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Urban River Restoration : a socio-ecological approach

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“I know the joy of fishes in the river through my own joy, as I go walking along it.”

Chuang Tzu

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Abstract

Rivers are hotspots for biological diversity and sources of ecosystem services. Because of the close interactions between riverine ecosystems and human activities, rivers are recognized as a socio-ecological system. Centuries of intensive exploitation of the ecosystem services, urbanization, and water management focusing on the use of water and safeguarding humans from floods and diseases, rather than on ecological health, have led to severe degradations and functional losses. In recent years, restoration has been recognized as essential to reestablish the quality of the rivers and an increasing number of restoration projects have been implemented. In Europe, the Water Framework Directive orchestrates restoration efforts, and demands that all water bodies achieve their good ecological status or potential. In urban areas, most rivers are heavily impacted by human activities and social demand for restoration is high. However, little knowledge exists about urban restoration practices. This research aims (1) to identify the different restoration practices and drivers, and examine the particularities of urban river restorations, and (2) to assess the potential conflicts inside the socio-ecological system.

In order to address these objectives, different methods from social and ecological sciences were applied. A first set of analysis concerned 153 river restoration projects located in France and Germany. A comparison between urban and rural restoration practices and a project typology using hierarchical clustering procedure and examination of the restoration drivers using textual analyses were performed. A second set of analysis concerned the case of the Isar restoration in Munich. The analysis of restoration success for target fish (*Thymallus thymallus* L., *Hucho hucho* L., and *Chondostroma nasus* L.) and plant species (*Myricaria germanica* L.*)* taking into account potential conflicts with human uses (recreation, hydro-electrical production) were based on field surveys (plant growth, user pressures, habitat structures), semi-experimental studies, and habitat modelling using Computer Aided Simulation Model for Instream Flow Requirements (CASiMiR).

Key findings concerning the first research objective identified five types of river restoration (RR) projects: *Fish RR*, *Blue RR*, *WFD RR*, *Flood protection RR*, and *Human RR* (Paper A). Surprisingly project types distinguished themselves from their social rather than ecological quality goals. Urban river restorations intend to restore domesticated

ecosystems but differ from rural counterparts based on the diversity of restoration goals, the project motivation, and the restored area (only aquatic in rural and often aquatic and riparian in urban areas). Interestingly, while the WFD is the obvious driver of the European restoration effort, it drives the national restoration trends with different intensities. Furthermore social drivers highly influence the trends, particularly in the case of urban river restorations (Paper B). Key findings on the second research objective suggested that restoration projects can recreate suitable habitats for sensitive plant (Paper C) and fish species (Paper D) but that recreational uses partly conflict with ecological quality goals. However, outcomes of the modeling procedure indicated that the identification of the best restoration scenario may depend of the specie target. Interestingly, the suppression of the water diversion did not succeed in recreating suitable habitats for all fish species targeted by the restoration (Paper E).

The research produced a dataset of projects that was not yet recorded in the national and European Dataset doubling the number of French river restoration projects recorded in RiverWiki and increasing of ten times the number of urban projects of the previously published databases. The study highlights the importance of societal driving forces in urban restoration projects and shows the need for policy adjustments according to a socio-ecological approach (Paper A and B). The research also enabled the reintroduction of an endangered plant species in the Isar (*Myricaria germanica L),* providing important conservation benefits. The inclusion of social parameters into the modeling procedure is a novelty that substantiates important insights to understand the failures and successes of the projects and to provide guidance on management strategies (Paper C, D and E).

To conclude, the socio-ecological system collapsed after decades of intensive exploitation of the ecosystem service provided by rivers. The current restoration approach had limited results and the return to a prior degradation status is, at least in urban area, a utopia. Better consideration of the socio-ecological system should furnish better outcomes and enable achievement of a hybrid and futuristic status that allows the maximum benefit for both humans and the environment.

French Abstract/Résumé

Les rivières sont un réservoir biologique et source de développement pour les sociétés humaines. À cause de l'étroite relation entre les Hommes et les écosystèmes fluviaux, elles furent identifiées comme un système socio-écologique. Hors, il s'effondre suite à l'exploitation intensive des services écosystémiques, à l'urbanisation croissante, et à la gestion de la ressource en eau priorisant la protection des biens, des usages et des personnes aux formes et fonctions des écosystèmes. Ces cinquante dernières années furent marquées par de nombreuses actions de restauration réalisées pour rétablir la qualité écologique et sociale des rivières. En Europe, la Directive Cadre sur l'Eau ratifiée en 2000 organise l'effort européen de restauration et demande l'atteinte du bon état ou potentiel écologique de toutes les masses d'eau des pays membres. Les rivières urbaines sont fortement affectées par l'impact anthropique mais leur restauration est particulièrement difficile. Alors que la science de la restauration évolue par les expériences passées, peu de connaissance existent sur les pratiques urbaines. Cette étude a pour objectif (1) d'identifier les différentes pratiques de la restauration et leurs forces motrices en mettant en avant les particularités des restaurations en milieu urbain. Et (2) d'évaluer les conflits au sein du système socio-écologique, notamment entre protection environnementale et usage récréatif et productif.

Pour atteindre ces objectifs, différentes méthodes des sciences sociales et écologiques ont été appliquées. Tout d'abord, une première série d'analyses portant sur 153 projets de restauration de rivières réalisés en France et en Allemagne fut réalisée. Les différentes pratiques de la restauration ont été identifiées utilisant une procédure de division hiérarchique. Les forces motrices de la restauration ont été quantitativement et qualitativement étudiées utilisant des analyses statistiques et textuelles standardisées. Les particularités des restaurations en milieu urbain ont été identifiées par une étude comparative. Ensuite, trois études a été menée analysant les potentiels conflits au sein du système socio-écologique dans le cas de la restauration de l'Isar à Munich (Allemagne). La première, évalua le succès de la restauration considérant une espèce végétale pionnière (*Myricaria germanica* L.) historiquement présente tout le long de l'Isar mais ayant été confinée par les dégradations morphologiques de la rivière à quelques bastions alpins. La seconde, considéra une espèce de poisson (*Chondostroma nasus* L.) historiquement présente à l'Isar à Munich mais ayant désertée le site d'étude et étant en déclin en amont

et en aval. Ces deux études évaluèrent les conflits entre restauration écologique et usage récréatif des zones restaurés utilisant une procédure de réintroduction et une modélisation des habitats physiques propices. La troisième, utilisa une modélisation des habitats physiques propices dans le cas de trois espèces de poissons : *Thymallus thymallus* L., *Hucho hucho* L., et *Chondostroma nasus* L. pour identifier le meilleur scénario de partage de la ressource en eaux entre production hydro-électrique et conservation des espèces.

Les résultats montrèrent l'existence de cinq types de projet de restauration (article A). De manière surprenante, alors que les différentes activités de restauration étaient différenciées par un gradient écologique, les types de projet trouvés se différencient davantage par leurs composantes sociales. Du plus, nous avons trouvé que les projets urbains diffèrent fondamentalement des projets ruraux, notamment par la diversité de leurs objectifs, de leurs forces motrices et de leur emprise géographique. Soulignons, que la Directive Cadre sur l'Eau influence l'effort de restauration, mais de manière plus forte en Allemagne qu'en France (article B). Ensuite, l'étude de cas montra que le projet de restauration reproduisit en partie les habitats propices pour les espèces étudiées mais que l'usage pour le loisir de proximité diminue la qualité des habitats et donc rentre en conflit direct avec les objectifs de qualité écologique (article C et D). Enfin, la modélisation des habitats montra que l'identification d'un scénario de restauration supportant un maximum d'habitat pour un maximum d'espèce est complexe mais que l'abandon des usages ne permet pas à lui seul un retour aux conditions d'origine (article E).

La recherche doctorale a permis de produire un set de données original sur les projets de restauration, doublant le nombre de projets réalisés en France et multipliant par dix le nombre de projets réalisés en milieu urbain en France et en Allemagne fichés dans les bases de données publiques. L'étude met en avant l'importance des forces motrices sociétales et demande un ajustement des politiques de l'eau intégrant le concept de système socio-écologique. Elle a permis la réintroduction d'une espèce floristique en péril et l'intégration de paramètre sociaux dans une procédure de modélisation des habitats. Pour conclure, les projets de restauration essayant de reconstruire des conditions d'origines ont montrés des résultats limités et une nouvelle approche intégrant les interactions du système socio-écologique devrait permettre d'atteindre des objectifs réalistes de restauration.

German Abstract/Zusammenfassung

Flüsse sind ein Hotspot für biologische Artenvielfalt und Erbringer vieler Ökosystemleistungen. Aufgrund der engen Wechselbeziehungen zwischen Flussökosystemen und menschlichen Aktivitäten werden sie als sozio-ökologische Systeme verstanden. Jahrhunderte massiven Nutzungsdrucks, Urbanisierung und eine Gewässerbewirtschaftung, die sich viel mehr der Versorgung der Menschen und dem Schutz derer vor Überschwemmungen und Krankheiten anstatt der Wahrung des ökologischen Gleichgewichts verschrieben hat, haben zu starken Zerstörungen und Funktionsverlusten dieser Ökosysteme geführt. In jüngster Zeit wurde die Notwendigkeit der Renaturierung von Flüssen zur Wiederherstellung ihrer Qualität erkannt und eine wachsende Zahl an Renaturierungsprojekten wurde realisiert. In Europa koordiniert die Wasserrahmenrichtlinie (*Water Framework Directive,* WFD) entsprechende Bemühungen und verlangt, dass alle Gewässer eine guten ökologischen Zustand oder ein gutes ökologisches Potenzial erreichen. In städtischen Gebieten sind die meisten Flüsse stark durch menschliche Aktivitäten geprägt und der Bedarf nach Renaturierungsmaßnahmen hoch. Dennoch gibt es nur wenige Kenntnisse über die Praktiken von Flussrenaturierungen in Städten. Diese Studie hat sich zum Ziel gesetzt (1) unterschiedliche Renaturierungspraktiken und deren Triebkräfte zu identifizieren und die Besonderheiten städtischer Flussrenaturierungen zu untersuchen und (2) die potenziell möglichen Interessenskonflikte im sozio-ökologischen System zu bewerten.

Um diese Zielsetzungen zu erreichen wurden unterschiedliche Methoden der Sozial- und Umweltwissenschaften angewandt. Zuerst wurde eine Analyse von 153 Flussrenaturierungsgsprojekten aus Frankreich und Deutschland durchgeführt. Sie beinhaltete einen Vergleich zwischen ländlichen und urbanen Renaturierungspraktiken, eine Projektentypologisierung wurde unter der Verwendung des hierarchischen Cluster-Verfahrens und eine Untersuchung der Triebkräfte von Renaturierungsprojekten mit Hilfe von Textanalysen. Ein zweites Analysepaket widmete sich dem Fallbeispiel der Isar Renaturierung in München. Der Renaturierungserfolg wurde gemessen an dem Vorkommen von wieder erwünschten Fischarten (*Thymallus thymallus* L., *Hucho hucho* L., und *Chondostroma nasus* L.) und einer Pflanzenart (*Myricaria germanica* L.) unter Berücksichtigung potenzieller Konflikte mit menschlichen Nutzungsformen (Erholung und Wasserkraft), ermittelt mit Hilfe von Feldstudien (Pflanzenwachstum,

Nutzungsdruck, Habitatstrukturen), semi-experimentellen Studien und dem Habitatmodell CASiMiR (*engl.* Computer Aided Simulation Model for Instream Flow Requirements).

Als wesentliche Ergebnisse des ersten Forschungsziels wurden fünf Typen von Flussrenaturierungsprojekten (*River Restoration*, RR) identifiziert (Artikel A). Unerwarteter Weise unterschieden sich die Projekttypen eher in ihren sozialen als weniger in ihren ökologischen Qualitätszielen. Urbane Flussrenaturierungen beabsichtigen die Renaturierung domestizierter Ökosysteme, unterscheiden sich aber von denen ländlicher Räume durch ihre Vielzahl an Renaturierungszielen, die Projektmotivation und das renaturierte Gebiet (ausschließlich aquatisch in ländlichen Gebieten, häufig aquatisch und die Uferregion betreffend in städtischen Gebieten). Während die Wasserrahmenrichtlinie offensichtlich die treibende Kraft bei europäischen Renaturierungsvorhaben darstellt, ist sie bei nationalen Entwicklungen interessanter Weise in unterschiedlichen Maßen beteiligt und wird teilweise dominiert von sozialen Triebkräften, vor allem im Falle urbaner Flussrenaturierungen (Artikel B). Die wesentlichen Ergebnisse des zweiten Forschungsziels haben gezeigt, dass Renaturierungsprojekte geeignete Lebensräume für anspruchsvolle Pflanzenarten (Artikel C) und Fischarten (Artikel D) wiedererschaffen können, aber auch, dass die Erholungsnutzung teilweise mit den ökologischen Qualitätszielen konkurriert. Die Ergebnisse der Modellierung zeigten aber auch, dass manche erwünschte Arten durch menschliche Nutzungsformen begünstigt werden, nämlich durch die Formierung von Flachwasserstellen im Zuge der Umleitung von Gewässern für Kraftwerke, während andere Arten von denselben Gegebenheiten negativ beeinflusst werden (Artikel E). Interessanter Weise hat eine Unterdrückung von Umleitungsmaßnahmen nicht dazu geführt, dass geeignete Lebensräume für alle erwünschten Fischarten der Renaturierung wiedererschaffen wurden.

Die Studie hat einen Datensatz von Projekten erstellt, welcher bislang kein Bestandteil nationaler und europäischer Datensätze war, hat zu einer Verdopplung der Anzahl an der in RiverWiki aufgeführten französischen Flussrenaturierungsprojekten geführt und die Anzahl urbaner Projekte um das Zehnfache erhöht im Vergleich zu zuvor veröffentlichten Datensätzen. Die Studie unterstreicht die Notwendigkeit der Beteiligung gesellschaftlicher Kräfte in urbanen Renaturierungsvorhaben und zeigt den Bedarf nach politischem Umdenken in Richtung eines sozio-ökologischen Ansatzes (Artikel A und

B). Die Studie plausibilisiert außerdem die Wiedereinführung einer bedrohten Pflanzenart an der Isar (*Myricaria germanica* L.), was wichtige Vorteile der Bestandserhaltung mit sich bringt. Die Integration von sozialen Parametern in die Modellierung ist eine Neuheit, durch welche wichtige Einblicke erlangt werden hinsichtlich der Misserfolge und der Erfolge von Projekten, und die Leitlinien für Managementstrategien hervorbringt (Artikel C, D und E). Abschließend wird festgestellt, dass das sozio-ökologische System nach Jahrzehnten intensiver Nutzbarmachung von Flussökosystemen zusammengebrochen ist. Der aktuelle Renaturierungsansatz hat nur zu beschränkten Ergebnissen geführt und die Rückkehr zu einem Pre-Degradationsstatus ist, zumindest in städtischen Bereichen, eine Utopie. Eine verbesserte Einbeziehung des sozio-ökologischen Systems könnte zu besseren Ergebnisse führen und dazu befähigen, einen hybriden und zukunftsträchtigen Status zu erreichen, der einen Maximalnutzen für Mensch und Ökologie generiert.

(Übersetzung von Laura Stratopoulos)

Chinese Abstract

城市河流修复–社会生态学方法（摘要，翻译：徐超）

河流是生物多样性研究的热点和诸多生态系统服务的来源。由于河岸生态系统与人类活动的密切相互作用，使得河流通常被认为是一种社会生态系统。几个世纪以来，生态系统服务的集约利用、城市化和水资源管理主要关注于水资源的有效利用和保障人类免受洪水和疾病的危害而往往忽视了生态健康，从而导致了严重的生态退化和功能的丧失。近年来，河流修复被公认为重建河流质量的必要手段并且越来越多的修复项目开始付诸实施。在欧洲，欧盟水框架指令对水资源的修复工作进行策划统筹，并对所有水体需达到的生态状况或生态潜力提出了高的要求。在城市地区，绝大多数的河流深受人类活动的影响并且对于河流修复的社会需求较高。然而，关于城市河流修复实践的相关知识还非常缺乏。本研究旨在：（1）区分不同的河流修复实践项目及其驱动力，以及研究城市河流修复的特殊性；（2）并对这一社会生态系统中存在的潜在冲突进行评估。

针对上述研究目标，本研究采用了不同的社会学和生态学的研究方法。第一组分析中涵盖了包括法国和德国在内的 153 个河流修复项目。首先对城市和乡村范围内的河流修复项目进行了比较研究，其次通过层次聚类分析和内容分析的方法分别对修复项目类型学和修复驱动力进行分析。第二组分析中以德国慕尼黑伊萨尔河的修复作为实例。在考虑到与人类用途（休憩，水力发电）之间潜在冲突的前提下，通过野外调查（植物生长，使用压力，栖息地结构）、半试验性研究以及基于河道需水量计算机辅助模拟模型（CASiMiR）的栖息地模拟等研究方法，对修复目标鱼类（*Thymallus thymallus* L., *Hucho hucho* L., and *Chondostroma nasus* L.）和目标植物物种（*Myricaria germanica L*）的修复成效进行了分析。本论文的撰写基于 5 篇同行评议出版物和一篇科研报告（参照贡献列表第 8 页）。

关于第一个研究目标，主要研究结果确定了五种不同的河流修复项目类型：鱼类河流修复，蓝色空间河流修复，水框架指令河流修复，防洪河流修复以及人文河流修复（论文 A）。出人意外地，不同项目类型的区别主要体现在其社会性目标的不同，而不是生态质量目标的差异。城市河流修复致力于修复已驯化的生态系统，其与乡村河流修复的区别在于修复目标、项目动机、和修复区域（乡村河流修复仅注重于水体而城市河流修复则包括水体与河岸）的差异。有趣的是，欧盟水框架指令作为欧洲水资源修复工作的一个明显趋动力，尤其是在城市河流修复中，其以不同的强度引导着不同国家的河

流修复工作的趋势并在一定程度上以社会驱动力为主导（论文 B）。针对第二个研究目标，主要结果表明，河流修复项目可以为敏感植物（论文 C）和鱼类（论文 D）重建适宜的栖息地，但其休憩用途在一定程度上与生态质量目标相冲突。尽管如此，模拟结果显示，在同样的水管理方案下，部分鱼种由于适应水电站引水造成的潜水而备受青睐，相反地其他鱼类则受到了消极的影响（论文 E）。有趣的是，对引水量的抑制也并不能为所有修复目标鱼类重建适宜的栖息地。

本研究所提供的项目数据集汇总了尚未在任何国家或欧洲范围内的数据集中记载的河流恢复项目，将 RiverWiki 中所记录的法国河流修复项目的数量扩充了一倍，同时将现已公布的数据集中城市河流修复项目的数量增加了十倍。与此同时，本研究还强调了城市河流修复项目中社会驱动力的重要性，通过社会生态学的方法揭示了政策调整的必要性（论文 A 和 B）。其次，本研究还论述了将一种濒危植物物种（*Myricaria germanica L*）重新引入伊萨尔河区域 以便提供重要保护效益的可能性。最后，将社会性参数创新性地纳入模拟过程不但可以加深对恢复项目得失的认知，而且可以更深层次地为管理策略提供指导。

总而言之，数十年来对河流生态系统服务的集约开采导致了这一社会生态系统的崩溃。现有的河流修复手段效果有限，至少在城市范围内，想要达到退化之前的状态是不切实际的。尽管如此，更多地从社会生态系统的角度出发应该能够为河流修复提供更好的思路和结果，从而使得一种人与生态共赢的未来混合状态成为可能。

(Translated by Chao Xu)

French long abstract/Résumé significatif

1. Introduction

Les rivières sont un réservoir biologique (Lytle & Poff 2004; Geist 2011; Schwalm et al. 2011; Arthington 2012a). Elles sont, grâce aux nombreux services écosystémiques qu'elles produisent (Millennium Ecosystem Assessment 2005; Arthington et al. 2010; Everard & Moggridge 2012; Scott Shafer et al. 2013; Vollmer & Grêt‐Regamey 2013; Vermaat et al. 2016), source de développement pour les sociétés humaines (Arthington et al. 2010; D'Odorico et al. 2010; Kondolf & Pinto 2016; Wantzen et al. 2016). Cependant, l'Homme ne profite pas passivement des avantages liés aux rivières mais il interagit avec elles. La liaison entre société et écosystèmes a été définie par le concept de système socio-écologique (Berkes & Folke 1998). Une approche holistique étudiant le cas des rivières a établi le concept socio-écologique de *river culture* selon lequel un déclin de la qualité écologique des rivières conduit à un déclin du bien-être humain et vice-versa (Wantzen et al. 2016). Malheureusement, la gestion du domaine fluvial et de la ressource s'est, jusqu'au 20ème siècle, seulement intéressée à l'aspect sécuritaire, soit, assurer la disponibilité de la ressource pour les usages et protéger les biens et personnes des crues et risques sanitaires (Holmes 1972; Lovett 1973; Getches 2001; Gerlak 2006; Goldin 2010; Victor et al. 2015). L'exploitation intensive des services écosystémiques et l'urbanisation ont sévèrement participé à la dégradation écologique des rivières (Walsh et al. 2005; Bernhardt & Palmer 2007; Castonguay & Samson 2010) qui résulta en une perte_ majeure des avantages sociaux fournis par les masses d'eau de surface (Castonguay & Samson 2010; Everard & Moggridge 2012; Kondolf & Pinto 2016; Wantzen et al. 2016). Depuis les années 80, les travaux de restauration sont de plus en plus reconnus comme essentiels pour rétablir les fonctions écologiques et sociales des rivières (EU 2000; SER 2004; Millennium Ecosystem Assessment 2005; Jørgensen 2015). Le nombre de projets réalisés et de recherches publiées augmente mais de nombreuses lacunes de connaissance spécifique persistent.

Une première lacune est la caractérisation et la définition des projets qui devraient être davantage axées sur, et adaptées aux, pratiques. Les projets de restauration sont nombreux et variés mais ont été regroupé dans un désir d'unité de la communauté scientifique sous le même terme de restauration de rivière (*river restoration)* (SER 2004). Cependant, de nombreuses sous-catégories existent, comme par exemple réhabilitation, renaturation, et revitalisation. De nombreuses définitions de ces actions ont été formulées se recoupant et étant utilisées différemment selon le contexte linguistique et culturel des projets (Morandi 2014). La confusion résultante a engendré des biais qui mettent en danger la comparaison des projets et les processus d'apprentissage par les expériences passées. La communauté scientifique et les praticiens ont formulé un besoin accru pour une caractérisation et une définition des différents types de projets basés sur des exemples pratiques et intégrants une approche socio-écologique (Jenkinson et al. 2006; Bernhardt et al. 2007a). Quelles sont les différents types de restauration de rivière ? La recherche doctorale s'intéressera dans un premier temps à la définition et caractérisation des différents types de projets de restauration se basant sur un inventaire des pratiques.

