Curriculum Vitae

Nils Kaczmarek

Education:

07/2019 – 09/2022	Ph.D. student in Environmental Sciences iES Landau, RPTU Kaiserslautern-Landau, Landau, Germany Macroinvertebrate community composition and ecosystem health in response to salinity and environmental change in the Draa River basin, Morocco
December 2018	Master of Science in Evolution and Ecology Eberhard Karl University of Tübingen, Germany Thesis: Hsp70 levels in different colour morphs of the Mediterranean land snail *Theba pisana*
November 2015	Bachelor of Science in Biology Eberhard Karl University of Tübingen, Germany Thesis: Merkmale des Jochbogens der Mammalia und der Einfluss der Ernährung und der Lebensweise auf dessen Form und Stärke
June 2012	General qualification for university entrance (Abitur) Berufsbildende Schule Wirtschaft Koblenz, Germany

Experience:

2020 - present	Scientific Assistant: AMAP Deutschland (Almada Mata Atlântica Project)
2019	Participant: SMIRES training school (Val Roseg, Switzerland) Science and Management of Intermittent Rivers & Ephemeral Streams EU COST Action SMIRES
2018	Research assistant: Ecotoxicology Sampling of Gammarids and water tests around Tübingen for freshwater monitoring Eberhard Karl University of Tübingen, Germany, Institute of Evolution & Ecology

2018	Research assistant: Plant Ecology Experimental setup of common garden experiment Eberhard Karl University of Tübingen, Germany, Institute of Evolution & Ecology
2017	Researcher: Fieldwork with Giant Otters Population dynamics of giant otters in a flooded forest Instituto Araguaia, Brazil
2016	Research assistant: Fieldwork with Northern Crested Newts Assessment of population by capturing individuals and taking tissue samples Eberhard Karl University of Tübingen, Germany, Institute of Evolution & Ecology
2015-2018	Research assistant: Comparative Zoology Behavioral and sexual selection with Alpine Newts Eberhard Karl University of Tübingen, Germany, Institute of Evolution & Ecology
2015	Research assistant: Fieldwork with Corn Buntings Observational study of feeding behavior Eberhard Karl University of Tübingen, Germany, Institute of Evolution & Ecology
2014-2019	Teaching assistant: Practical courses in Zoology and Ecology Native animal species identification, soil ecology and behavioral ecology courses Eberhard Karl University of Tübingen, Germany, Institute of Evolution & Ecology
2014-2015	Field trip leader: Zoological field trip for bachelor students Primates and carnivorans in the zoological-botanical garden Wilhelma Eberhard Karl University of Tübingen, Germany, Institute of Evolution & Ecology
2013-2016	Field trip leader: Ornithological field trip for bachelor students Native bird species around Tübingen Eberhard Karl University of Tübingen, Germany, Institute of Evolution & Ecology

Publications:

Benlasri, M., **N. Kaczmarek**, M. El Alami, M. Ghamizi, & E. Berger, 2023. Inventory and pattern of distribution of mayflies (Insecta, Ephemeroptera) in the Draa river basin, southern Morocco. Alpine Entomology 7: 13–20. https://doi.org/10.3897/alpento.7.96436

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