Une seconde lacune concerne les bases de données existantes qui sont incomplètes. L'écologie de la restauration est une science expérimentale qui évolue grâce au partage d'expérience. C'est pourquoi, un grand effort a été fourni afin de recenser les projets de restauration (Bernhardt et al. 2005; Jenkinson et al. 2006; Nakamura et al. 2006; Bernhardt et al. 2007b; Brooks & Lake 2007; Kondolf et al. 2007; Feld et al. 2011; Morandi & Piégay 2011; Aradóttir et al. 2013; Barriau 2013; Pander & Geist 2013; Morandi et al. 2014; Kail et al. 2016; Muhar et al. 2016; Speed et al. 2016). Cependant, Jenkinson et Barnas (2006) ont souligné que les bases de données ne recensent qu'une petite proportion de l'effort global. Malgré de nombreux fonds européens dédiés à la création de bases de données publiques (par exemple REFORM ou RiverWiki) et de grands moyens humains déployés, les bases de données restent incomplètes et ces inventaires sont marqués par une grande différence entre les pays européens. Cette recherche doctorale participera à combler ce manque.

Une troisième lacune est le manque de connaissance sur les restaurations de rivières urbaines. Alors qu'aux États-Unis, les restaurations en milieu urbain attirent les efforts et moyens (Bernhardt et al. 2005; Hassett et al. 2007), ils sont particulièrement faiblement représentés au sein des bases de données européennes. La recherche en laboratoire urbain est particulièrement importante parce que la population mondiale croît rapidement et les aires urbaines à forte densité vont absorber une majeure partir de cette croissance (U.N 2014). Alors qu'en 1952, la plus grande ville était New York (U.S.A) avec à peine huit millions d'habitants, en 2001, dix-sept étaient plus peuplées qu'elle et elles étaient quarante-quatre en 2010. En 2030, 85% de la population d'Europe et d'Amérique du Nord vivra en milieu urbain (U.N 2014). Cette croissance démographique couplée à celle des aires urbaines n'est pas sans répercussion sur les espaces naturels. L'urbanisation a d'ores déjà engendré des dégradations écologiques majeures, et les rivières urbaines sont davantage touchées par l'impact anthropique que leur tronçons ruraux (EEA 2012; Yuan et al. 2017). Leurs dysfonctionnements sont caractéristiques et ont été nommées *urban river syndrom* (Walsh et al. 2005). De plus, malgré un intérêt croissant des populations citadines pour les rivières urbaines (Bethemont & Pelletier 1990; Brown 1999; Booth et al. 2004; Bonin 2007; Akers 2009; Castonguay & Samson 2010; Costa et al. 2010; Romain 2010a; Romain 2010b; Kehoe 2011; Brun & Simoens 2012; PUB 2012; Mahida 2013; Chou 2016; Smith et al. 2016; Wantzen et al. 2016), celles-ci sont particulièrement difficiles à restaurer (Bernhardt et al. 2005; Bernhardt et al. 2007a). La recherche sur les rivières urbaines reste peu développée (Moran 2007; Francis 2012), mais à cause de ses particularités, les résultats de recherches menées en milieu rural sont difficilement extrapolables au milieu urbain. Ainsi une recherche spécifique devrait constituer un apport intéressant pour la science. Quelle sont les particularités des restaurations en milieux urbain ? Cette étude doctorale va établir la différence de pratiques en fonction du contexte géographique, soit urbain ou rural, comparant des projets réalisés dans un même contexte législatif et culturel.

Une quatrième lacune traitée dans cette étude est qu'alors que les rivières sont reconnues comme un système socio-écologique, peu de considération a été accordée à l'identification des forces motrices sociétales des projets de restauration. La dégradation écologique des écosystèmes et la perte relative en services écosystémiques ont été définies comme les principales forces motrices des projets de restauration (Galatowitsch 2012). Cependant, l'effet de forces indirectes telles que morale, idéologique, politique, démographique et économique n'a été que supposé (Clewell & Aronson 2006; Baker et al. 2014) et peu d'attention a été accordé à leur identification et à l'estimation de leur influence sur les pratiques de la restauration (Eden & Tunstall 2006; Grêt-Regamey et al. 2016; Parr et al. 2016). Quelles sont les forces motrices sociétales de la restauration ? Cette étude s'intéresse à l'impact les forces motrices législative, politique, culturelle et idéologique sur les pratiques de la restauration.

Une cinquième lacune concerne l'évaluation du succès des projets. Elle est une condition nécessaire pour comprendre les expériences passées et apprendre d'elles. La revue littéraire expose les six limitations majeures des procédures d'évaluation actuelles : 1) les données sont manquantes ou partielles car peu de projets réalisent un suivi

(Bernhardt et al. 2005; Pander & Geist 2013; Morandi et al. 2014); 2) L'utilisation d'une référence historique est utopique (SER 2004; Moss 2008; Dufour & Piégay 2009; Josefsson & Baaner 2011; Belletti et al. 2015; Bouleau & Pont 2015), et les sites de références sur le même cours d'eau sont souvent inexistants (Morandi et al. 2014; Bouleau & Pont 2015); 3) Les indicateurs biologiques ont un pouvoir limité pour expliquer les causes de succès et d'échec (Niemi & McDonald 2004; Friberg et al. 2011; Smucker & Detenbeck 2014); 4) Les indicateurs utilisés ne sont pas représentatifs des objectifs de la restauration (Pickett et al. 1997; Meyer et al. 2005; Walsh et al. 2005; Morandi et al. 2014) et les indicateurs sociaux sont manquants (Rogers & Biggs 1999; Chiari et al. 2008; Jaehnig et al. 2011; Pander & Geist 2013; Morandi et al. 2014); 5) Lorsqu'une évaluation est réalisée, elle est faite sur le court terme (Pander & Geist 2013; Morandi et al. 2014), mais les espèces nécessitent de plus longues périodes pour se rétablir (Haase et al. 2013; Morandi et al. 2014; Kail et al. 2015); et 6) Les zones rivulaires ne font pas partie de la zone de suivi (Januschke et al. 2011; Morandi et al. 2014). Les praticiens nécessitent une méthode qui dépasse ces limites et évalue les conflits potentiels. La modélisation des habitats utilisant la méthode CASiMiR et présentée dans cette étude. Elle est un outil prometteur pour combler les lacunes existantes.

Enfin, l'évaluation écologique des projets de restauration n'est pas réaliste si elle ne considère pas les aspects sociaux (Wortley et al. 2013) et plus particulièrement les interactions décrites par le concept de système socio-écologique (Berkes & Folke 1998; Berkes et al. 2003; Ostrom 2009; Hinkel et al. 2014). L'interaction des Hommes avec l'écosystème fluviale a conduit à la dégradation des habitats. Ainsi, la pression des usages devrait être intégrée à l'évaluation des projets afin d'identifier les conflits et de formuler des solutions. Cette étude doctorale va aborder le cas de deux usages, soit les usages récréatifs et productifs, c'est-à-dire la production d'énergie hydro-électrique. Elle traite des deux questions suivantes : Est-ce que les usages récréatifs limitent le succès écologique des projets de restauration ? Est-ce que la diminution de l'exploitation de la ressource pour produire de l'énergie accroît les résultats de la restauration morphologique des rivières ?

L'étude doctorale traite de ces six lacunes et ses objectifs sont doubles:

(1) Identifier les différentes pratiques de la restauration et les forces motrices en mettant en avant les particularités des restaurations en milieu urbain.

(2) Évaluer les potentiels conflits au sein du système socio-écologique, notamment entre protection environnementale et usage récréatif et productif.

2. Méthodes

Afin d'étudier le système socio-écologique et de produire des avancées pour un développement durable des projets de restauration, l'étude doctorale s'intéresse aux relations entre les composants primaires du système social, soit la *gouvernance* et les *usagers* (Ostrom 2009), et le système écologique, soit la rivière (Ostrom 2009). Différentes méthodes ont été appliquées pour répondre de manière adaptée aux différentes questions de recherche citées préalablement.

Tout d'abord, afin d'identifier les différentes pratiques de la restauration, leur forces motrices et d'examiner les particularités des projets en milieu urbain (objectif 1), une analyse exploratoire au niveau national et transnational a été réalisée. Face au manque de données disponibles sur la restauration en milieu urbain, une base de données a été créée utilisant un recensement téléphonique auprès de toutes les villes de plus de 100 000 habitants en France et en Allemagne (N=132). Malgré l'existence d'internet comme source d'information permettant des recherches standardisées, les interviews directes menées par téléphone sont certes coûteuses en temps, mais elles ont été définies comme la méthode la plus efficace pour obtenir des informations sur les projets de restauration passés (Bernhardt et al. 2005; Alexander & Allan 2006; Brooks & Lake 2007; Morandi & Piégay 2011). La méthode et le questionnaire utilisés se basent sur des méthodes des sciences humaines et sont détaillés dans le chapitre 3.2.3. L'inventaire renseigne sur les caractéristiques majeures de projets définis par la littérature publiée (Bernhardt et al. 2005; Jenkinson et al. 2006; Nakamura et al. 2006; Brooks & Lake 2007; Kondolf et al. 2007; Aradóttir et al. 2013) et l'analyse statistique s'appuie sur elles pour comparer les projets. Dans un premier temps, cherchant à établir une typologie de projet qui établisse les types de projet de restauration existant, une méthode de division hiérarchique avec approche descendante utilisant un partitionnement en k-moyennes a été appliqué. Il s'agit d'une analyse factorielle multiple hiérarchique (Husson et al. 2011) utilisant le package FactoMineR (Multivariate Exploratory Data Analysis and Data Mining) version 1.24 de R dédié à l'analyse exploratoire multidimensionnelle de données. Dans un second temps, pour comparer les projets en fonction de leur contexte géographique, soit urbain soit rural, une analyse bivariée a été menée sur ces mêmes caractéristiques majeures des projets. Cependant, d'après l'étude bibliographique préliminaire, l'utilisation des projets localisés dans différents pays européens pourrait causer un biais (Falkner & Treib 2008; Keessen et al. 2010; Couch et al. 2011; Albrecht 2013; Sala et al. 2014). Pour cette raison, cette analyse n'a été menée que pour des projets réalisés en France. Les projets urbains recensés ont été comparé aux projets ruraux documentés dans la base de données produite par l'ONEMA. La compatibilité des bases de données a été vérifiée préalablement. Enfin, pour étudier l'effet de la gouvernance comme force motrice de la restauration, une analyse qui s'appuie sur une méthode des sciences humaines a été appliquée, soit une analyse textuelle (LERASS 2014), basée sur la description des projets fournit par les maîtres d'œuvre.

Ensuite afin d'évaluer le succès écologique des projets de restauration et les conflits potentiels entre usage et biodiversité (objectif 2), une étude de cas a été réalisée, s'appuyant sur des méthodes des sciences écologiques qui ont été étoffées de paramètres sociaux. La restauration de l'Isar à Munich (Allemagne) est avancée par la littérature comme un projet phare et comme un exemple à l'échelle mondiale de projet urbain ayant de très fortes retombées écologiques et sociales. C'est pourquoi ce cas est étudié dans le détail. Tout d'abord, afin d'étudier le succès écologique du projet, une attention particulière a été portée au test des preuves supposées d'échec. Le projet subi un monitoring attestant le rétablissement écologique des communautés biologiques à l'exception de rares espèces particulièrement sensibles qui étaient pourtant en partie cible du projet, par exemple *Myricaria germanica* L. (une espèce végétale) et *Chondostroma nasus* L. (une espèce de poisson). Concernant l'espèce végétale, dans le cadre de cette étude une réintroduction a eu lieu dans les sites supposés propices par un inventaire des micro-habitats. Pour ce qui est de l'espèce ichtyologique, afin de contourner un suivi ne permettant pas d'établir les causes de succès ou d'échec d'une tentative de réintroduction et des relevé long et coûteux, une modélisation des habitats physiques a été réalisée à l'aide du logiciel CASiMiR (Schneider et al. 2010; Noack et al. 2013). Celui-ci s'appuie sur les trois variables déterminantes pour les habitats du poisson : la hauteur de la colonne d'eau, la vélocité des courants, et le substrat de surface. Les deux premières variables ont été simulées par un modèle hydromorphologique à haute résolution (filet de 1m x 1m) et la troisième par des relevés de terrain (N = 1 628). Ensuite, afin d'étudier l'impact d'un usage spécifique (le loisir de proximité) sur le rétablissement de ces espèces, des relevés d'usage ont été réalisés. Les dommages sur le matériel végétal ont été mesurés, ainsi que la cause de mortalité de la plante. De plus, la densité des usages et leur localisation ont été intégrées au modèle des habitats physiques. La sensibilité de l'espèce aquatique à la pression des usages récréatifs a été estimée par des experts locaux par interviews directes. Enfin, afin d'évaluer les conflits des usages productifs sur la qualité écologique, l'effet de la diversion de l'eau alimentant des centrales hydroélectriques sur la qualité d'habitats aquatiques pour le poisson a été étudié. L'augmentation du débit minimal a été définie comme une mesure de restauration favorable à l'ichtyofaune (Arthington 2012a) mais reste une mesure peu appliquée (Morandi 2014). Cette dernière demande des négociations intensives entre les associations de protection de la nature et les agences de production d'électricité. Le calcul des débits minimaux nécessite la considération de la morphologie fluviale locale et des besoins spécifiques des espèces présentes ou cible de la restauration. La méthode CASiMiR utilisée dans cette étude est présentée comme une approche standardisée à moindre coût. Cette étude simule les modifications de quantité et de qualité des habitats physiques pour trois espèces de poisson cibles de la restauration, soit *Chondostroman nasus* L., *Hucho hucho* L., *Thymallus thymallus* L., dans quatre cas de figure : débit minimal tel qu'avant la restauration, débit minimal accru suite à la restauration de l'Isar, débit minimal tel que demandé par les associations de protection de la nature, et débit « naturel », soit sans diversion approvisionnant les centrales hydroélectriques.

3. Résultats et discussion

Les résultats de cette étude doctorale sont multiples et ont été présentés dans cinq articles scientifiques à large visibilité et un rapport scientifique.

- Zingraff-Hamed A., Greulich S., Pauleit S., Wantzen K. M. (2017) Urban and rural river restoration in France: a typology, *Restoration Ecology*, 25(6) : 994-1004, doi: 10.1111/rec.12526

- Zingraff-Hamed A., Sabine Greulich S., Wantzen K.M., Pauleit S. (2017) Societal Drivers of European Water Governance: a Comparison of Urban River

Restoration Practices in France and Germany, *Water* (9) 206; doi:10.3390/w9030206

- Zingraff-Hamed A., Egger G., Greulich S. (2014) Wiederansiedlung der Deutschen Tamariske im Stadtgebiet München, Ville de Munich (Germany), 13 pages.

- Zingraff-Hamed A., Greulich S., Egger G., Pauleit S., Wantzen K.M. (2017) Urban river restoration, evaluation and conflicts between ecological and social quality. Dans Deutsche Gesellschaft für Limnologie (Hrsg.): Erweiterte Zusammenfassungen der Jahrestagung in Wien 2016; Hubert & Co., Göttingen, ISBN 978-3-9818302-0-1.

- Zingraff-Hamed, A., Noack, M., Greulich, S., Schwarzwälder, K., Wantzen K. M., Pauleit, S. (2018) Model-Based Evaluation of Urban River Restoration: Conflicts between Sensitive Fish Species and Recreational Users, Sustainability (6) *10*, 1747; https://doi.org/10.3390/su10061747

- Zingraff-Hamed, A., Noack, M., Greulich, S., Schwarzwälder, K., Pauleit, S., Wantzen K. M. (2018) Model-Based Evaluation of the Effects of River Discharge Modulations on Physical Fish Habitat Quality, Water (10) 374; doi:10.3390/w10040374

3.1. Typologie de projet

Tout d'abord, une grande diversité de projets a été recensée mais cinq types ont été identifiés et dénommés *Fish RR*, *WFD RR*, *Blue RR*, *Flood protection RR*, et *Human RR (Zingraff-Hamed et al. 2017b)*. Les projets de type *Fish RR* sont les plus fréquents et concernent 40% des projets réalisés. Ils restaurent principalement la continuité écologique pour l'ichtyofaune, notamment pour les espèces migratrices ciblent de la restauration. Par exemple, sont compris dans ce groupe les projets portant principalement sur une action locale de type suppression d'ouvrages transversaux. Les projets de type *WFD RR*, sont également très fréquents (38%) et regroupent les projets réalisés dans le but primaire de répondre aux attentes de la Directive Cadre sur l'Eau. Ce sont des projets à l'échelle de quelques kilomètres et ayant de multiples objectifs. Cependant, suivant les demandes de la Directive Cadre sur l'Eau, l'effort de restauration se concentre sur la zone aquatique, soit le lit mineur de la rivière. Les projets sont principalement des restaurations hydromorphologiques. Ils sont dans la continuité des projets dénommés *Blue RR*. Ils représentent 6% de l'effort de restauration et regroupent tous les projets « pilot**es** » qui ont été implantés avant la signature de la Directive Cadre sur l'Eau. Ils sont proches des *WFD RR* mais se caractérisent par deux aspects: leur date de réalisation antérieure à 1999 et un suivi inexistant. Les projets de type *Flood protection RR* (5%) sont les plus chers et visent à augmenter la capacité de rétention de la zone fluviale pour lutter de manière écologique et raisonnée contre les crues d'importance. Ils incluent souvent une relocalisation des habitants résidant en zone à risque et le rachat de terres. Ces projets intègrent également un volet paysagé et récréatif de la zone de rétention aménagée en parc. Enfin les projets dénommés *Human RR*, sont les troisièmes plus fréquents (11%) et sont initiés pour satisfaire des besoins humains : qualité de vie, esthétique urbain, engagement idéologique. Cependant, ces projets ont une approche holistique combinant des objectifs sociaux et écologiques. Ils ont une grande emprise spatiale et inclus la restauration de la zone aquatique et rivulaire. Dans certains cas, le projet modifie également la structure urbaine, améliorant les connexions écologiques, supprimant des infrastructures grises et favorisant les circulations lentes. De manière intéressante, alors que les sous-définitions théoriques du concept de restauration étaient différenciées par leurs ambitions écologiques, la classification de projets établit dans cette étude montre que la différence entre les projets réside principalement dans leur volet social (absent, présent, ou dominant). La méthode de classification dépend fortement des variables utilisées lors de la procédure statistique. Cependant, les caractéristiques majeures de projet intégrées à l'analyse sont sélectionnées par un large support bibliographique et supposent la fiabilité de la méthode. Toutefois, le nombre de projets utilisés pour établir la typologie est limité. D'autres types de projet sont susceptibles d'exister tel que ceux de type *Water RR*, qui seraient motivés par un juste partage de la ressource (Orthofer et al. 2007; Sagie et al. 2013), et ceux de type *Climate RR*, qui seraient initiés pour modérer les effets du changement climatique (Kim et al. 2008; Olaya-Marín et al. 2012). Ainsi, la méthodologie proposée devrait être appliquée à un plus large échantillon de projets.

3.2. La restauration de rivières urbaines

La comparaison entre les restaurations réalisées en contexte urbain et rural présenté par Zingraff-Hamed et al. (2017b) montre une différence majeure entre les projets. Alors que les restaurations urbaines sont davantage de type *Human RR*, les restaurations rurales sont souvent de type *Fish RR* et *Blue RR*. Les projets de type *WFD*

RR et *Flood protection RR* sont implantés de manière indifférenciée au sein des deux contextes géographiques. Les projets en milieu urbain sont plus chers mais ils sont également largement plus étendus et englobent souvent l'ensemble de la traversée urbaine. De plus, ils ont un double objectif : améliorer la qualité écologique de la masse d'eau et promouvoir un usage récréatif intensif et juste, augmentant la qualité de vie des citadins. Enfin, les projets urbains ne se limitent pas au milieu aquatique, mais ils intègrent les espaces rivulaires pouvant être mis à disposition, assurant une plus grande emprise du projet. De nombreux éléments contextuels peuvent expliquer en partie ces différences. Par exemple, à cause de contraintes physiques majeures, la Directive Cadre sur l'Eau établit des objectifs de qualité écologique moindre pour les projets réalisés en milieu urbain. Ainsi, la plupart des rivières urbaines n'ont pas à atteindre le bon état écologique mais seulement leur bon potentiel. Par conséquent, les chefs de projet et les commanditaires ont davantage de liberté. Ensuite, à cause de leur caractère urbain, les rivières doivent participer à l'apport d'une haute qualité de vie pour les citadins. Ainsi les demandes sociales y sont plus fortes qu'en milieu rurale. Enfin, les auteurs du projet sont différents. Ehrenfeld (2000) avait déjà montré que l'orientation des projets pour une restauration des espèces, des fonctions, ou des services, dépend des corps de métier impliqués. De même, Morandi et Piégay (2014) avaient montré que le type de suivi appliqué dépend des organismes en charge du projet. Il est à remarquer que les restaurations urbaines ne sont pas moins écologiques mais davantage en accord avec le concept de système socio-écologique que les restaurations en milieu rural.

3.3. Les forces motrices de la restauration

L'étude des forces motrices a montré que la législation européenne et notamment la Directive Cadre sur l'Eau était une des principales forces motrices de l'effort de restauration. Elle influence les projets réalisés en milieu urbain et ruraux avec la même intensité. Cependant, elle n'est pas la seule. Les forces motrices sociales telles que la demande d'usage ont également une très forte influence sur les projets. En milieu rural, la préservation de ressource en poisson pour la pêche de loisir et les ambitions éthiques motivent la plupart des projets. En milieu urbain, le regain et l'exploitation des services écosystémiques culturels et récréatifs initient un grand nombre de projet (Zingraff-Hamed et al. 2017b). Cependant, il est intéressant de constater que la Directive Cadre sur l'Eau a une plus grande influence sur les projets urbains en Allemagne qu'en France (Zingraff-Hamed et al. 2017c). De multiple raisons peuvent expliquer en partie ces résultats. Par exemple, le contexte culturel et historique du projet semble avoir une influence majeure sur les forces motrice le motivant. Ainsi, en Allemagne, l’idéologie de restauration écologique est plus ancienne qu’en France et a débuté suite aux pollutions majeures du Rhin. Depuis le début des années 90, l’Allemagne a entamé une restauration de ses cours d’eau en axant ses projets sur la préservation des habitats et sur un rétablissement des conditions hydromorphologiques antérieur aux dégradations humaines. De plus, la perception de la relation homme-nature diffère entre les pays et des études ont déjà mis en avant que ces différences se reflètent dans les aménagements paysagers (Romain 2010a; Madureira et al. 2015; Skandrani & Prevot 2015). Enfin, la structure urbaine est historiquement différente en France et en Allemagne. Ainsi, les projets urbains ne disposent pas des mêmes contraintes et problématiques. Remarquons que si les conditions hydromorphologiques des rivières sont similaires, le tissu urbain et les connections ou obstacles à la relation entre les citadins et leur rivière diffèrent. Par exemple, en France les voies sur berges sont très répandues, causant une rupture entre les habitants et leurs rivières. Malgré une haute signification des résultats, l’étude porte sur un nombre limité de projets et d’autres forces motrices non connues peuvent également participer aux résultats ou les biaiser.

3.4. Conflit entre usages récréatifs et restauration écologique

L’étude de cas montre dans un premier temps que l’état hydromorphologique de la rivière après restauration pourrait permettre de supporter le rétablissement des espèces sensibles étudiées. Cependant, les résultats nécessitent un suivi plus long pour *Myricaria germanica* L. (Zingraff-Hamed et al. 2014; Zingraff-Hamed et al. 2017a) et le soutien d’observation de terrain (pour *Chondostroma nasus* L. (Zingraff-Hamed et al. 2018b). Toutefois, les deux expériences se rejoignent et montrent que l’usage récréatif limite la disponibilité des habitats propices et ~~r~~entre en compétition avec l’occupation des niches écologiques. Malgré une très forte densité d’usagers, une coexistence reste possible. Cependant, au-delà du maintien des populations, leur développement est limité par les usages récréatifs. En effet, les cycles de vie les plus sensibles (débourrement des bourgeons, fleurissement, fraye et croissance des juvéniles) concordent avec les périodes et les sites ayant les plus fortes densités d’usagers. Remarquons que l’impact de l’usage a été évalué en considérant la limite supérieure de la densité des usagers, soit le nombre d’usagers maximum lors d’un nombre limité de journées correspondant à celles étant les plus favorables aux usages récréatifs. Il est attendu que l’impact réel soit plus faible. Une estimation des usagers sur le long terme s'appuyant sur davantage de jours devrait apporter plus de fiabilités dans les résultats. Soulignons que l'étude n'a été réalisée que pour deux espèces, et que la tolérance aux pressions, et la capacité d'adaptation aux pressions anthropiques, est propre à chacune d'entre elles. L'extrapolation des résultats est donc limitée. De plus, d'autres pressions ou facteurs non considérés par l'étude peuvent influencer la répartition des habitats propices.

3.5. Partage de la ressource en eau entre usage productif et qualité des habitats

La modélisation des habitats physiques pour les scenarii donnés dans le cas de l'Isar à Munich publié par Zingraff-Hamed et al. (2018a) montre que la plupart des habitats bénéficient d'une légère augmentation du débit minimal (de 5 à 12 m^2/s) d'eau. La plupart des habitats pour les adultes gagnent en quantité et qualité pour des débits supérieurs, mais davantage d'habitats propices pour la fraye sont disponibles pour des débits fiables. Cependant, chaque espèce réagit différemment aux modifications des débits et aucun scénario étudié ne permet d'atteindre le maximum d'habitats propices pour les trois espèces étudiées et les habitats relatifs aux différentes étapes du cycle de vie. Il est intéressant de constater que le scénario sans diversion ne permet pas de produire des habitats propices pour toutes les espèces et cycles de vie de ces poissons historiquement présents dans la rivière. Ceci souligne ainsi un décalage entre l'état morphologique de référence et l'état atteint. Cependant d'autres facteurs non considérés par l'étude (par exemple : la température et la ressource alimentaire) peuvent influencer la répartition des habitats propices.

3.6. Apports méthodologiques et pratiques

L'étude doctorale a apporté de nouvelles connaissances au domaine de la restauration, notamment concernant les pratiques en milieu urbain et l'évaluation socio-écologique des projets. La recherche doctorale se caractérise par de nombreuses avancées pratiques. L'une d'entre elles concerne la production de données brutes. La base de données collectée a permis de doubler le nombre de projets recensés en France par rapport à la base de données européenne RiverWiki consultée en 2013. Il est inquiétant de constater que des bases de données incomplètes ont servi de support pour estimer l'effort de restauration, son succès, ses limites ainsi que pour formuler des guides de bonnes pratiques. Cette étude montre les limites de l'approche participative pour le recensement de projets. Toutefois, la méthode d'inventaire utilisée dans cette étude est certes très productive et présente une forte fiabilité des données produites, mais elle demande un grand investissement en temps. Ensuite, la typologie de projet développé permet la classification claire et universelle des pratiques. Leur comparaison et les processus d'apprentissage et de maturation des pratiques s'en trouveront facilité. De plus, la comparaison de projet en fonction de leur contexte urbain ou rural met en avant les avancés spécifiques des restaurations en milieu urbain. Elles devraient dans le futur se profiler comme modèle de restauration socio-écologique. Ensuite, la réintroduction de *Myricaria germanica* L. apporte des avancées pour la conservation de cette espèce menacée et elle ouvre de nouvelles perspectives pour de futures réintroductions. Enfin, les avancés produites pour la modélisation des habitats physiques sont les plus importantes et les plus prometteuses. Ce travail doctoral a permis l'inclusion de variables sociales telles que la densité des usages récréatifs dans la modélisation écologique des habitats aquatiques. Cette innovation propose de nouvelles perspectives dans le domaine de la simulation, la modélisation, et l'évaluation des succès et échecs des projets de restauration.

4. Conclusion

Alors que les rivières ont été reconnues comme un système socioécologique, les pratiques sont motivées principalement par le cadre législatif européen qui simplifie les systèmes à ses composants écologiques. En milieu urbain, la Directive Cadre sur l'Eau à moins d'emprise, laissant ainsi davantage de possibilité à l'expression des autres forces motrices telles que la demande sociale. Il est encourageant de constater que dans le cas des restaurations urbaines, les projets intègrent un panel plus large de buts couvrant les différents aspects du système, soit la demande écologique, politique, et sociale. Cependant, même s'ils intègrent des objectif sociaux, tels que l'augmentation de la qualité de vie et du potentiel récréatif de la zone fluviale, ces aspects restent abordés en parallèle au processus de restauration écologique. De cette manière, les interactions ne sont pas considérées et sont source d'une nouvelle instabilité du système. Par conséquent, il conviendrait d'améliorer la prise en considération des impacts positifs et négatifs entre les différentes composantes du système socio-écologique afin de développer une approche de restauration plus durable, apportant une harmonie au sein du système. Cette étude a apporté_ de nouveaux éléments dans cette direction. Il ne s'agit que d'un cas d'étude, mais ses résultats et méthodes sont applicables à un large éventail de projets réalisés ou à venir, en milieu urbain comme en milieu rural. De plus, cette étude s'est intéressée de façon ciblée au cas urbain. A ce titre, ses apports dans le contexte d'une urbanisation croissante sont particulièrement importants. Toutefois, elle conserve une approche tournée vers l'écologie et ne considère que l'impact de l'homme sur l'écosystème. Les interactions positives et les influences de la nature sur l'homme devraient être dans le futur davantage étudiées.

Content

List of contributions

The following five research papers and one scientific report present the basis of this cumulative dissertation and are included at the end of the document (pending copy right instructions of the editors). At the time of the thesis submission, four of them have been already published, and two are in the process of review. Hereinafter, reference to the original articles is made by citation, i.e. Paper A, Paper B, Paper C, Paper D, Paper E, and Scientific Report A, as listed below.

Research papers

A. Zingraff-Hamed A., Greulich S., Pauleit S., Wantzen K. M. (2017) Urban and rural river restoration in France: a typology, Restoration Ecology 25(6), 994-1004, doi: 10.1111/rec.12526

B. Zingraff-Hamed A., Sabine Greulich S., Wantzen K.M., Pauleit S. (2017) Societal Drivers of European Water Governance: a Comparison of Urban River Restoration Practices in France and Germany, Water (9) 206; doi:10.3390/w9030206

C. Zingraff-Hamed A., Greulich S., Egger G., Pauleit S., Wantzen K.M. (2017) Urban river restoration, evaluation and conflicts between ecological and social quality. In Deutsche Gesellschaft für Limnologie (Hrsg.): Erweiterte Zusammenfassungen der Jahrestagung in Wien 2016; Hubert & Co., Göttingen, ISBN 978-3-9818302-0-1.

D. Zingraff-Hamed, A., Noack, M., Greulich, S., Schwarzwälder, K., Wantzen K. M., Pauleit, S. (2018) Model-Based Evaluation of Urban River Restoration: Conflicts between Sensitive Fish Species and Recreational Users, Sustainability (6) *10*, 1747; https://doi.org/10.3390/su10061747

E. Zingraff-Hamed, A., Noack, M., Greulich, S., Schwarzwälder, K., Pauleit, S., Wantzen K. M. (2018) Model-Based Evaluation of the Effects of River Discharge Modulations on Physical Fish Habitat Quality, Water (10) 374; doi:10.3390/w10040374

Scientific Report

Zingraff-Hamed A., Egger G., Greulich S. (2014) Wiederansiedlung der Deutschen Tamariske im Stadtgebiet München, City of Munich (Germany), 13 pages

For the above-listed publications, the first author, Aude Zingraff-Hamed, conducted the study, namely: Identify the knowledge gaps and research questions; Develop the conceptual idea and analytical framework; Design questionnaires; Conduct field survey; and Perform analyses and calculations. All these research steps were discussed with the research supervisors: Prof. Stephan Pauleit, Prof. K. Matthias Wantzen, and Dr. Sabine Greulich. Contributions were written by Aude Zingraff-Hamed in collaboration with all the co-authors. The identification of the reintroduction sites presented in Paper C was realized in cooperation with Prof. Gregory Egger (WWF-Auen Institut KIT). The 2D hydromorphological model, which was used as input data for the habitat model procedure CASiMiR as presented in Paper D and E, was simulated by Dr. Markus Noack (University Stuttgart) and SKI GmbH + Co.KG. The hydromorphological field survey at the Isar was conducted by Aude Zingraff-Hamed in collaboration with Dr. Kordula Schwarzwälder (Technical University of Munich) and associated staff.

Scientific oral communications

The preliminary results of the thesis were also presented at six international scientific conferences.

Zingraff-Hamed A., Greulich S., Egger, G., Kollmann J., Wantzen K. M., Pauleit S. (2015, April) Urban river restoration evaluation - a hybrid between ecological and social monitoring, presented at AAG 2015 Annual Meeting, Chicago (USA)

Zingraff-Hamed A., Greulich S., Wantzen K. M., Pauleit S. (2014, July) Urban River Restoration – between Ecology and Society, presented at InterZA 2014 - la journée Rivières Urbaines, Paris (France).

Zingraff-Hamed A., Greulich S., Pauleit S., Wantzen K. M. (2014, May) River restoration in France and in Germany, presented at Chinon River Sciences 2014 – an international workshop on River Restauration: towards an agenda for research, action, and teaching, Chinon (France).

Zingraff-Hamed A., Greulich S., Pauleit S., Wantzen K. M. (2014, May) Urban River Restoration in Europe – Assessment Methods, presented at Symposium at the Institute for Modelling Hydraulic and Environmental Systems of the University of Stuttgart, Stuttgart (Germany).

Zingraff-Hamed A., Greulich S., Pauleit S., Wantzen K. M. (2014, April) Fish habitat modelling as a tool for river restoration assessment, presented at the Chair of Aquatic Systems Biology of the Technical University of Munich, Freising (Germany)

Zingraff-Hamed A., Greulich S., Wantzen K. M., Pauleit S. (2014, February) Urban Flussrenaturierung – Naturschutz und Naherholung, presented at EcoMeetIng 2014, Innsbruck (Austria).

List of Tables

List of Figures

List of Abbreviations

CASiMiR : Computer Aided Simulation Model for Instream Flow Requirements

HHS : Hydraulic Habitat Suitability index

HMFA : Hierarchical Multiple Factor Analysis

HQ : higher water volume

HQ100, HQ10, and HQ1: 100-, 10-year, and 1-year maximum discharge

HSI : Habitat Suitability Index

MQ: mean discharge

NQ : minimal water volume

NRRSS : National River Restoration Science Synthesis (is the U.S. database of river restoration)

ONEMA : French water agency

p : p-value

RR : River Restoration

RRR : Rural River Restoration

URR : Urban River Restoration

U.S. : United States

SER : Society of Ecological Restoration

SMS : Surface Modelling System

WFD : Water Framework Directive

WUA : Weighted Usable Area

2D : two-dimensional

1. Introduction

Rivers are important source of biological diversity (Lytle & Poff 2004; Geist 2011; Schwalm et al. 2011; Arthington 2012a) and societal development (Arthington et al. 2010; D'Odorico et al. 2010; Kondolf & Pinto 2016; Wantzen et al. 2016). Many ecosystem services for humans are linked to riverine ecosystems (Millennium Ecosystem Assessment 2005; Arthington et al. 2010; Everard & Moggridge 2012; Scott Shafer et al. 2013; Vollmer & Grêt - Regamey 2013; Vermaat et al. 2016). Humans do not passively benefit from ecosystem functions but interact with the river system. The linkage between society and ecosystems had been defined as the *socio-ecological system* (Berkes & Folke 1998). The socio-ecological approach *river culture* states that a decrease of ecological quality of rivers leads to a decrease of human well-being and vice versa (Wantzen et al. 2016). Unfortunately, until the 20th century waterway management focused only on guaranteeing water use and safeguarding humans from floods and diseases (Holmes 1972; Lovett 1973; Getches 2001; Gerlak 2006; Goldin 2010; Victor et al. 2015). Furthermore, intensive exploitation of ecosystem services and urbanization also severely impacted rivers (Walsh et al. 2005; Bernhardt & Palmer 2007; Castonguay & Samson 2010). The resulting ecological degradations led to a decrease of the socio-ecological functions of the rivers (Castonguay & Samson 2010; Everard & Moggridge 2012; Kondolf & Pinto 2016; Wantzen et al. 2016). In recent years, river restoration was recognized as essential to reestablish socio-ecological functions of the rivers (EU 2000; SER 2004; Millennium Ecosystem Assessment 2005; Jørgensen 2015). The amount of projects and research on river restorations has increased since the 1980s. However, knowledge gaps remain (details in Chapter 2): Practice-oriented definitions and project characterizations based on project main design features are needed to ease project comparison and cross-fertilization (knowledge gap 1); Little knowledge exists about urban projects and their specificities remain to be defined to formulate an appropriate framework (knowledge gap 2); Social driving force of the restoration effort remains to be identified (knowledge gap 3); Few urban projects were recorded in European databases weakening the learning arena (knowledge gap 4); Evaluation procedure did not yet consider the socio-ecological characteristics of the rivers (knowledge gap 5); and studies on the potential conflicts between the socio-ecological restoration and their different uses remain limited (knowledge gap 6).

This doctoral research aimed to contribute to closing these knowledge gaps with a study on river restorations, focusing on the case of urban areas. Its objectives were (Figure 1):

(1) To identify the different restoration practices and drivers, and examine the particularities of urban river restorations (knowledge gaps 1, 2, 3, and 4).

(2) To assess the potential conflicts inside the socio-ecological system, namely between ecological river restoration and uses of the river systems, e.g. recreational uses and hydroelectric production (knowledge gaps 5 and 6).

The following research questions were posed and investigated in detail (Figure 1):

i. What are the different types of river restoration practices?

ii. What influence does the geographical context of the river, e.g. rural or urban, have on the restoration practices?

iii. Which socio-ecological drivers of the river restoration influence the practices?

iv. Do recreational uses decrease the ecological success of the restoration?

v. What effect does water use, e.g. diversion for hydroelectric production, have on fish habitat suitability of a restored river section?

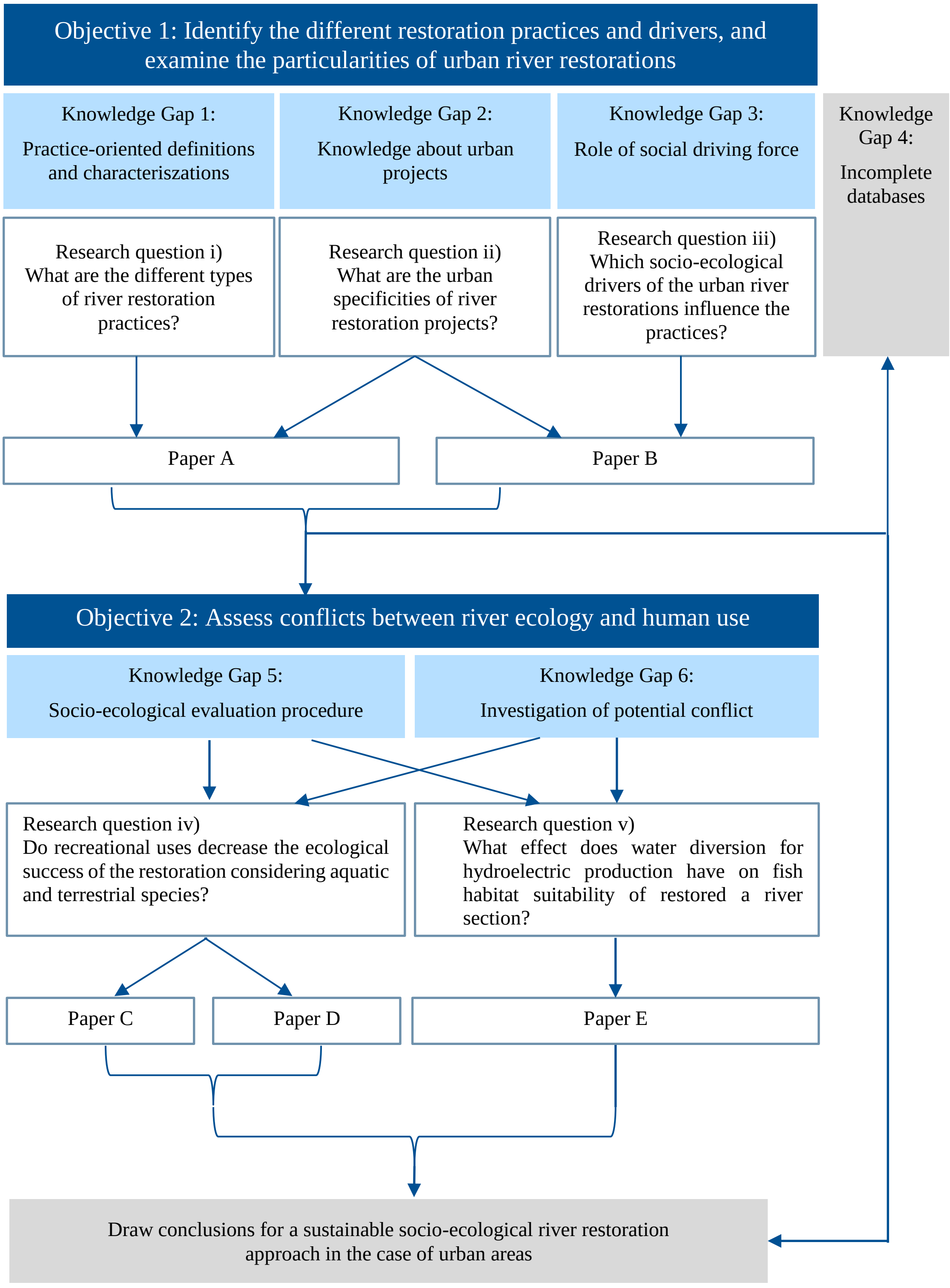

Figure 1 Overview of the structure of the dissertation

2. Literature review

2.1. Concept of socio-ecological system

2.1.1. The general approach

Worldwide, the major environmental problem is the potential loss of resources, e.g. fisheries, forests, and water, caused by ecological degradations. Ecological science denounces the risks and searches for solutions. However, historically, ecological science has excluded humans from the study of ecology and many social sciences ignored environmental linkage to humans (McDonnell & Pickett 1993; Machlis et al. 1997; Berkes et al. 2001; Berkes et al. 2003; McDonnell 2011). However, the understanding of the human-nature relationship changed in the late 20th century with the inclusion of the *socio-ecological concept*, also referred to as the socio-ecological linkage (Berkes & Folke 1998).

Elinor Ostrom was one of the foremost researchers on the socio-ecological system. She stated that self-organizing harvesters and leaders will develop an effective and sustainable management of the resource (Ostrom 2009). The term socio-ecological system is commonly used to emphasize the integrated concept of humans in its ecosystem, to delineate human from nature, and to emphasize interaction between human beings and resources as both part of a common ecosystem (Berkes et al. 2001). Thanks to its interactions (Figure 2), the socio-ecological system is able to adapt, reorganize, and evolve, displaying a long-term resilience (Berkes et al. 2003).

According to Ostrom (2009) and to Berkes and Folke (1998), a major issue in studying the socio-ecological systems, preventing its collapse, and establishing its sustainability is the identification and analysis of relationships among the four first-level core subsystems of the system (Figure 2). The *governance*, namely the government and the rules which manage the system, and the *users* (e.g. recreational and commercial users) composed the social system. The *resource units*, namely species or agent (e.g. water), and the *resource system* (e.g. designated water system) are the components of the ecological system.

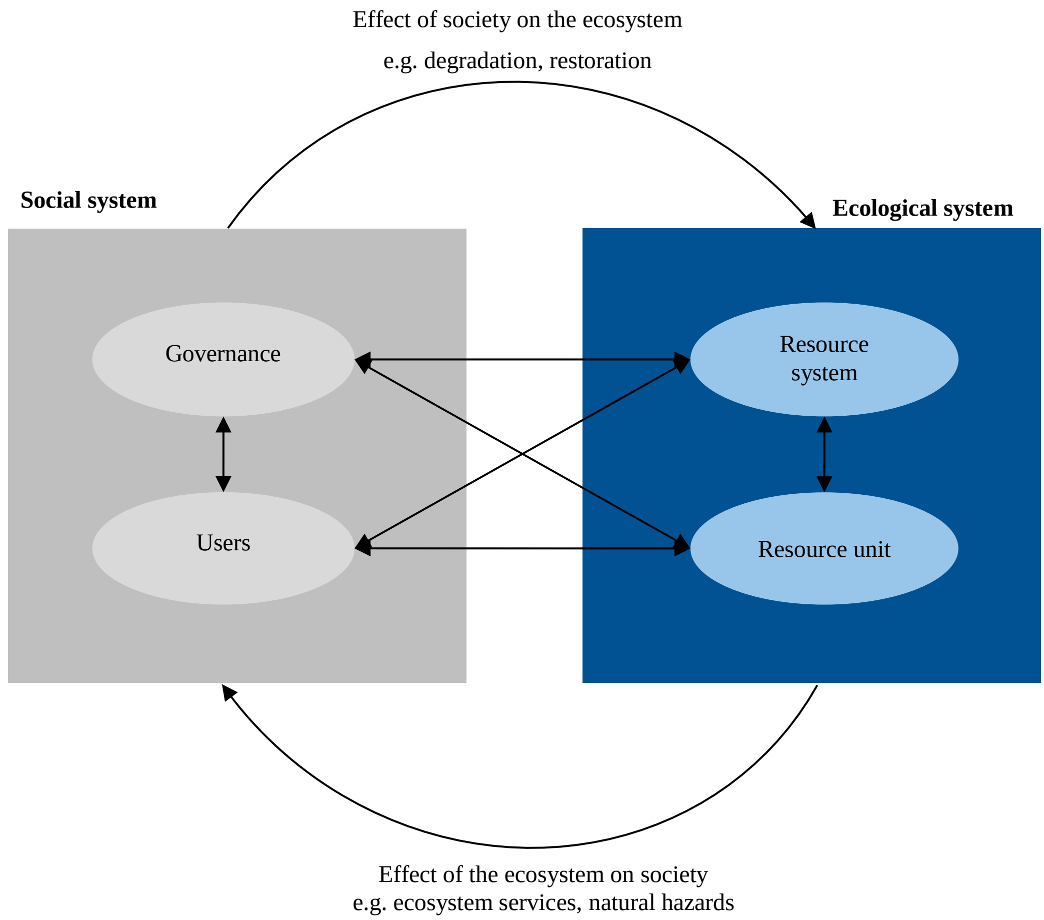

Figure 2 Theoretical framework of interactions in the socio-ecological system (after Ostrom et al. 2009)

2.1.2. Rivers as socio-ecological systems

Rivers are hotspots of biological diversity. The riverine ecosystem is composed of aquatic zones, i.e. wetted river bed and wetlands, and of terrestrial periodically flooded zones, i.e. river embankments and floodplains. Riverine ecosystems are water resources for species, habitats for biota, vectors for energy, materials, and organisms, and river water is an agent of geomorphic changes and disturbances (Sponseller et al. 2013). Pulsing floods and drought events re-organize physical habitat structure, establish and cut lateral connectivity between mainstream and floodplain, and mobilize energy and matter bound by periodically flooded and aquatic biota (Junk & Wantzen 2004; Wantzen et al. 2008). The steep gradients of environmental parameters cause a high diversity of biological, geochemical, and geomorphological processes (Lytle & Poff 2004; Geist

2011; Schwalm et al. 2011; Arthington 2012a), resulting in an extraordinarily high biological diversity.

Rivers are also hotspots of societal development (Wantzen et al. 2016). More than 70 % of the Earth’s surface is covered by water but surface freshwater, i.e. rivers and lakes, represent only 0.7% of the resource (Shiklomanov's 1993) and is necessary for the survival of human beings. Freshwater availability, quality, and movements, and its associated ecosystem richness influence many social processes, e.g. human survival, development, and well-being (Arthington et al. 2010; D'Odorico et al. 2010; Kondolf & Pinto 2016; Wantzen et al. 2016). The term *ecosystem services* was introduced in the early 1980s to describe human benefits provided by ecosystems (Mooney & Ehrlich 1997; Reid et al. 2005). Besides fundamental human needs, e.g. water supply and sanitation purposes, many more direct and indirect services for humans are linked with rivers and their floodplains (Millennium Ecosystem Assessment 2005; Arthington et al. 2010; Everard & Moggridge 2012; Scott Shafer et al. 2013; Vollmer & Grêt‐Regamey 2013; Vermaat et al. 2016):

- Provisioning services: Riverine areas provide many goods for humans. For example, rivers and streams supply freshwater, hydraulic energy, food, gravel, biodiversity and the riparian zone make available, among others, a wide diversity of wood products.
- Regulating services: Rivers and their floodplains perform processes maintaining the world in which it is biophysically possible for humans to live, e.g. climate stabilization, nutrient sequestration, water purification, and mitigation of flood damages.
- Cultural services: Rivers make the world a place in which people want to live, offering for example recreation possibilities, aesthetic, intellectual, and spiritual inspirations.
- Supporting services: Riverine ecosystem processes are of major importance among for nutrient cycling, landscape formation, and creation of habitats.

Rivers are a socio-ecological system. There is strong evidence that, since the earliest days of humanity, rivers have provided crucial services to humans and have been used by them (Allan 2004; Manning et al. 2011; Ozainne et al. 2014). Rivers and their valleys are fundamentally a *socio-ecological system* (Bohensky 2006) and the importance of the linkage between ecological health and human well-being have been demonstrated with the concept of *River Culture*. It is “a socio-ecological approach to mitigate the biological and cultural diversity crisis in riverscape” with two dimensions: “the influence of biophysical setting of rivers on the expression of elements of human culture in general and the aspect of learning from the river for the development of technologies and management options” (Wantzen et al. 2016).

Urban rivers are an obvious show-room of socio-ecological interactions but benefitted only lately from ecological science interest. In ancient times, humans settled near freshwater resources and the interactions between human and ecosystems in cities have a deep-rooted nature (Kondolf & Pinto 2016). However, despite few forerunner studies performed by the Berlin School of Urban Ecology in 1990 (Sukopp 1990), urban areas became the center of interest of the ecological sciences only in the late 1990s (Grimm et al. 2000; Sukopp 2008; McDonnell 2011; Wu 2014), mostly due to the growing urban population (U.N 2014), due to cultural shifts, such as the growing concern of sustainability in cities and towns (Birch & Wachter 2008), and due to the understanding that humans are part of the ecosystem (McDonnell & Pickett 1993) and that global biosphere transformation is induced by urbanization (Vitousek 1997). Facing human-dominated habitats and requiring a sophisticated understanding of how the social processes affect the urban ecology, ecological sciences had to identify the urban mosaics as social–ecological system and switched from the study of the ecology *in* the city to the ecology *of* the city (Pickett et al. 2016). Ecologists have to collaborate with the social scientists, and vice-versa, to study the socio-ecological system integrating the pervasive, reciprocal, and intertwined interactions between social and ecological structures and processes (McIntyre et al. 2000; McPhearson et al. 2016). In human-dominated areas such as in major cities, the consideration of ecosystem services and the inclusion of the socio-ecological concepts could provide new insights in nature protection in the perspective of human benefit (Brauman et al. 2007).

2.2. Social and ecological loss of quality of the river system

2.2.1. Ecological degradations

According to the socio-ecological concept, societies do not passively benefit from ecosystems but interact with them (Figure 2). However, neither the effects of society on the ecosystem nor the effects of ecosystems on society are purely positive. The actions of humans on the riverine system have caused modifications and alterations of their original forms and related functions. Anthropic impact and resulting ecological degradations have been intensively described. In Europe, the European Environmental Agency regularly publishes the assessment of the ecological status of the water bodies and related pressures, i.e. pollution and hydromorphological pressures (EEA 2012). A varying scale of human degradations can be identified:

- Local modifications: Humans have, among others, changed the hydromorphological structure of many rivers (e.g. channelization), polluted river waters (e.g. point source pollution), and modified biota structure (e.g. species introduction) (Walsh et al. 2005; Mattson & Angermeier 2007; Falcone et al. 2010; Vörösmarty et al. 2010; Spänhoff et al. 2012; Yuan et al. 2017).

- Modifications of the catchment area: Streams and rivers, as the low-lying points of the landscape, are sensitive to changes occurring in the whole catchment area, e.g. land use changes and urbanization (Walsh et al. 2005). Characteristic degradations are water insecurity, a decrease of the overall ecological health, chemical pollution, hydromorphological and biota composition changes.

- Global modifications: Climate change alters the hydrological cycle and related ecosystem functions, e.g. discharge (Gadeke et al. 2017), water availability (Azevedo et al. 2017), chemical composition (Kumar et al. 2017), and species assemblage changes (Garssen et al. 2017).

In general, urban water bodies are in worse ecological status than their rural counterparts, at least considering the morphological patterns of the rivers (EEA 2012; Yuan et al. 2017). Their dysfunctions have been described as the *urban river syndrome* (Walsh et al. 2005) that is characterized by poor water quality, altered channel morphology, hydrograph changes, decrease of the biotic richness and increase in the tolerant species (Paul & Meyer 2001; Meyer et al. 2005; Walsh et al. 2005; Fletcher et al. 2013).

2.2.2. The loss-loss situation and challenges

Urban rivers have also a high social value (Kondolf & Pinto 2016). However, human disturbances impacting rivers reduce the quality of, and services provided by, river ecosystems (Vörösmarty et al. 2010; Wantzen et al. 2016; Yuan et al. 2017). Accordingly, anthropic impact led to a loss-loss situation.

Freshwater bodies are affected worldwide by the decrease of the water quality (Viswanathan & Schirmer 2015). Human use of the water and land resources caused direct, e.g. pollutant discharge (EEA 2012), diffuse, e.g. heavy metal and nutrient enrichment (Walsh et al. 2005), and indirect pollution, e.g. red tides[1] (Ueda 2012), etc. Polluted water may cause the death of plants and animals, decrease their reproduction potential and/or have teratogen effects, be aesthetically unpleasant and unsafe for recreational or domestic uses. Despite ambitious and expensive inventory programs, the chemical status of many rivers and streams remains unknown in many areas, even in the European Union (EEA 2012). Since the first E.U. directives establishing water quality standard was adopted in the mid-1970s, water quality increased and point source pollution became a marginal issue (EEA 2012). However, much remains to be done at the catchment area level, since the major sources of pollution remain diffuse and indirect, e.g. agricultural stormwater runoffs (Walsh et al. 2005; Yuan et al. 2017).

To facilitate urbanization, to produce energy, and to protect cities against floods, the hydromorphological patterns of the rivers and streams have been strongly modified and altered for decades and sometimes for centuries, e.g. by straightening, canalization, disconnection of floodplains, land reclamations, dams, weirs, bank reinforcements, etc. (EEA 2012). Anthropogenic changes of the morphological patterns of the riverine system caused negative effects on both ecosystems and humans (Vörösmarty et al. 2010), e.g. aesthetic landscape degradation, loss of freshwater availability and usability, loss of cultural and recreational functions, socio-economical risk, etc. (Morandi et al. 2014; Kondolf & Pinto 2016; Wantzen et al. 2016). In Europe, more than a half of the rivers and streams were reported to be in less than *good ecological status* or *potential* (EEA 2012). For example, in-stream habitat degradations, namely loss and/or homogenization of aquatic habitats (40%), fauna degradation (36%), ecological longitudinal connectivity disruption (30%) and floral degradation (27%), were identified as the most frequent types

[1] Red tides are algal bloom of dinoflagellates species that give a red/orange color of the water and that are toxic.

of ecological river degradation in France (EEA 2012; Morandi et al. 2014). Engineering knowledge exists to remove man-made river constructions (Prominski 2012; Pan et al. 2016; Speed et al. 2016) but their implementation in urban areas remains difficult because of spatial limitations (Bernhardt & Palmer 2007).

Human uses of water (e.g. water abstraction and diversion), man-made modifications of the river morphology (e.g. weir construction) and urbanization of the land cause degradations of flow regimes and water level fluctuations (EEA 2012). While freshwater abstraction, diversion and man-made retention make available an important quantity of water for human needs, they also significantly and negatively degrade aquatic ecosystem functions and services. More than 70% of the large rivers of northern third of the world, e.g. Europe, North America, Russia, were strongly regulated in the 1920s (Dynesius & Nilsson 1994) and two-thirds of the worldwide rivers are obstructed by more than 800,000 dams (Rosenberg et al. 2000). In Europe, dam distribution and density is unequal between the countries. The highest density of dams is in central Europe, e.g. Germany (EEA 2012). Recent studies estimated that despite of, and because of, river modifications, 1.8 billion people live under a high degree of water stress (Vörösmarty et al. 2010). Even in Europe, socio-ecological demands for freshwater often exceed availability (Vörösmarty et al. 2010; EEA 2012). Loss of freshwater availability for human and loss of environmental flow are major socio-ecological issues. In the context of increasing water scarcity and climate change, sustainable socio-ecological water resource management became an important issue worldwide (Bogardi et al. 2012).

2.3. River restoration

2.3.1. Definitions

The sustainability of the rivers as social-ecological systems is threatened and actions are urgently needed. River restoration was recognized as essential to re-establish functions of the rivers (EU 2000; SER 2004; Millennium Ecosystem Assessment 2005; Jørgensen 2015) but face a diversity of interrelated problems and many local specificities (Walsh et al. 2005). Accordingly, the term *river restoration* is applied to a wide range of activities. Allison (2007) stated that “Restoration is a practice in which choosing the best language to describe that practice has been especially problematic”. Different definitions of river restoration exist and are often overlapping in their content. The 16 most commonly used (Morandi 2014) can be grouped into four categories: Ecological definitions with focus on the return of the ecosystem to a previous status; Definitions with focus on (long-term) sustainability in ecosystem structure and function; Comprehensive definitions that consider social functions of the river; And practical definitions of *river restoration* listing the restoration measures considered. (Table 1).

Table 1 Synthesis of the main definitions of river restoration published in the international literature (Additional material published in Zingraff-Hamed et al. 2017a)

Definitions with focus on return of the ecosystem to a previous status
"restoration implies return of an ecosystem to a close approximation of its condition prior to disturbance" (Shields et al. 2003)
"an acid test for ecology" (Bradshaw 2002)
"should be defined as returning an ecosystem to its condition prior to disturbance (if known and possible), or, as in most cases, to a state as similar as possible to that prior to disturbance" (Amoros 2001)
"implies full return to a prior structure and function" (Brookes & Shields 1996)
"restoration, by its strictest definition, as a return to the original conditions" (Gore & Shields 1995)
"Restoration means returning an ecosystem to a close approximation of its condition prior to disturbance. Accomplishing restoration means ensuring that the ecosystem structure and functions are recreated or repaired and that natural dynamic ecosystem processes are operating effectively again" (N.R.C. 1992)
"the complete structural and functional return to a pre-disturbance state" (Cairns 1991)
"the act of restoring to a former state […] or to an unimpaired or perfect condition" (Bradshaw 1996)
"the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (SER 2004) definition of the Society for Ecological Restoration
Definitions with focus on (long-term) sustainability in ecosystem structure and function
"Restoration is a complex endeavor that begins by recognizing natural or human-induced disturbances that are damaging the structure and functions of the ecosystem or preventing its recovery to a sustainable condition" (F.I.S.R.W.G. 1998)
"minimize human-mediated constraints, thereby allowing natural reexpression of productive capacity" (Stanford et al. 1996)
"Restore the most probable form [..] and the effective design for the most long-term stability and function" (Rosgen 1994)
Comprehensive definition of "river restoration"
"repairing waterways that can no longer perform essential ecological and social functions" (Palmer & Bernhardt 2006)
Practical definitions of "river restoration"
"river restoration is a term applied to a wide range of specific management activities, from replanting riparian trees or fencing live-stock out of stream corridors to the removal of dams and full-scale redesign of river channels" (Bernhardt et al. 2007b)
"restoration projects must recreate the physical conditions needed to maintain natural communities, including substrate, water depth and velocity, inundation frequency, and temperature" (Kondolf & Micheli 1995)
"a historically influenced exercise in environmental enhancement through morphological modification" (Downs et al. 1991)

Palmer and Bernhardt (2006) formulated that river restoration is the action of "repairing waterways that can no longer perform essential ecological and social functions" and is the only definition clearly combining social and ecological functions of rivers as an equal priority. Facing a broad variety of projects, the Society of Ecological Restoration (SER) established that all restoration activities, e.g., *ecological restoration*, *rehabilitation*, *reclamation*, and *mitigation*, are gathered under the term *restoration* but differ in their ecological quality goals (SER 2004). According to SER definitions, the *ecological restorations* aim the re-establishment of a historical status in terms of form, species composition, and community structure. *Rehabilitations* also target the re-establishment of a historical ecological status but emphasize the restoration of ecosystem processes, products, and services. *Reclamations* are rehabilitations in the context of mined lands and include the stabilization of the terrain and revegetation. *Mitigations* do not aim at historical status but a pre-disturbance status and compensate environmental damages (Figure 3).

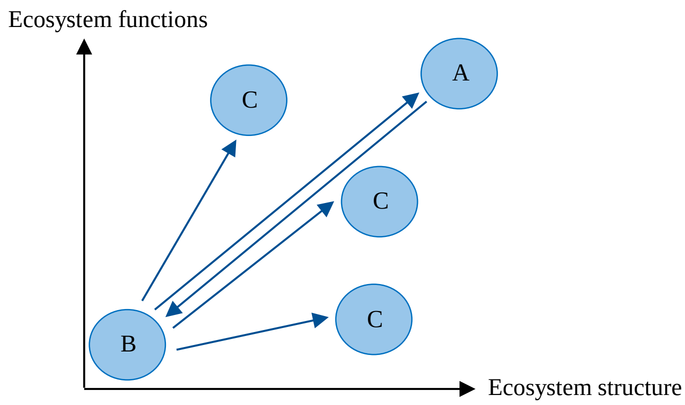

Figure 3 Schematic illustration of the distribution of the restoration activities on ecosystem structure and ecosystem functions
The original state (A) is the goal of the ecological restoration of a degraded ecosystem (B). The other restoration practices, e.g. Rehabilitation, Reclamation, Mitigation (C), lead to partial recovery (after Dobson and Bradshaw 1997)

The use of the single term *restoration* for such a wide range of restoration activities led to misunderstanding and may jeopardize comparison and cross-fertilization. For instance, U.S. projects reported by Bernhardt and Palmer (2005) and French projects reported by Morandi and Piégay (2014) differed regarding the targeted ecological quality. Practice-oriented definitions and project characterizations are needed (Jenkinson et al.

2006; Bernhardt et al. 2007a). These could form the basis for more suitable guidelines and evaluation procedures for projects.

2.3.2. River restoration effort

Restoration sciences are experimental sciences and evolve by learning from success and failure (Clewell et al. 1993; Palmer et al. 2005). Great efforts have been made to inventory river restorations enhancing experience transfer (Bernhardt et al. 2005; Jenkinson et al. 2006; Nakamura et al. 2006; Bernhardt et al. 2007b; Brooks & Lake 2007; Kondolf et al. 2007; Feld et al. 2011; Morandi & Piégay 2011; Aradóttir et al. 2013; Barriau 2013; Pander & Geist 2013; Morandi et al. 2014; Kail et al. 2016; Muhar et al. 2016; Speed et al. 2016). Several surveys were carried out as part of national and international research programs. One of the first was the National River Restoration Science Synthesis (NRRSS), which recorded U.S. projects (Bernhardt et al. 2005). In Europe, two databases were simultaneously developed. One was part of the EU REFORM project and recorded hydromorphological restorations (http://wiki.reformrivers.eu). The other is the RiverWiki database (https://restorerivers.eu/wiki/index .php?title=Main_Page), which was the major output of the EU LIFE+ RESTORE project (2010–2013) and contains currently 1,022 river restoration case studies (consulted June 2017). River restoration projects are recorded using a participative procedure but records are proved by the River Restoration Center (Cranfield University, http://www.therrc.co.uk/) to assure proper reporting. The website management is funded by the UK Environment Agency.

Interestingly, the intensity of the restoration effort seems to differ between European countries (Table 2). Furthermore, the NRRSS showed that U.S. river restorations in urban contexts represent a large share of the river restoration effort, namely 29% of the river restoration projects (Bernhardt et al. 2005; Bernhardt et al. 2007b) and 50% of the findings (Hassett et al. 2005). In the case of Europe, according to RiverWiki (consulted in June 2017), only 12% of the river restorations concerned urban contexts (Table 2). Knowledge gap about urban river restoration was identified (Moran 2007; Francis 2012) and remains.

Table 2 Number of river restorations, and number of projects classified "urban" inside the RiverWiki Database (Consulted the 13th June 2017)

Countries	Number of River Restorations	Number of Urban River Restorations
England	584	91
Spain	77	3
Wales	43	3
Scotland	39	4
France	38	4
Austria	37	4
Finland	28	0
Italy	26	2
Netherlands	23	1
Sweden	21	0
Germany	16	1
Slovenia	15	2
Hungary	14	1
Romania	14	1
Denmark	12	1
Belgium	11	0
Other countries	<10	<2

2.3.3. Drivers of river restoration

A *driver* is a factor that causes a phenomenon to happen or to develop (Oxford dictionary). Restoration drivers have been categorized under five types (Clewell & Aronson 2006) : *Technocratic drivers* such as legislation and institutional missions; *Biotic drivers* as for instance local biodiversity; *Heuristic drivers* such as experimental project to elicit or demonstrate ecological principles and biotic expressions; *Idealistic drivers* such as personal and cultural concern for environmental degradation; and *Pragmatic drivers* namely aiming for the maximal supply of natural services and products. The loss of ecosystem services, namely provisioning services, regulation services, and cultural services, has been suggested as the major driver of river restoration (Galatowitsch 2012). However, indirect drivers, such as idealistic or moral changes and environmental policies, have also been suggested as important for the evolution of the restoration trend (Clewell & Aronson 2006; Baker et al. 2014).

In many countries, water policies took a decisive turn in the 20th century focusing newly on development and conservation of natural resources rather than previously on ensuring water usability for economic and domestic purposes and maintaining the navigability (Holmes 1972; Lovett 1973; Getches 2001; Gerlak 2006; Goldin 2010; Victor et al. 2015). The water policies are country-specific but a worldwide trend can be observed. First, shortly after the second world war, water policies aimed at regulating water sharing between users and to improve the water quality for easier human use and higher recreation potential (Gerlak 2006; Victor et al. 2015), e.g. the *Clean Water Act* and *Safe Drinking Water Act* in the U.S.A., the *National Drought Policy* in Australia, the *Water Code* in Brazil, the *White Paper on Water Supply and Sanitation* in South Africa. Then, since the 1970s, policies radically changed in the face of new environmental concerns, needs for climate change adaptation, and an increase in demands for nature-based solutions, as for example for flood control through environmental mitigation, restoration, and storm water retention areas (Botterill & Wilhite 2005; Kiem 2013; Reimer 2013), e.g. the *National Environmental Policy Act*, the *Water Resources Development Act*, and the *Endangered Species Act and Wild and Scenic Rivers Act* in the U.S.A, the *National Plan for Water Security* in Australia, the *National Environmental Policy Act* in Brazil, the *Water Ten Plan* in China, and the *Water Framework Directive* in Europa. These new policies, because of their content, obviously drive ecological restoration efforts (Gerlak 2008; Reimer 2013; Smith et al. 2014; Victor et al. 2015).

The Water Framework Directive (WFD) (EU 2000) is the most ambitious environmental legislation worldwide (Giménez-Sánchez 2003; Moss 2008; Petersen et al. 2009; Hering et al. 2010; Josefsson & Baaner 2011; Albrecht 2013; Voulvoulis et al. 2016). It demands that all water bodies inside the European Union achieve a good biological, hydromorphological, and chemical quality. It differentiates between *natural water* bodies that have to achieve their *good ecological status*, from *heavily modified* and *artificial water bodies* that have to achieve their *good ecological potential* (EU 2000). The WFD demands their restoration if the quality goals are not achieved. Accordingly, it is an obvious driver of the European river restoration effort (Giménez-Sánchez 2003; Kaika 2003; Hering et al. 2010; Smith et al. 2014). The WFD adopted the concept of reference conditions, meaning that the condition of the water body is evaluated comparing the current status and an undisturbed status, namely with or without minor anthropogenic alterations (EU 2000; EC 2016). However, this concept is criticized by many scientists who argue that this status underestimates the natural evolution of environmental systems (e.g. water course changes and natural incision), and does not consider the whole socio-ecological system (Moss 2008; Dufour & Piégay 2009; Josefsson & Baaner 2011; Bouleau & Pont 2015).

While the WFD remains vague considering the restoration goals for urban rivers, river restoration projects in cities are supported by the increasing interest of the urban population in living on the borders of healthy rivers (Bethemont & Pelletier 1990; Brown 1999; Booth et al. 2004; Bonin 2007; Akers 2009; Castonguay & Samson 2010; Costa et al. 2010; Romain 2010a; Romain 2010b; Kehoe 2011; Brun & Simoens 2012; PUB 2012; Mahida 2013; Chou 2016; Smith et al. 2016; Wantzen et al. 2016). With population growth and increasing demands for recreational opportunities in urban areas, an increase in the use of river embankments for leisure activities has been predicted since the 1990s (Flather & Ken Cordell 1995), especially on urban rivers with improving water quality (Wantzen et al. 2016). However, restoration projects were limited by the available space (Bernhardt & Palmer 2007) and the need to integrate flood protection for close-by areas (Rode 2010). With deindustrialization, opportunities increased to change the urban waterfronts (Binder 2008; Akers 2009). Geomorphologic restorations of urban rivers were carried out (Ehlinger et al. 2001; Nilsson et al. 2003; Bernhardt et al. 2005; Brooks & Lake 2007; Nilsson et al. 2007) but a return to pre-disturbance conditions is unlikely in urban areas (Brown 1999; Martín-Vide 2001; Department 2003; Bonin 2007; Binder 2010; Romain 2010b; Barraud 2011; Brun & Simoens 2012; PUB 2012; Mahida 2013; Orlamünde 2013; Tal 2017).

2.4. Evaluation of river restoration projects

2.4.1. State of the art

Project assessment is a major issue for providing feedback and guidance. However, few projects implement a monitoring procedure. In the U.S.A and in Bavaria (Germany), less than 10% of projects have been monitored (Bernhardt et al. 2005; Pander & Geist 2013). Morandi and Piégay (2014) carried out a study in France about the implemented evaluation procedure. They found that only 50% of the monitored projects used a before-after comparison, and most of them included only one-year of pre-restoration monitoring. Long-term monitoring, namely occurring more than 10 years after implementation, was applied in less than 15% of the monitored cases. They found that more than 84% of the monitoring procedures carried on after a restoration project in France measured fish diversity and richness, 80% monitored macroinvertebrates, 57%

surveyed stream and floodplain vegetation, and 30% monitored other fauna, e.g. reptilians, birds. These investigations focused on the biological response monitoring the whole community attributes rather than target species and neglected social goals.

In Europe, the WFD demands the evaluation of the river status prior to projects to establish the most relevant restoration goals, and post project to proof the success of the implemented measures and to enable adaptation of the restoration goals (EU 2000; Hering et al. 2010; EC 2016; Voulvoulis et al. 2016). The ecological evaluation of the water bodies should investigate three aspects: biological quality, chemical quality, and morphological quality (EU 2000). A panel of parameters and indicators to assess the ecological river status was identified and metrics to evaluate the ecological status of the freshwater bodies have been developed. For example, in France, the most common metrics used are those proscribed by the WFD (Morandi et al. 2014): a) Hydromorphology quality is mostly investigated using hydrological metrics, morphological dynamics, morphometric, habitat characteristics, habitat suitability index. b) Biological quality is mostly investigated using fish monitoring (reproduction rate, species richness, biotic index, community structure and population structure), invertebrate monitoring (richness, biotic index, community structure and phenotypic traits), diatomea survey (biotic index) and sometimes aquatic and riparian vegetation inventories (per cent of cover, richness, biotic index and community structure). c) Physical-chemical analyses investigate mostly nutrients, dioxygen concentration, and temperature but other analyses are performed in the laboratory identifying for example metals, pesticides and industrial chemicals listed in Annex X of the WFD (EU 2000).

2.4.2. Limitations of evaluation procedures

There are six major limitations to the current procedures for evaluating river restoration projects:

- Requisite data are missing: Assessing the ecological outcomes of the restoration projects is crucial to estimate its success (Pander & Geist 2013). However, pre and post-restoration monitoring are absent for many projects (Bernhardt et al. 2005; Pander & Geist 2013; Morandi et al. 2014).

- Control sites are inappropriate: Use of spatial reference sites for assessing the success of restoration showed serious limitations: The use of historical reference status has been identified as utopic (SER 2004; Moss 2008; Dufour & Piégay 2009; Josefsson & Baaner 2011; Belletti et al. 2015; Bouleau & Pont 2015), and spatial reference sites may not exist (Morandi et al. 2014; Bouleau & Pont 2015).

- Metrics are inappropriate. Biological indicators have serious limitations (Niemi & McDonald 2004; Friberg et al. 2011; Smucker & Detenbeck 2014), such as a lack of identification of the causes of failures in restoration. Morphological evaluation methods do not consider the physical processes and the interaction between hydrological and morphological components (Belletti et al. 2015).

- Evaluation procedure do not fit with the restoration goals and with the socio-ecological character of the river: river restoration projects are comprehensive, and their evaluation requires a broad perspective including social, economic and political dimensions (Pickett et al. 1997; Meyer et al. 2005; Walsh et al. 2005; Morandi et al. 2014). Social evaluation of river status remains lacking (Rogers & Biggs 1999; Chiari et al. 2008; Jaehnig et al. 2011; Pander & Geist 2013; Morandi et al. 2014).

- Monitoring duration is not adequate for reliable results: When a monitoring procedure is implemented, it often occurs over a very short period (Pander & Geist 2013; Morandi et al. 2014), but species need a longer time spans to recover (Haase et al. 2013; Morandi et al. 2014; Kail et al. 2015).

- Seasonally flooded areas are not monitored: while riparian vegetation has a great impact on water quality and habitat quality, riparian zone monitoring and assessment remain one of the less frequent evaluation procedures (Januschke et al. 2011; Morandi et al. 2014).

2.4.3. Alternative method to estimate river restoration outcomes

Habitat models came into use in the late 20th Century to access river restoration measures. They are very promising tools and may bypass the lack of data usually limiting the use of evaluation procedures based on biological and chemical monitoring The first widely available physical habitat model was the Physical Habitat Simulation (PHABSIM) but it ignored interactions among physical habitat variables (Jorde et al. 2000). Habitat models improved and proved their value for investigation on the physical aspects of habitats and their ecological functions and interactions (Schneider 2001; Mouton et al.

2007; Schneider et al. 2010; Lange et al. 2015; Pisaturo et al. 2017). The Computer Aided Simulation Model for Instream Flow Requirements (CASiMiR) is a popular tool in Europe to simulate riverine habitats (aquatic and periodically flooded) (Arthington 2012b). CASiMiR uses a new approach based on fuzzy sets and rules to integrate the interactions between physical habitat variables (Jorde et al. 2000; Schneider 2001; Noack et al. 2013). It has been developed to investigate habitat suitability of the investigated river section for fish, invertebrate and/or plant species (Schneider et al. 2010).

Fish habitats are a clear indicator of the richness of aquatic habitats (Mouton et al. 2007; Feld et al. 2009; Mouton et al. 2009; Birk et al. 2012; Fukuda et al. 2013; Pander & Geist 2013; Boavida et al. 2014; Pander et al. 2015). Fish diversity and richness is one of the indicators demanded by the WFD. However, fish species may need some time to recover after restoration. Modeling of physical fish habitats is a suitable tool for assessing the potential impact (positive or negative) of hydromorphological changes on physical instream habitats (Schneider et al. 2010; Noack et al. 2013). Fish habitat models such as CASiMiR are increasingly used in water management (Mouton et al. 2007), to investigate the impact of water management plan on aquatic habitats, e.g. hydropeaking damages (Boavida et al. 2015; Holzapfel et al. 2017; Pisaturo et al. 2017), the impact of hydraulic structures, e.g. reservoirs (Yi et al. 2014), and the potential benefits of restoration measures (Shih et al. 2008; Im & Kang 2011; Im et al. 2011; Lange et al. 2015). However, the modeling procedure simplifies the ecosystem to a finite number of variables and is exclusively used to investigate the social system.

2.4.4. Socio-ecological evaluation of river restoration

While the river system is recognized as a socio-ecological system, the study of rivers up to this point has been either undertaken from a sociological or from an ecological point of view, but rarely from a truly holistic and transdisciplinary approach. Specifically, the evaluation of river restoration has been completed thus far mostly taking into consideration the effect on the biotic aspects, and the social evaluation has been neglected (Morandi et al. 2014). Consequently, few studies have yet evaluated the socio-ecological success of the restoration projects applying an interdisciplinary approach. So far, the integrative assessments of restoration success concern the public acceptance for projects aiming at the improvement of the water quality (Macedo & Magalhães 2010) and the aesthetical improvements related to the reestablishment of the near natural morphological pattern (Bulut et al. 2010; Ozguner et al. 2012).

However, according to the socio-ecological approach, ecological degradation leads to a decrease of the ecosystem services available, and an increase in the ecological quality should lead to an increase in human well-being (Wantzen et al. 2016). Evaluation of the ecological response without considering societal outcomes may fail to provide an understanding of the full benefits of the restoration (Wortley et al. 2013). For instance, the success of the hydromorphological restoration is mostly assessed by monitoring the biological responses, e.g. the fish assemblage (Morandi et al. 2014). Lacking improvements of the ichthyological status is often ascribed to other biological stressors (Lepori et al. 2005; Haase et al. 2013; Kail et al. 2015). Other studies stated that improvements of the morphological quality of the river increase its attractiveness for recreational users (Barraud 2011; van Marwijk et al. 2012; Polizzi et al. 2015). However, none of these studies included the increase in pressure by recreational users to explain the missing recruitment of fish species.

2.5. Knowledge gaps

- Missing practice-oriented project typology (knowledge gap 1)

River restoration projects are increasingly numerous and combine a broad spectrum of goals and measures. The term *river restoration* is applied to a wide range of activities (SER 2004), e.g., *rehabilitation*, *reclamation*, and *revitalization*, and many definitions exist (Morandi 2014). This diversity may lead to misunderstanding and may jeopardize project outcomes comparison, and cross-fertilization. Furthermore, few definitions underscore the socio-ecological characteristic of the system river. Scientists and practitioners have formulated the need for more practice-oriented project characterizations. A typology based on main project features may help, in the future, to develop practical guidelines and an evaluation procedure for each project type.

- Need for research on urban crossing section of rivers (knowledge gap 2)

Urban studies are particularly important because of the rapid growth of the world's human population and the fact that major growth is expected to occur in urban areas (U.N 2014). While in 1952, the largest city (New York, U.S.) had less than eight million inhabitants, in 2001 seventeen cities were larger than that, and in 2010 there were 44. In Europe, as in North America, the percent of urbanites should reach 85% of the population by 2030 (U.N 2014). Intensive use and urbanization result in a poor ecological status of urban water bodies that is described as the *urban river syndrome* (Walsh et al. 2005). Urban river restorations are more difficult than restoration in rural areas but are supported by the increasing interest of the urbanites. While many urban river restoration projects have been initiated (Bernhardt et al. 2005; Bernhardt et al. 2007a), scientific studies on urban freshwater body restorations remain rare, especially in the case of major cities (Francis 2012). Characterization of the specificities of urban river restoration should provide important insights for future projects.

- Better consideration of the social driving force of the restoration effort (knowledge gap 3)

The loss of ecosystem services has been defined as the major driving force of the river restoration trend (Galatowitsch 2012). The role of indirect drivers, such as idealistic or moral changes, environmental politics, demographic or socioeconomic changes, has also been suggested (Clewell & Aronson 2006; Baker et al. 2014). However, little concern has been given to identifying societal driving forces (Eden & Tunstall 2006; Grêt-Regamey et al. 2016; Parr et al. 2016), e.g. social, cultural, recreational, political, and historical, which influence river restoration practices.

- Incomplete Database (knowledge gap 4)

The publication of feedback is an important issue to improve restoration governance, sciences, and practices. In this spirit, great efforts have been made to inventory river restorations. However, restoration effort is unequally reported between European countries (Table 2). Jenkinson and Barnas (2006) stated that river restoration inventories only recorded a small part of the real river restoration effort. An inventory of urban river restoration project should (at least partly) fill this knowledge gap.

- Socio-ecological tool to assess urban river restoration success and failures (knowledge gap 5)

Few river restoration projects have been monitored and recent studies identified the difficulties of the evaluation of river restoration projects. A cost-saving monitoring procedure that is independent of a physical reference site and which could bypasses missing pre-restoration data, informs about potential conflicts, integrates social and ecological assessment, and investigates the quality of the physical habitat is needed. Habitat models such as CASiMiR are promising tools but are solely based on physical hydromorphological variables. The integration of pressure related to human uses, e.g. impacts by recreational users, should provide important progress in the field.

- Identification of conflicts within the socio-ecological system (knowledge gap 6)

Ecosystem perturbations caused by human pressure and benefits of the restoration have been widely investigated. However, restoration of the socio-ecological system may result in new conflicts. For example, recreational uses increase in restored river sections but high user density may negatively impact the species target of the restoration (Wood 2015). Regulations prohibiting access to the restored area may secure species habitats but will affect recreational potential and related public acceptance (Schenk et al. 2007). Accordingly, a method to investigate the habitat and user distributions may be an important tool for the design of a realistic restoration project. Another example is the modification of minimal water flow. Minimum flow requirements for aquatic habitats were intensively studied and guidelines were formulated but these conflict with increasing demand for hydroelectric power (Arthington 2012a). Most guidelines suggested minimum flows calculation based on river hydrology, namely a third of annual mean low discharge but this standardized approach did not consider the local specificities of aquatic habitats. Furthermore, an increase in minimum flow is related to a decrease of the water quantity diverted for human uses, e.g. hydroelectric power plants, which cause important economic loss. Accordingly, a systematic method to design the best scenario may provide important insight to design the most effective future restoration measures.

3. Methods

3.1. Methodological approach

To investigate the socio-ecological systems and to draw conclusions for its further development aiming at sustainability, the study focused on analyzing the relationships among the first-level core of the social systems, i.e. *governance* and *users* (Ostrom 2009), and the ecological system. Different methods were applied regarding specific research questions and different levels of the study (from macro to micro-level). First, at the macro level, the study identified the component of the socio-ecological system defining the project types, the specificities of the urban system, and the *governance*, e.g. drivers, of the restoration. Then, at the micro level, namely in the case of the Isar restoration in Munich, the interaction between the *users* and the *system unit*, e.g. fish species, plant species and water flow that were the target of the restoration, were studied and discussed. To answer the research questions, methods used in social sciences were integrated into the methods commonly used in ecological sciences. The methodological approach is described in the following (Figure 4).

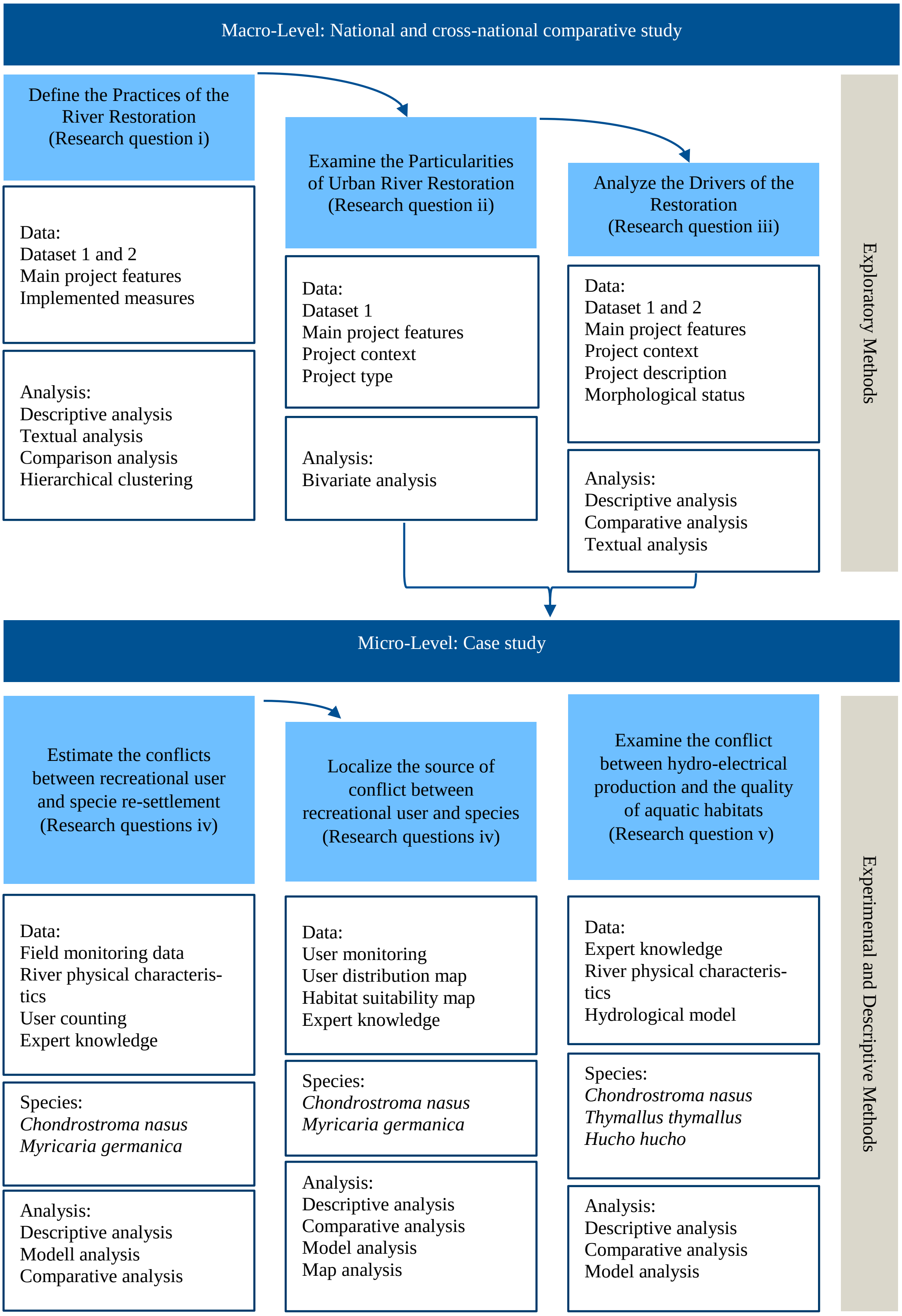

Figure 4 Overview of the methodological approach

3.1.1. Objective 1: To identify the different restoration practices and drivers and examine the particularities of urban river restorations

As presented in the literature review (Chapter 2), despite intensive effort to record river restoration projects and to create learning arenas, major gaps remain, e.g. very little record of urban river restorations exist inside the current databases. Consequently, for this study a dataset of river restorations was created focusing on projects implemented in urban areas. Despite information available in internet, a project survey by phone call was identified as the most effective way to access to project information and was commonly used in previous studies (Bernhardt et al. 2005; Alexander & Allan 2006; Brooks & Lake 2007; Morandi & Piégay 2011). Accordingly, projects were surveyed according to survey protocol used in the social sciences (Kelley et al. 2003). The detail of the procedure is described in section 3.2.3. The investigations on objective 1 were explorative and descriptive. Consequently, as described in section 3.2.4, explorative statistical analyses were performed on the dataset.

Research Question i: What are the different types of river restoration practices?

Previous publications identified the main features of the project design which characterized them (Bernhardt et al. 2005; Jenkinson et al. 2006; Nakamura et al. 2006; Brooks & Lake 2007; Kondolf et al. 2007; Aradóttir et al. 2013). They are presented in section 3.2.3. and used for the analyses. The establishment of a practice-oriented and transparent project typology requires the use of clustering methods. Looking for subcategories of the river restoration concept, a divisive method using top-down approach was applied, namely the hierarchical clustering procedure (Husson et al. 2011).

Research Question ii: What influence does the geographical context of the river, e.g. rural or urban, have on the restoration practice?

To compare projects considering their context, i.e. rural or urban, bivariate analysis was performed on the main features of the project design. However, the outcomes of literature review suggested that differences between the countries may exist, even inside the European Union (Falkner & Treib 2008; Keessen et al. 2010; Couch et al. 2011; Albrecht 2013; Sala et al. 2014), and may cause bias. Consequently, the analysis was carried out on dataset 1 (Table A1 in supplementary material), namely only on projects implemented in one country: France.

Research Question iii: Which socio-ecological drivers of the river restoration influence the practices?

To qualitatively investigate the effect of governance, i.e. driving forces, on the restoration practices, methods of the social sciences were required. Consequently, methods as textual analyses (LERASS 2014), i.e. word frequency and word co-occurrence, were combined with the descriptive statistical analysis. To investigate the effect of different socio-cultural and political approaches on the practices, a comparison was made between Germany and France. The analyses were carried out on the dataset 2 (Table A2 in supplementary material).

3.1.2. Objective 2: To assess the success of restoration and the potential conflicts inside the socio-ecological system

To assess restoration success and to estimate conflicts between ecological restoration goals and social river uses, i.e. recreational uses and hydroelectric production, methods from, and considerations of, the social sciences were added to evaluation procedures using ecological methods. The investigations on objective 2 tested stated hypotheses and consequently employed confirmatory research design, also known as hypothesis testing research design (Shields & Rangarjan 2013), i.e. experimental and descriptive analyses. Complementary studies at the micro-level, namely for the case study Isar River in Munich (Germany), investigated in depth the conflicts between human uses of the river and ecological restoration (Figure 4).

Research Question iv: Do recreational uses decrease the ecological success of the restoration?

To assess conflicts between recreational uses and ecological restoration goals, conflict potential was estimated and localized, and management measures for reducing these conflicts were formulated. Investigations were performed on aquatic and riparian species considering the species target of the restoration (section 3.3.2). For the plant species, semi-experimental approach based on field observation was possible. The recreational uses were considered as a potential competitor for the habitats and destructor of the plants and the study applied related ecological field measurement, namely methods to estimate the intensity of the pressure (section 3.3.5), and related damages. For the aquatic species, since the selected fish species disappeared from the study area field and reintroduction showed limited success, field observation was not possible. A descriptive approach based on a habitat suitability model enable the estimation of the recreational effect on the fish habitat availability. Habitat suitability and fish sensitivity to recreational disturbance were estimated by expert-knowledge.

Research Question v: What effect does water use, e.g. diversion for, have on fish habitat suitability of the restored river section?

To estimate the effect of minimal water flow caused by water diversion for hydroelectric production on fish habitats and to define a better water sharing strategy providing better habitats at a lower economic cost, different scenarios were investigated. Because of temporal and economic limitation, this investigation was only possible using a simulation procedure. Habitat suitability changes for a broad span of life cycle stages of three fish species, i.e. *Chondostroman nasus* L., *Hucho hucho* L., *Thymallus thymallus* L. (section 3.3.2) were simulated using a habitat suitability model and scenarios were compared.

3.2. Investigations on the socio-ecological aspects of river restoration (at the macro-level)

This study was presented in Paper A and B (Figure 1). Both used similar exploratory methods to answer the research questions A, B, and C but analyzed data from two different study areas. While the first paper defined and characterized the difference between French river restoration practices (Dataset 1, Table A1), and examined spatial differences, the second paper defined the cultural drivers of the river restoration and analyzed the cultural variations of urban river restoration practices comparing the case of France and Germany (Dataset 2, Table A2). The methods used can be explained as following.

3.2.1. Study area

The investigation of the river restoration approach was conducted in the case of France and Germany. The overall length of watercourses in both countries is similar: 428,906 km of French rivers (IGN 2014) and almost 400,000 km of German rivers (EEA 2012). However, according to the classification formulated by the WFD, the overall ecological status of the German rivers is lower than for French counterparts. For example, the longitudinal connectivity of German rivers is interrupted around every second kilometer, and only 21% of the rivers are still in natural or slightly to moderately altered status (BMU/UBA 2010). In France, the river longitudinal obstacles are half as numerous as in Germany and only 5 % of the French rivers are classified as highly modified or artificial water bodies (EEA 2012).

The comparison between France and Germany is particularly interesting since both countries have a long standing tradition of restoration and have developed similar environmental policy strategies (Parker & Fordham 1996). However, German landscape planning policies and landscape approaches are more nature conservation-oriented than their French counterparts, which are more oriented towards the interests of human users (Sala et al. 2014). Furthermore, socio-cultural understanding of the concept of *nature* also differs between the countries (Fall 2007; Couch et al. 2011; Sagie et al. 2013; Kovács et al. 2014; Lim et al. 2015; Madureira et al. 2015; Skandrani & Prevot 2015). While German citizens appreciate “true nature” in the cities, French citizens prefer “controlled nature” and dislike non-organized, wild and muddy natural elements.

3.2.2. Datasets

To enhance the transfer of experience, numerous databases of river restoration synthetizing research results have been published in the 21st Century (Bernhardt et al. 2005; Nakamura et al. 2006; Feld et al. 2011; Pander & Geist 2013; Morandi et al. 2014; Kail et al. 2016; Muhar et al. 2016; Speed et al. 2016). But aggregation of databases is arduous since inventory protocol may differ and since variables and their modality recorded depend of the purpose of the research carried out. Two databases recorded river restoration projects on a larger scale in Europe. One is the database resulting from the EU REFORM project (http://wiki.reformrivers.eu), which recorded river restorations focusing on hydromorphological projects. Unfortunately, the website hosting the French projects changed and the project descriptions were not made available at the date of this research. Another database is the RiverWiki database (https://restorerivers.eu/wiki/index .php?title=Main_Page) resulting from the EU LIFE+ RESTORE project (2010–2013). It is currently the largest source of standardized project descriptions at the European level. However, the number of projects remains lower than in national databases. For example, the database produced by the French water agency (ONEMA) contained 78 river restoration projects, while RiverWiki recorded only 38 French cases (both consulted in March 2013). According to this context and to the objective of the study, two datasets were created for this doctoral study (Figure 5).

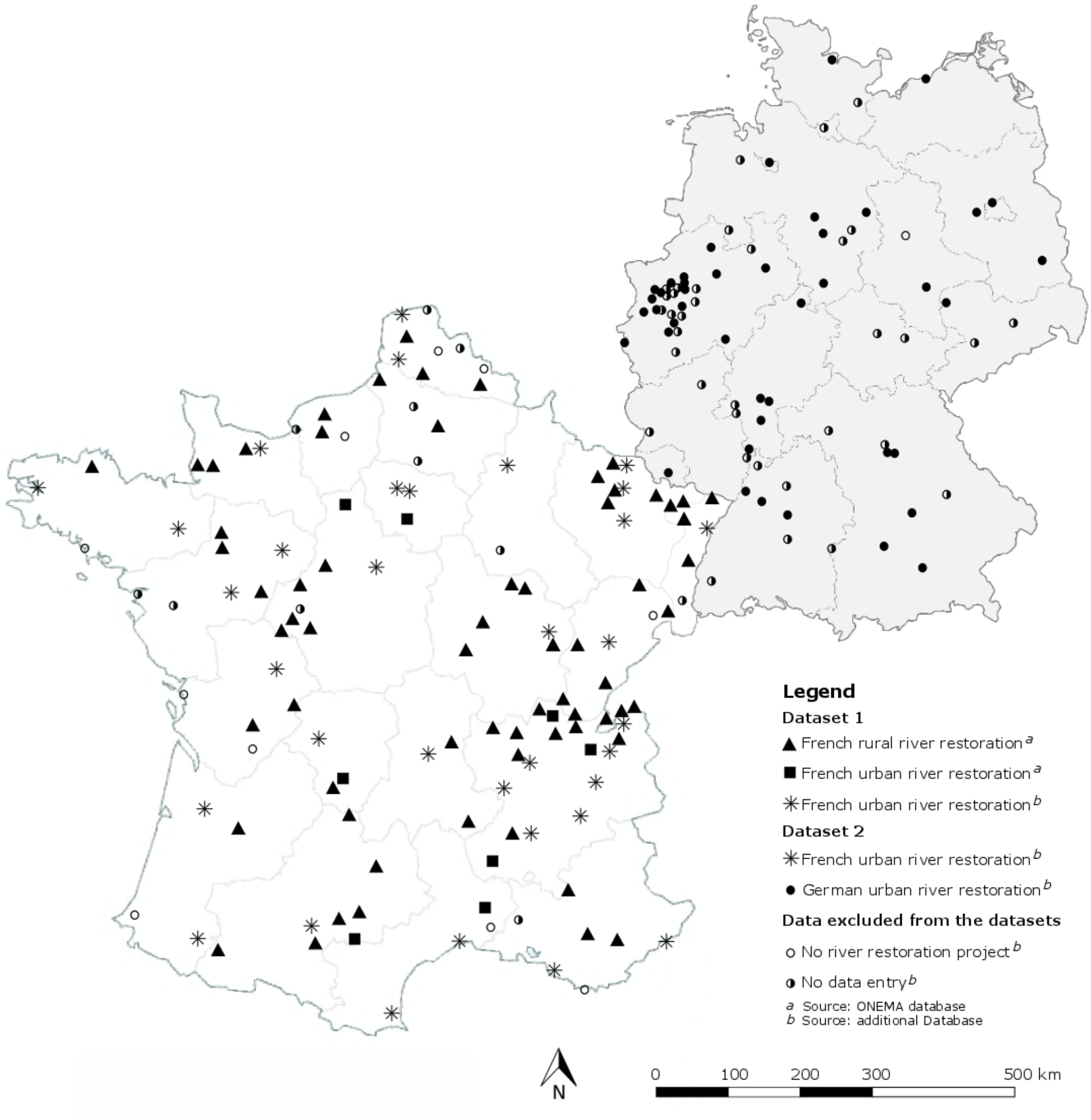

Figure 5 Map of the river restoration projects distribution in France and Germany (after Zingraff-Hamed et al. 2017a and 2017b)

First, to give a detailed picture of the French river restoration practices (Research question A) and to examine the spatial difference of river restoration practices (Research question B) the database produced by the ONEMA was used because it provides the larger number of French projects. However, it contains only 11 river restorations in urban areas, which did not allow significant comparison between urban and rural projects (Research question C). In this context, a dataset (Dataset 1) was established aggregating both the existing public database produced by the ONEMA (n = 78) and an additional database produced for this study (n = 33) and recording only urban river restoration in France (Figure 5). The survey protocol applied to create the additional database is presented briefly in the following paragraph and in great detail in Paper A. The compatibility of the databases was presented in Paper A.

Second, to define and analyze the socio-ecological drivers of the urban river restoration (Research question C), a dataset (Dataset 2) of 75 urban river restorations in major French and German cities (Figure 5) was established. The survey was conducted between March and October 2013 in all the major French and German cities with more than 100,000 inhabitants (n = 132). The selection of the projects followed the method defined by Bernhardt and Palmer (2005), namely, "No judgments were made of the validity of the terms restoration or project". One person carried out the entire data collection to avoid operator bias. The project data were collected via phone interviews with the staff of city planning departments and river management districts ("Syndicats de bassin versant"). The response rate of 65% enabled a significant statistical comparison analysis to be performed between France and Germany. The phone interviews were conducted using a direct closed technique (Kelley et al. 2003), namely a standardized multiple choice questionnaire (Form A1 in Supplementary material).

3.2.3. Variables: main design features of the project

Eight themes were identified as the most important project design features to describe river restoration projects (Jenkinson et al. 2006): project motivation, restoration goals, project cost, project size, project dates, evaluation procedure, source of funding, and river characteristics. To describe and characterize the river restoration practices and driving forces (Research question A, B and C), we collected information about this theme for each project of the datasets 1 and 2. The variables were presented in Paper A and B and their modalities are listed in Table 4 (Main variables).

To compare restoration projects in urban and rural contexts (Research question B), the projects were labeled URR (Urban River Restoration) or RRR (Rural River Restoration) according to population density of the surrounding area. The classification used was formulated by the European Commission (EC 2011). However, high-density (>1,500 inhabitants/km2 and >50,000 inhabitants) and urban areas (>300 inhabitants/km2 and >5,000 inhabitants) were merged under urban.

To define the drivers of the restoration practices (Research Question C), qualitative variables were added to the eight themes mentioned above. The textual descriptions of the projects and the project labels were translated into English to enable comparison between the countries using the *Dictionary of Landscape and Urban Planning* (Evert et al. 2004) (Table 3).

Table 3 Example of the translation of the project label

English	**French**	**German**
Reclamation	Amenagement de la rivière Renaturation	Naturnahe Umgestaltung
Restoration	Restauration	Renaturierung des/der…
Daylighting	Ré-ouverture	Offenlegung des/der…
Rehabilitation	Requalification Revalorization	Rehabilitation Erneuerung/Sanierung

Descriptions of the morphological status of the river prior to restoration measures were also added to inform about the cultural context of the river management and restoration (Table 4). More details about these supplementary variables are presented in Paper B.

Table 4 Variables classified under eight main themes and four supplementary variables (Table published in Zingraff-Hamed et al. 2017a)

Theme	Variables	Entries
Main variables		
Project motivation	Implementation of the WFD Reestablishment of the migration potential for fish Nature conservation (Natura 2000) Restoration of (sensitive) habitats Improvement of the flood protection management strategy Improvement of the quality of life for citizens	chose 1 of the 6 variables only
Restoration goals	Improving flood protection potential	Yes/No
	Reestablishing the longitudinal connectivity	Yes/No
	Improving the water quality	Yes/No
	Reestablishing near natural patterns of the river hydromorphology	Yes/No
	Restoring aquatic habitats	
	Restoring riparian habitats	Yes/No
	Improving the esthetics of the riverscape	Yes/No
	Enhancing the recreational potential at the river	Yes/No
	Integrating the river into the city structures	Yes/No
Project costs	Project cost (€)	Numerical
	Cost per meter (€/meter)	Numerical
Project dimension	Project length (meter)	Numerical
Project dates	Project start (year)	Numerical
	Project end (year)	Numerical
	Duration (month)	Numerical
Evaluation procedure	Monitoring	Yes/No
	Chemical analysis	Yes/No
	Social indicators	Yes/No
	Fish	Yes/No
	Macroinvertebrates	Yes/No
	Vegetation	Yes/No
River characteristics	Annual mean discharge (m³/s)	Numerical
Sources of funding	European Union	Yes/No
	State and Water Agency	Yes/No
	City government	Yes/No
	Non-Governmental Organization	Yes/No
Supplementary variables		
Project context		URR/RRR
Project description and Project label		Textual
Morphological status	Channelized river course	Yes/No
	Straightened channel	Yes/No
	Impervious riverbank	Yes/No
	Artificial river bed	Yes/No
	Longitudinal connectivity (for fish migration) damaged	Yes/No
	Existence of national road or highway at the river side	Yes/No
	Buried river	Yes/No
	Navigable	Yes/No
Implemented measures	to improve the flood protection potential to improve the water quality to restore riparian habitats to restore aquatic habitats to reestablish near-natural patterns of the river hydromorphology to renew city planning to enhance the recreational potential at the river to reestablish the longitudinal connectivity to reduce pressures caused by hydropower	listed in Figure 12 and 16

3.2.4. Analysis

To investigate the socio-ecological character of river restoration focusing on urban areas, first the different restoration practices were identified, then the urban particularities were characterized, and finally the relationship between restoration practices and socio-ecological drivers was analyzed. The statistical analyses were performed on the datasets presented above and using R version 1.31.3. All analyses were considered significant at $p < 0.05$. Textual analyses was performed using IRaMuTeQ 0.7 alpha 2 supported by R (LERASS 2014). The software developed by the research team LERASS of the Universities of Toulouse and Montpellier (France) enables qualitative lexical data analyses.

Practices of the river restoration

To describe the restoration effort, statistical analysis on the dataset 1 and 2 was performed and was associated to textual analysis on the project label. In order to group river restoration projects with similar characteristics, we performed a Hierarchical Multiple Factor Analysis (HMFA) using the package FactoMineR - Multivariate Exploratory Data Analysis and Data Mining version 1.24. This package permitted a summary, visualization, and description of the datasets with qualitative and quantitative variables (Husson et al. 2011). Since the variables were ordered in eight themes, the clustering procedure was based on a Multiple Factor Analysis. The HMFA allowed agglomerative clustering using the *k*-mean method (Husson et al. 2011). The major output of the method was a project typology.

Particularities of river restoration in urban areas

The dataset 1 was used to examine and analyze the difference between restoration practices in rural and urban context. In order to compare projects considering their context, bivariate analyses were performed on all the variables of the eight themes, i.e. *project motivation*, *restoration goals*, *project dates*, *costs*, *size*, *funding*, *river annual discharge*, and *implemented evaluation procedures*, and the variable *project type* resulting from the HMFA analysis. Fisher's exact test, which is a test of equal or given proportion, was performed.

Drivers of the restoration

To define the driving forces and analyze the relationship between restoration practices and socio-ecological drivers, statistical analyses were performed in four steps. First, descriptive analysis on the variable *project motivation* were performed on dataset 1 and 2. Second, to identify socio-cultural variations, comparative analyses was performed between the project types (Dataset 1) and between projects in France and Germany (Dataset 2). Tests for equality of proportions on the variable *project motivation*, *restoration goals*, and the *date of implementation* were performed. Third, to inform more deeply about the restoration drivers, a textual analysis, namely comparison of word frequency and word co-occurrence, was performed on the variables *project descriptions* and *project labels* of the Dataset 2 using IRaMuTeQ 0.7 alpha 2. Finally, to investigate the influence of the urban planning history on projects, tests of equality of proportion were performed between the variable of the Dataset 2, namely the *project motivation* and the morphological status of the river prior restoration measures, i.e., straightened channel, existence of highways along the riverbank, channelization, impervious embankments, impervious river beds, longitudinal connectivity damage, buried rivers, and navigable rivers.

3.3. Assessment of conflicts between ecosystem use and restoration (at the micro-level)

This study was presented in Paper C, D, and E. The methods used were experimental for the case of *Myricaria germanica* L. (Paper C) and model-based in the case of the fish species, i.e. *Chondostroma nasus* L., *Thymallus thymallus* L., and *Hucho hucho* L. (Paper D and E). Paper C presented investigations on the periodically flooded habitats and, Papers D and E presented investigations on aquatic habitats for fish species.

3.3.1. Study area

The Isar River drains the Karwendel Mountains that are located in the north of the Alps. The 295 kilometer-long river originates at the Eiskarlspitze (47°23'09"N 11°31'59"E), a 1,160 meter, high rocky mountain in (47°22′29″N, 11°24′43″E) and joins the Danube River (48°48′11″N 12°58′35″E) (Figure 6). It is the fourth largest river in Bavaria and the second most important tributary of the Danube in Germany. Since prehistoric time the river was used as trade route for wood rafts from the Alps but only slight morphological changes have been made for navigation. Environmental issues began in 1920 with the construction of 43 hydro-electric power plants. The river below the Sylvenstein reservoir (1954-1959) is canalized, the river water is diverted several times to supply run-of-river hydropower or to cool a nuclear power plant, and the river longitudinal connectivity is damaged due to storage of hydropowers and weirs. With growing urbanization, many parts of the historical floodplain have been cut off by flood protection infrastructures, e.g. dikes, and then covered by housing areas. The ecological quality of the river water benefits from relatively low inputs from agriculture and industry. Furthermore, the cold and fast flowing water resulting from snowmelt and post-rain runoff assures a great level of oxygenation. However, the morphological patterns of the river (flow and morphology) have been seriously damaged, causing the decline of biodiversity (Binder 2005; Kamp et al. 2007). Since the 1990s, river restoration projects have been carried out to improve the morphological status of the river.

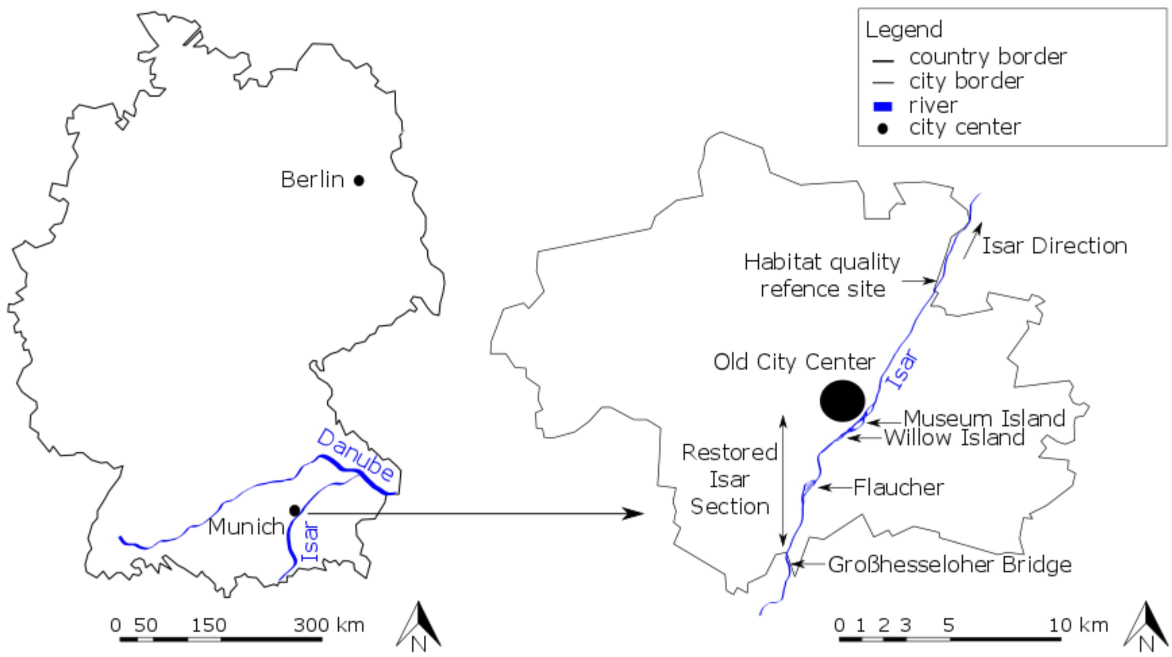

Figure 6 Locations of Munich, the Isar river restoration in Munich, and the sites of importance
The *Flaucher* is the reference site of the restoration, the project limits are the *Museum Island* and *the Großhesseloher Bridge*. The *Willow Island* is a man-made island constructed to increase the aesthetic of the area, and the reference site was used for the habitat suitability model. (Maps published in Zingraff-Hamed 2017c)

The Isar River crosses the city of Munich from Großhesseloher Bridge (48°4′29.59″N, 11°32′24"'O) to the Oberföhring storage hydropower (48°10′8"'N, 11°36′59"'O) (Figure 6). Inside the urban area, the Isar and its canals supply 11 hydroelectric power plants that produced 73.5 million kilowatt hours of electricity (balance of 2013). According to the records from 1959 to 2012 performed by the Bavarian Environmental agency (Bayerisches Landesamt für Umwelt) available online www.hnd.bayern.de (Figure 7), the mean discharge in Munich is 63.8 m³/s. However, the water volume flowing into the riverbed and the canals highly depends on the season. The drier season is the winter with 11 to 202 m³/s. In spring, small flood events occur, mainly caused by snowmelt. During the summer, the discharge variations are very high with dryness caused by missing rain events (minimal water volume NQ= 8.63 m³/s), and flood events that may cause flash flood with very high discharges (higher water volume HQ=1050 m³/s). Despite discharge regulation and water flow diversion, the Isar river bed, which is composed of gravel, benefits from frequent natural remodeling. We calculated that the medium gravel substratum (26 mm) starts to move at 290 m³/s and that the fine grain sediment (<10 mm) already drifts at 80 m³/s.

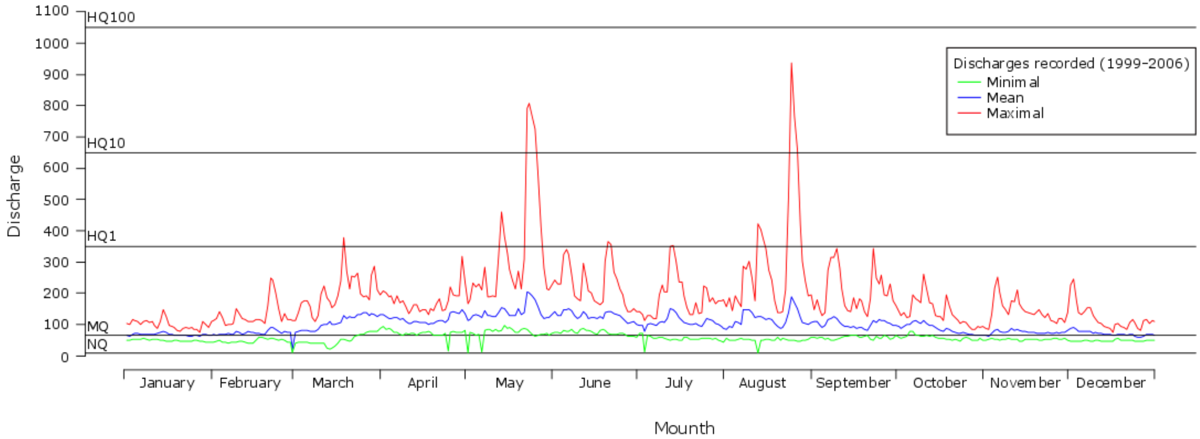

Figure 7 Minimum, mean, and maximum discharges of the Isar in Munich
Discharges recorded between 1999 and 2006 by the Bavarian Water Agency. HQ100, HQ10, and HQ1: 100-, 10-year, and 1-year maximum discharge; MQ: mean discharge; NQ: minimum discharge (published in Zingraff-Hamed 2017c)

From 1999 to 2011, the Munich city government and the Bavarian water agency initiated the project *New Life for Isar* (Figure 8) that aimed to improve the ecological status of the river, decrease flood risk, improve aesthetic aspects of the riverscape, and increase the recreational potential at the river (Rädlinger 2012). The project extended from the *Großhesseloher Bridge* (48°4′29.59″N, 11°32′25.83″E) to *Museum Island* (48°7′41.42″N, 11°34′46.88″E). The 400 meter long *Flaucher* site (48°6′18.14″N, 11°33′11.37″E to 48°6′25.04″N, 11°33′26.70″E) was used as a social and ecological reference site (Figure 9). The restoration measures implemented should enable the achievement of the good ecological quality expected by the WFD (Pottgiesser & Rehfeld-Klein 2011; Laub et al. 2012). However, biological monitoring remains partly unsatisfactory (Orlamünde 2013), mainly because of missing recovery of the fish population.

Figure 8 The restored Isar in Munich
(Aude Zingraff-Hamed, April 2011)

Figure 9 The east arm of the Isar at the *Flaucher* in Munich
(Aude Zingraff-Hamed, March 2010)

3.3.2. Species selection and biology

3.3.2.1. Fish species

Since the long term ecological monitoring of the Isar showed that according to the WFD criteria, the chemical status of the water is good, the macroinvertebrate and diatom survey proved the good ecological status of the river, and the oxygenation levels are good all year long. However, since the fish survey showed no improvement of the fish community (Schubert et al. 2012; Orlamünde 2013), we investigated the success of the Isar river restoration considering fish habitats. Target species were identified by description of the historical fish structures and density in the Isar in Munich (Hennel 1991; Reinartz 1997; Hüber 1998; Freyhof & Kottelat 2008; Nutzel & Krönke 2008; Freyhof 2011b; Schubert et al. 2012), and from the restoration goals of the project *New Life for the Isar* (Binder 2005; Binder 2010; Mahida 2013; Orlamünde 2013; Düchs 2014). We investigated the physical habitat of three emblematic fish species: *Thymallus thymallus* L., *Hucho hucho* L., and *Chondostroma nasus* L.

Thymallus thymallus L. commonly named European grayling, is a widespread species in pre-alpine rivers with cold, fast flowing, and well oxygenated water and with a hard sand or stone bottom (Kottelat & Freyhof 2007). According to the Red List Category, the European grayling is classified as “Least Concern”, but the last survey in 2012 showed the population in the Isar in Munich was small with less than 5 fish per 100 meters of river, while the population may have more than 150 fish pro 100 m river (Schubert et al. 2012). The population suffers from river pollution, dam constructions and river regulation (Freyhof 2011b). Based on the literature, three habitat types were identified (Mallet et al. 2000; Uiblein et al. 2001; Nykanen & Huusko 2002; Vehanen et al. 2003; Nykanen et al. 2004; Kottelat & Freyhof 2007; Mouton et al. 2008; Nutzel & Krönke 2008; Riley & Pawson 2010; Freyhof 2011b; Tuhtan et al. 2012; Fukuda et al. 2013; Weiss et al. 2013; Cattaneo et al. 2014; Bui & Rutschmann 2015; van Leeuwen et al. 2016; Auer et al. 2017): habitats for Adults, for Juveniles and for Adults spawning (Table 5).

Hucho hucho L., commonly named European huchen or Danube salmon, is an endemic Salmonidae to the Danube drainage. It inhabits fast flowing and well oxygenated streams with gravel bars (Holcik 1995; Freyhof & Kottelat 2008). European huchen is listed as “Endangered” in annex II of the European Flora Fauna Habitat directive (EC

1992), in the Appendix III of the Convention on the Conservation of European Wildlife and Natural Habitats (EC 1979) and on the Red List. Despite major threats caused by flow regulations from hydropower production (Holcik 1990; Kottelat 1997; Freyhof & Kottelat 2008), *Hucho hucho* L. occurs in very low density in the Isar in Munich and its tributaries, namely less than 5 fish for 100 meter of river (Nutzel & Krönke 2008; Schubert et al. 2012). Drawing on available literature, three habitats types were identified (Jungwirth et al. 1989; Holcik 1990; Jatteau 1991; Holcik 1995; Kottelat 1997; Nikcevic et al. 1998; Freyhof & Kottelat 2008; Sternecker & Geist 2010; Kucinski et al. 2014): Habitats for Adults, for Adults during the reproduction and for Adults during spawning activities (Table 5).

Chondrostoma nasus L., generally referred to as common nase, is an endemic species of the Danube basin. It inhabits moderate to fast-flowing large to medium sized rivers with rock or gravel bottom (Hennel 1991; Reinartz 1997; Kottelat & Freyhof 2007; Freyhof 2011a). It is classified as “Least Concern” by Red List Category, but is protected by the Convention on the Conservation of European Wildlife and Natural Habitats (EC 1979). Furthermore, it is locally threatened in the Isar by damming and destruction of spawning sites (Kottelat & Freyhof 2007). The common nase historically occurred in the Isar in Munich but currently no individual fish remain (Schubert et al. 2012). The species occurs upstream and downstream from Munich, but between 1995 and 2012, the species’ abundance dropped from 40 to fewer than 5 individuals per 100 meters in these sections of the river (Schubert et al. 2012). At the age of three, the fish can reproduce and adults in suitable habitats may live around 20 years. The missing recruitment of juvenile fishes is a major issue for the conservation of the species. In the last 20 years, in the Isar River, as in other Danube tributaries, the *Chondrostoma nasus* L. population lost 41% of adult fish of reproductive age (Schubert et al. 2012). From the literature, six habitats were identified (Hennel 1991; Reinartz 1997; Bruslé & Quignard 2001; Kottelat & Freyhof 2007; Freyhof 2011a): Habitats for Adults during the summer, during the winter, during pre-reproduction period, during spawning, for Juveniles and for larval development (Table 5).

Table 5 List of habitats associated with life-cycle stages of *Thymallus thymallus* L., *Hucho hucho* L. *Chondrostoma nasus* L. described in terms of their physical characteristics

(Table published in Zingraff-Hamed et al. 2018a)

Fish species	Habitat type	Life-cycle stage	Season	Water velocity	Water depth	Substratum
Thymallus thymallus L.	TTA	Adults	All	Moderate to high (0.7 to 1.1 m/s)	High (100-140 cm)	Medium to fine-grained substratum
	TTS	Spawning	Spring (January-April)	Very low (0.2 to 0.4 m/s)	Low to very high (10 cm to 230 cm)	Fine-grained substratum
	TTJ	Juveniles	All	Moderate to high (0.7 to 1.1 m/s)	Moderate (50-80 cm)	Fine-grained to medium substratum
Hucho hucho L.	HHA	Adults	All	Moderate to very high (>0.7 m/s)	High (>100 cm)	Fine-grained to medium substratum
	HHR	Adults (pre-reproduction)	Spring (February-April)	High to very high (>1.0 m/s)	Moderate to high (30-150 cm)	Medium gravel to large stones
	HHJS	Spawning	Spring (February-May)	High to very high (>1.0 m/s)	Moderate (20 to 60 cm)	Medium gravel
		and Juveniles	All			
Chondrostoma nasus L.	CNS	Spawning	Spring (March to May)	High (1.0 to 1.5 m/s)	Moderate (20 to 40 cm)	Medium to fine-grained substratum
	CNL	Larvae	Spring	Low (0.5 to 0.7 m/s)	Low (5 to 10 cm)	Fine-grained substratum
	CNJ	Juveniles	All	Low (under 0.6 m/s)	Low (5 to 20 cm)	Coarse substratum
	CNAW	Adults	Winter	High (1.0 to 1.5 m/s)	High (1 to 2 m)	Variable substratum
	CNR	Adults (pre-reproduction)	Spring (February to May)	Low to very low (less than 0.7 m/s)	Moderate (20 to 40 cm)	Medium gravel to large stones
	CNAS	Adults	Summer	Moderate to high (0.7 to 1.5 m/s)	Moderate (20 to 50 cm)	Rock to gravel

3.3.2.2. Plant species

The standardized evaluation procedure to establish the ecological quality of a river as formulated by the WFD did not consider floodplain species such as plants. However, plant response to restoration measures may be faster than among fish when the source populations are close (White & Stromberg 2011) and plants are also good indicators of the overall ecological quality of the environment. Furthermore, plant species, unlike animal species, cannot escape recreational user pressure and user pressure can easily be estimated in recording damages. Pioneer and endemic plant species settling on gravel bars, such as the German Tamarisk *Myricaria germanica* L., are excellent indicators of the environmental flow dynamic of the Isar (Bill et al. 1997b; Bill 2000; Bill 2001). *Myricaria germanica* L. historically occurred in the Isar in Munich (Rädlinger 2012); the project *New Life for the Isar* aimed to enable the resettlement of the German Tamarisk (Binder 2010; Rädlinger 2012; Mahida 2013; Düchs 2014), since the plant is an indicator species of the good ecological status of alpine and pre-alpine rivers with gravel bar (Bill et al. 1997b; Bill 2000; Bill 2001). Moreover, since the plant is a emblematic indicator of the (pre)alpine waterscape (Rädlinger 2012), *Myricaria germanica* L. was used to investigate the socio-ecological quality of the river.

Myricaria germanica L, commonly named German Tamarisk or False Tamarisk, is an endangered species and indicator of the good ecological functions of (pre-)Alpine gravel bar rivers influenced by floods (Bill 2001). It is a pioneer shrub on sand to gravel bars. The False Tamarisk is a characteristic plant of the Natura 2000 habitat type 3230 “Alpine rivers and their ligneous vegetation with *Myricaria germanica*”. Historically, the false Tamarisk was found in almost all the (pre-)Alpine rivers in France, Italy, Germany, Austria, and Slovakia (Ellenberg 1996; Kudrnovsky 2005; Kudrnovsky 2011; INPN 2013; Kudrnovsky 2013b; Kudrnovsky 2013a; Kudrnovsky & Stöhr 2013) including the entire Isar until its mouth (Oberdorfer 1992; Bill 2001). In the 1950, False Tamarisk have been found near to the German museum in Munich (Rädlinger 2012). However, the current distribution is scattered throughout the Alps (Müller 1988; Weis 2007; Kudrnovsky 2013a; Schneider 2013) and a vital population at the Upper Isar remains (Bill et al. 1997b; Bill 2001; Kudrnovsky 2005; Weis 2007). The main threat for the species in the Isar is the heavy morphological changes caused by flood protection infrastructure and hydro-electrical production (Bill et al. 1997b; Staffler 1999; Werth et al. 2014). The plant has a high degree of regenerative ability and settles on gravel bars of natural and dynamic rivers with continuously altered sites and repeatedly shifting gravel banks (Bill 2000).

3.3.3. Physical aquatic characteristics of the river

The physical habitat quality for a fish species is mainly determined by three physical river characteristics: substratum, velocity, and water depth (Bovee 1982; Heggenes & Traaen 1988). To investigate the quality of the aquatic habitats for the targeted fish species, these three physical river characteristics were collected.

The substratum properties were determined by field measurements performed in summer 2014. At mean low discharge (22.6 m³/s) low depth, and clear water enabled performance of a classic survey procedure by boat. Substratum types were visually distinguished on the basis of the grain size of the dominant component on a five meters grid (N = 1,628). Nine classes of substratum have been identified: 1) organic matter or detritus; 2) silt, clay, or loam; 3) sand (<2 mm); 4) fine gravel (2–6 mm); 5) medium gravel (6–20 mm); 6) large gravel (2–6 cm); 7) large stones (6–12 cm); 8) boulders (>20 cm); and 9) rock or concrete. Substratum properties were assumed to be constant over time and were digitalized using SMS 10.

Subsequently, the one-meter accurate morphological model based on the Masterplan of the restoration projects and used for prior implementation of the restoration project to simulate a very high discharge flood event (1,100 m³/s) was used to establish a 2D hydromorphological model with these three river characteristics (velocity, water depth, substratum) for the eight kilometers of restored Isar river reach, namely from *Großhesseloher Bridge* (48° 4'29.59"N, 11°32'25.83"E) to *Museum Island* (48° 7'41.42"N, 11°34'46.88"E). The resulting two-dimensional hydrodynamic-numerical model enabled simulation of the spatial distributions of water depths and flow velocities for the investigated discharges flowing inside the riverbed using Hydro_AS-2D (version 3). The model solved the shallow-water-equations using the finite-volume-discretization. The simulated scenarios were: minimal water volume of 5 m³/s; low discharge (NQ = 12 m³/s); mean low discharge (MNQ = 16.5 m³/s); minimal water volume of 17 m³/s; annual mean discharge (MQ = 63.8 m³/s); annual mean maximum discharge (HQ1 = 350 m³/s); biennial mean maximum discharge (HQ2 = 405 m³/s); 5-year maximum discharge (HQ5 = 550 m³/s); 10-year maximum discharge (HQ10 = 650 m³/s); 50-year maximum discharge (HQ50 = 880 m³/s); and 100-year maximum discharge (HQ100 = 1,050 m³/s).

The software SMS (Surface Modelling System, Aquaveo, USA) was applied to generate a five meter grid and simulate data.

3.3.4. Reintroduction of Myricaria germanica

Myricaria germanica L. disappeared in the study area in the 1920s (Rädlinger 2012). The nearest known remaining population is around 30 km upstream and separated from the study area by four weirs. Even if seed propagation by wind was possible by anemochory (Bill et al. 1997a; Bill 2000), it remains unlike that seeds would land in appropriate substrate and area. Research showed that wind propagation remains near to the mother plant (< 100 m) (Lener 2011; Lener et al. 2013). The main effective method of propagation is by water (Bill 2000; Werth et al. 2014). However, studies showed that weirs cause population isolation (Werth et al. 2014). According to this context, natural resettlement remains unlikely and in this study, a man-made reintroduction was performed.

Characteristics of a suitable meso-habitat were defined using local literature resources (Müller 1988; Kiem 1992; Oberdorfer 1992; Petutschnig 1994; Ellenberg 1996; Bill et al. 1997a; Bill 2000; Bill 2001; Kudrnovsky 2005; Weis 2007; Benkler & Bregy 2010; Lener 2011; INPN 2013; Kudrnovsky 2013b; Lener et al. 2013; Schneider 2013), expert knowledge (Prof. Egger of the WWF Auen-Institut Rastatt, KIT) and observations of the meso-habitats at three reference sites, where a naturally established population of *Myricaria germanica* L. remains: between Vorderriss and Krün (47°32’35.9’’N 11°22’10.6’’E), at Lenggries (47°44’19.1’’N 11°33’45.8’’E), and at the Pupplinger Aue (47°56’00.8’’N 11°26’13.6’’E). At the Isar in Munich, suitable habitats were supposed on fresh gravel bar with sand spots (Egger et al. 2010), areas located at the HQ1 flood line (Staffler 1999; Kammerer 2003; Schletterer & Scheiber 2008; Egger et al. 2010; Nikowitz 2010), existence of understorey vegetation, e.g. Salix eleagnos L. (Oberdorfer 1992; Ellenberg 1996; Jürging & Schauer 1998; Kammerer 2003), located around 0.2 to 0.4 meters above groundwater level (Ellenberg 1996; Egger et al. 2010), and with very low vegetation cover and high sun exposure (Bill et al. 1997b; Benkler & Bregy 2010; Lener 2011). The survey of the potential meso-habitats for *M. germanica* inside the whole restored stretch took place on March 22, 2014 while walking along the river. Eight sites have been defined as “suitable” to support the experimental reintroduction of *Myricaria germanica* L.

Two hundreds of seedlings have been produced for reintroduction in the Isar by Dr. Habersbrunner (BUND – Vorsitzender, Ortgruppe München West). The seeds were collected in September 2009 at the Pupplinger Aue (47°56’00.8’’N 11°26’13.6’’E) and planted in flower pots filled with substratum from the Isar (a mix of fine and medium grain substratum). After the first year, the plants did not receive any further care, e.g. no watering. Five years after planting, 27 seedlings remained. The experimental procedure was approved by the local authorities on May 10, 2014 and the transplantation of those plants was conducted on May 11, 2014. To date, the approximately 30 centimeter high plants were mature, already had flowered the year before but were in poor condition (Figure 10). The planting protocol followed the method described by Egger et al. (2010) and the standardized watering protocol has been described in Paper C. In order to investigate the influence of the recreational user pressure on *Myricaria germanica* L. reintroduction, the plants have been randomly transplanted in two areas with different user pressure intensity: one near to the southern limit of the city (48°7'39.49"N, 11°34'44.82"E), where user pressure was moderate, and another near to the city center (48° 4'47.70"N, 11°32'31.52"E), where user pressure was high. To document the results of the reintroduction over the long-term, the survivor rate, the cause of death, the length of each stream, the number of buds, the existence of flowers, and marks of damage were documented in detail over four years: each second weekend during the first year, once a month in the second year, every two months and after major flood events in the third and fourth years. To compare the similarity of the sites, abiotic factors were recorded. The temperature at 20 cm of the soil surface and light intensity and duration was recorded during the first summer with Logger HOBO Pendant ® Temp/Light 64 K. The soil moisture was visually estimated by measuring the distance between the surface and the first wetted soil shape during the monitoring procedure at five randomly chosen points inside the experimental areas. No significant differences of lightness and soil moisture between the two sites were found in the first year.

Figure 10 ***Myricaria germanica (*****L.*****) Desv*** **reintroduced in the Isar River in Munich, Germany (Aude Zingraff-Hamed, May 2014)**

3.3.5. Recreational user pressure

To evaluate the recreational pressure (type and intensity) and its influence on habitats for fish and plant species, two types of on-site user inventory were performed. Two types of riverine recreational activities have been identified: water-based from May to October, e.g., boating and swimming, and land-based throughout the year, e.g., sunbathing, walking, and cycling (Zingraff-Hamed 2011). In accordance with common practices in recreational intensity studies (Eagles & McCool 2002; Clivaz 2013; Pander & Geist 2013; Rupf & Wernli 2013; Lupp et al. 2016; Riera et al. 2016), user pressure was evaluated by counting users on a limited number of sampling days.

First, the transversal distribution of the users and the temporal variation of the density during the day were investigated by counting users inside two 200-meter wide cross sections. Investigating the influence of users on aquatic habitats and pioneer species on gravel bars, the transversal section extended from the middle of the water course to the beginning of the woody vegetation. Users were counted during eleven sunny summer days, every 40 minutes, and for 20 minutes in order to include users crossing the areas. The number of users, the activity of each of them and their locations (on the gravel bar, inside pioneer vegetation, inside the shrub vegetation, or on paths) were recorded. The counting procedure took place between 10 a.m. and 21 p.m.

Second, the longitudinal distribution of the users and the seasonal variation of the density were investigated by counting users along the eight kilometers of the restored river over 10 days (three during spring, three during summer, three during autumn, and one during winter). To estimate the maximal pressure, counting took place during sunny, non-working days between noon and 3 pm. All the recreational users encountered while walking along the river were counted differentiating land-based and water-based activities in 10 meter intervals.

3.3.6. The habitat suitability model

Physical habitat suitability of the wetted area for targeted fish species was modeled using the interface CASiMiR-fish (Schneider et al. 2010; Noack et al. 2013). CASiMiR software was designed to determine the suitability of aquatic habitats for selected indicator species using hydraulic and morphological characteristics (Schneider et al. 2010; Noack et al. 2013), namely the three main parameters that determine fish habitat preferences (Bovee 1982; Heggenes & Traaen 1988): temporal and spatial variability of water depth, flow velocity, and bed substrate type.

The multivariate fuzzy logic approach used by the software to link these abiotic attributes with the habitat requirements of fish is based on descriptive physical properties as formulated in terms of linguistic categories, i.e., *very high*, *high*, *medium*, *low*, and *very low* and has proven to be an excellent modeling technique for ecological purposes (Salski 1993). The physical limits of the linguistic categories for each investigated fish species were based on the literature. The influence of the interactions between the variables on the habitat suitability has been described by fish biologists during direct interviews. The resulting fuzzy rules set a description of the habitat requirement for each fish species and habitat types were presented in Table A3 and A4 (supplementary material).

To investigate the influence of the recreational uses on fish habitat availability, user density was classified into five ranks, i.e. *very high*, *high*, *medium*, *low*, and *very low*, to enable the integration of this variable into the CASiMiR modeling procedure. A user density map was digitalized using SMS 10 and was added as an additional parameter into the input of the modeling procedure. Given that there is little published information available on the behavior of fish, and particularly for *Chondostroma nasus*, when facing man-made recreational stressors such as walkers, swimmers, and large groups of humans on the embankment, the physical limits of the categories of the user pressure were based on expert knowledge. The accuracy of the model was assessed for the common nase simulating the habitat suitability of the wetted area of a near Isar section with existing fish population.

The outputs of the model were threefold: (a) Habitat suitability maps, which inform in a graphical way about value of the habitat suitability index (HSI) of each element of the hydromorphological grid (five meters elements). The HSI values vary between 0 and 1: between 0 for the most unsuitable habitat and 1 for the most suitable habitat. It is the most common index for describing biological responses to abiotic attributes and represents the suitability of a habitat for a target species and a specific life stage (Noack et al. 2013). (b) Tables listing the surface of wetted area for each HSI value. (c) Tables listing the weighted usable area (WUA) and hydraulic habitat suitability index (HHS) for each scenario. Both the WUA and the HHS represent functions that relate the habitat suitability to the flow regime but HHS values eliminate the influence of the area under water and enables a direct comparison between scenarios with different discharge (Jorde 1996). Afterwards, 200 elements of the habitat suitability maps were randomly chosen to perform a statistical comparison test. Highly suitable habitats were defined as those with an HSI value up to 0.6.

3.3.7. Analysis

To investigate the conflict between ecological restoration and human uses of the river restoration focusing on urban areas, we first estimated the potential conflicts between recreational users and habitats (periodically flooded and aquatic) for sensitive species, then analyzed the spatial distribution of conflicts, and finally examined the conflict for the water volume between hydro-electrical production and aquatic habitat suitability. The output data and experimental data were analyzed using R version 1.31.3. All analyses were considered statistically significant for $p < 0.05$.

Sharing the space between recreation users and sensitive species

The investigations on the conflict between recreational uses and habitat suitability for target species were performed separately for plant and fish species. To investigate the impact of recreational uses on *Myricaria germanica* L., the Welch test to compare survivor rate and user number and type was applied between two sites with different user intensity (Mc Donald 2014). To investigate the impact of recreational uses on fish habitat suitability in the case of *Chondostroma nasus* L., we performed a model analysis adding the recreational pressure to the CASiMiR physical habitat suitability modeling tool. The model was run for 108 scenarios (six habitat types, nine discharges, and two modalities). First, a descriptive analysis of the model output was performed. Then, a comparative analysis between scenarios with and without recreational pressure using the Mann-Whitney-Wilcoxon and Ansari-Bradley test (Mc Donald 2014) were performed on the HSI values of 200 randomly chosen elements of the mesh. Finally, in order to spatially define potential conflicts and investigate the success of management measures, such as user distribution modifications, we analyzed the users and habitat suitability maps.

Sharing the resource between humans and fish species

The CASiMiR habitat suitability modeling procedure was run to investigate the influence of the quantity of water available for the aquatic habitat on the quality and quantity of the suitable physical habitats. The physical habitats were simulated for a) discharges from 5 (pre-restoration minimal water flow agreement) to 68.5 m^3/s (natural water flow) and b) four scenarios: 5, 12, 17 m^3/s of minimal water flow and no diversion. The WUA, HSI, and HHS values have been compared using Kruskall-Wallis rank test and pairwise comparisons using t tests with pooled standard deviance.

4. Results

4.1. Understanding river restoration

4.1.1. River restoration practices (Paper A and B)

River restorations in France and Germany had various project motivations, multiple restoration goals (Figure 11), and a broad spectrum of implemented measures. However, two restoration goals were significantly mentioned more often during the interviews: improvement of the ecological quality of the river (79%) and improvement of the riverine recreational potential (76%). Projects aiming at the ecological improvement of the rivers commonly intended to improve their hydromorphological quality. The improvement of the water quality was surprisingly the least common restoration goal.

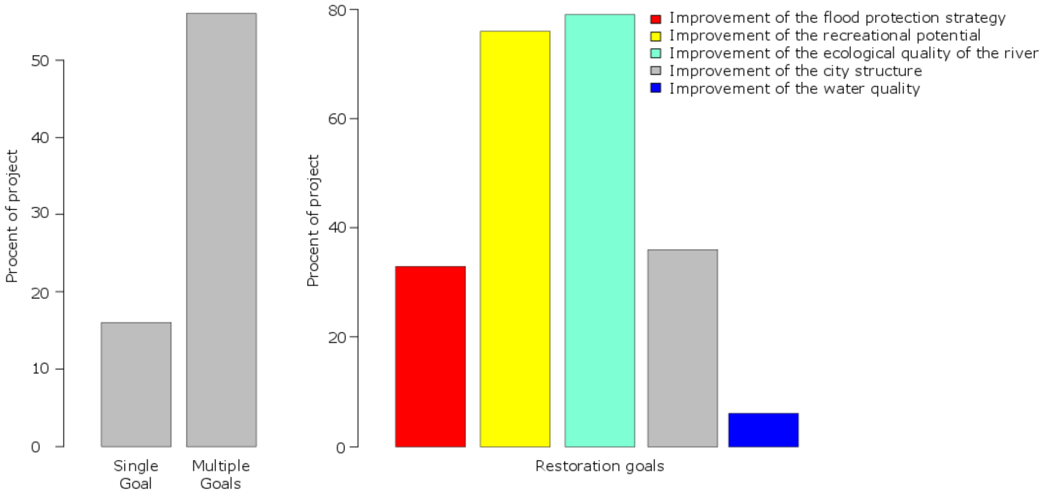

Figure 11 Proportion of the river restoration projects with single or multiple goals (left) and distribution of the goals (right) Plot produced with Dataset 1, namely rural and urban projects in France

Interviewees were questioned about the existence of river restoration projects and mentioned projects had a wide variety of labels, e.g. *restoration* (37%), *reclamation* (17%), *daylighting* (7%), *rehabilitation* (4%). Comparison of implemented measures showed that projects differences were substantial and partly related to the project label. While projects labeled *restoration* focused mostly on the ecological restoration of the hydromorphological structure of the river and on the reestablishment of the longitudinal connectivity, projects with another label, e.g. *reclamation*, were more comprehensive, integrating social and ecological goals (Figure 12).

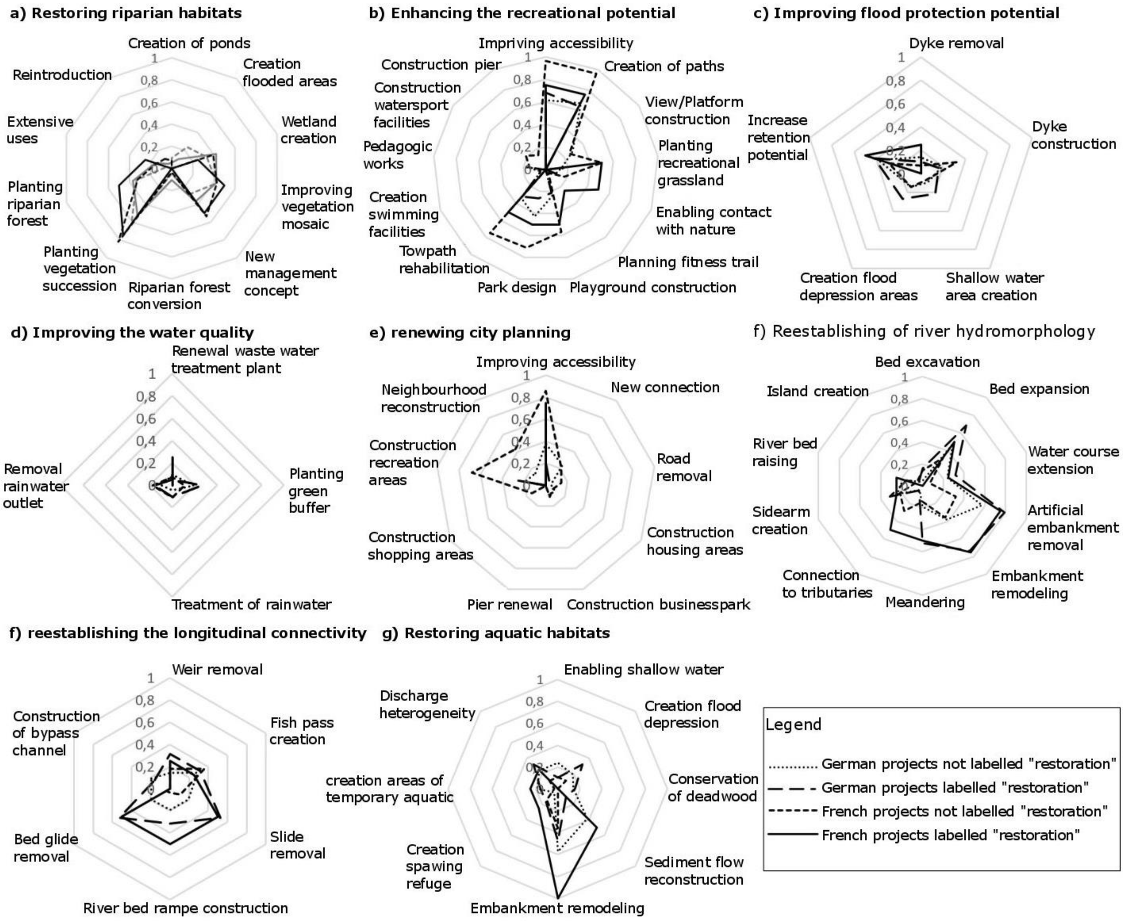

Figure 12 Frequency of implementation of the restoration measures regarding restoration goals, title of the project and the country where the project was implemented
(published in Zingraff-Hamed et al. 2017b)

From the hierarchical clustering analysis of 110 river restorations in France, five different river restoration types were defined and labelled *Fish RR*, *WFD RR*, *Blue RR*, *Flood protection RR*, and *Human RR* (Figure 13). All variables investigated were involved in the clustering procedure but the restoration goals and the project motivation differentiated most between the different project types (Figure 14 and Table 6). *Fish RR* were the most frequent (40%) and aimed the longitudinal restoration of the river intending to reestablish the migration potential for fish, for example, removing weirs and dykes. *WFD RR* were almost as frequent as *Fish RR* (38%) and were initiated to implement the Water Framework Directive, covering a broad spectrum of measures but focusing on aquatic zones, e.g. restoring aquatic habitats, improving hydromorphology and longitudinal connectivity. *WFD RR* were unlike *Fish RR* since they were comprehensive, aimed at both longitudinal and transversal improvement of the aquatic zone and restoring longer sections of the rivers. *Blue RR* (6%) were initiated to restore aquatic habitats, improving the river hydromorphology through measures such as river course and riverbed remodeling. *Blue RR* can be distinguished from *WFD RR* by both the year of implementation, namely before 1999, and the lack of monitoring procedure to evaluate the success and failure of the project. *Flood protection RR* (5%) were the most expensive and aimed at improving flood protection using nature-based solutions, as for example the design of new flood release zones. These projects also increased the riverscape esthetics, and the recreational potential of the riverine area but may include expensive land acquisitions and even the relocation of residents. Finally, *Human RR* (11%) were initiated to improve the quality of life for citizens and were comprehensive, focusing on both social goals (e.g. improving the riverscape, the recreational potential, and the city structure) and ecological goals (e.g. improving habitats). While *WFD RR*, *Fish RR* and *Blue RR* focused on aquatic areas, *Flood protection RR* and *Human RR* focused on riparian areas. Interestingly, three-fifths of the project types and 54% of the river restoration projects were comprehensive, namely combining social and ecological goals and measures.

Table 6 Main project-type characteristics and context (rural and /or urban) to which project types are associated (at p < 0,05). (published in Zingraff-Hamed et al. 2017a)

Project type	Type label	Main characteristics	Localization
1	*Fish RR*	Projects a) are initiated to reestablish the migration potential for fish, b) focus on the reestablishment of longitudinal connectivity, and c) are short (mean project length: 960 meter).	Rural
2	*Blue RR*	Projects a) are initiated to improve the ecological status of the river, b) were implemented before the WDF came into force, and, c) aim for the restoration of (sensitive) habitats and the reestablishment of the longitudinal connectivity.	Rural
3	*WFD RR*	Projects a) are initiated to implement the WFD, b) aim for the restoration of aquatic habitats, the reestablishment of longitudinal connectivity and near natural patterns of river morphology, and c) implement an evaluation procedure according to WFD expectations.	Rural and urban
4	*Flood protection RR*	Projects are initiated to improve the flood protection strategy.	Urban (rural)
5	*Human RR*	Projects a) are initiated to improve the quality of life for citizens, b) aim for the restoration of riparian habitats, the integration of the river into city structures, the improvement of the esthetics of the riverscape, the enhancement of the recreational potential at the river, and ecological improvement, and c) are long and expensive.	Urban

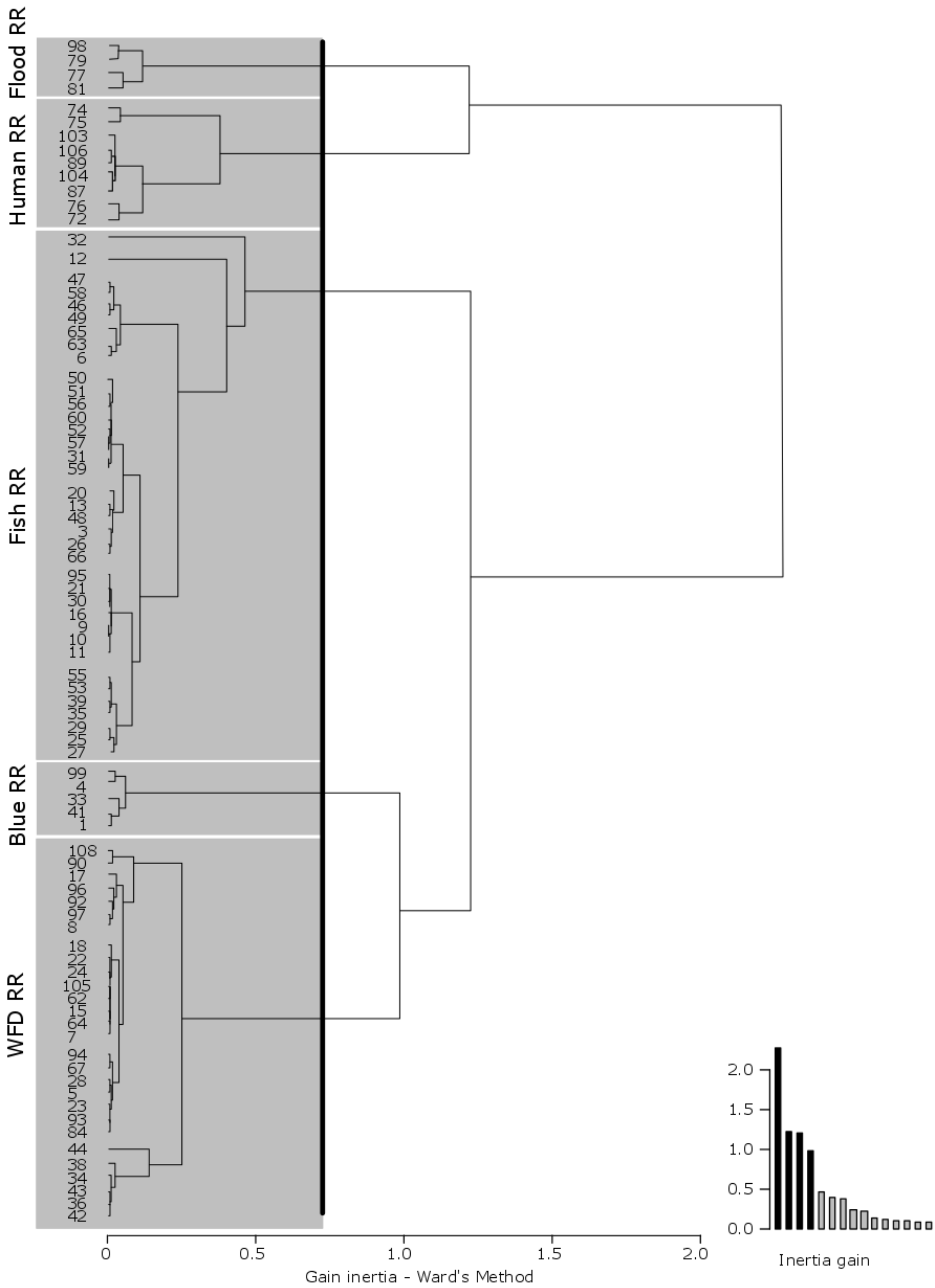

Figure 13 Hierarchical Multiple Factor Analysis classifying the project into 5 project types. This classification is based on 8 themes: project motivation, restoration goals, project dates, size, costs, annual mean discharge, evaluation procedure, and sources of funding.

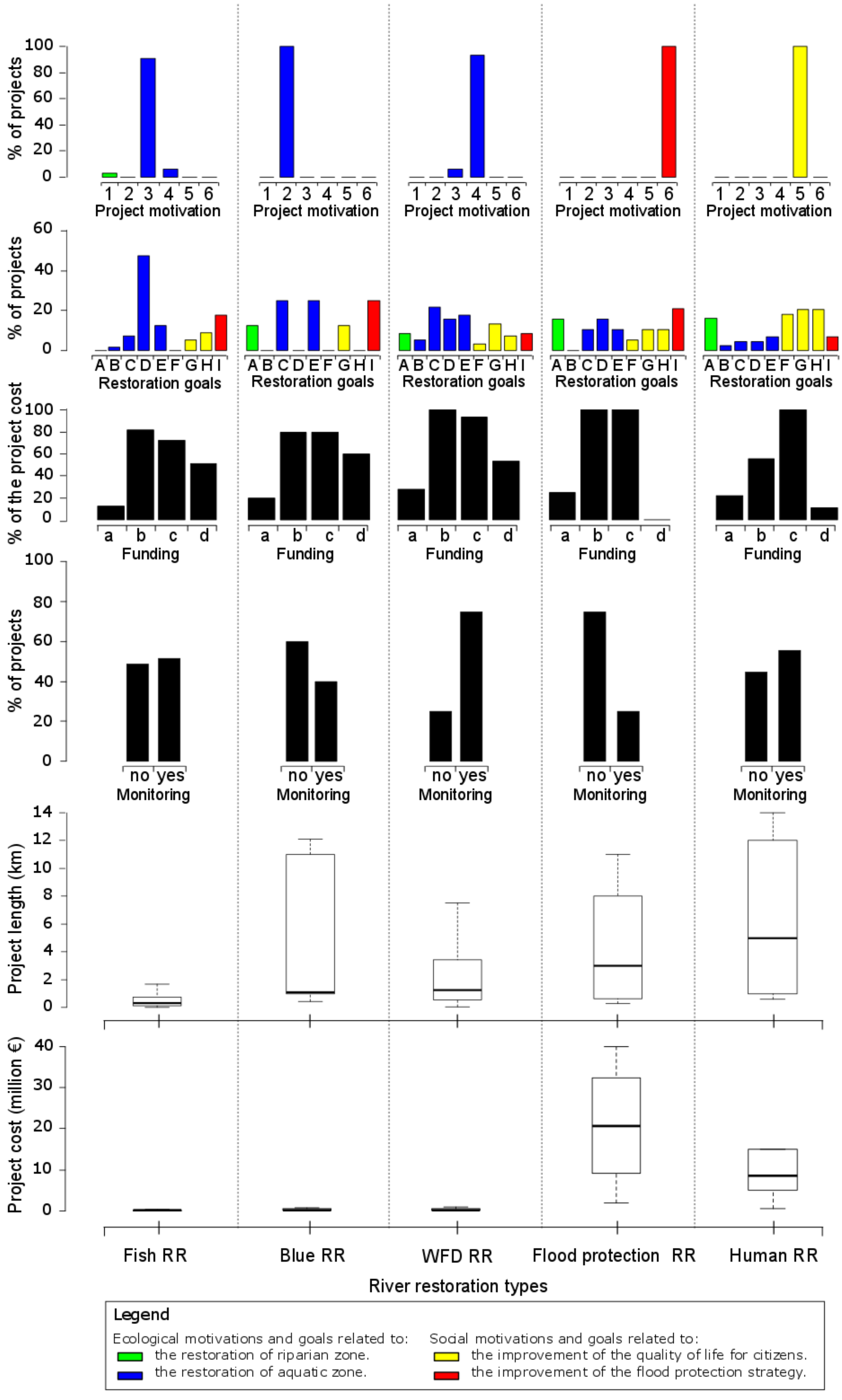

Figure 14 Description of the main variables for the five types of river restoration project
1: Nature conservation (Natura 2000); 2: Reestablishment of the migration potential for fish; 3: Improvement of the flood protection management strategy; 4: Restoration of (sensitive) habitats; 5: Improvement of the quality of life for citizens; 6: Implementation of the WFD; A: Restoring riparian habitats; B: Improving the water quality; C: Restoring aquatic habitats; D: Reestablishing the longitudinal connectivity; E: Reestablishing near natural patterns of the river hydromorphology; F: Integrating the river into city structures; G: Improving the esthetics of the riverscape; H: Enhancing the recreational potential of the river; I: Improving flood protection potential; a: European Union; b: State and Water Agency; c: City government; d: Non-governmental organization

(published in Zingraff-Hamed et al. 2017a)

4.1.2. Urban river restorations (Paper A)

More than the half of French cities with more than 100,000 inhabitants (62%) implemented a river restoration project (N=33). It was more than previously recorded by the ONEMA and Riverwiki. The ONEMA database recorded 11 French urban river restorations and only one of these was located in a major city. RiverWiki recorded (consulted the 05.18.2017) 38 French river restorations; four of them were designated as urban river restorations.

Comparison between French rural (N=67) and urban (N=44) restoration projects implemented between 1980 and 2015 revealed that urban river restorations incurred higher expenses (URR median cost per meter: €885 compared to €95), restored longer river sections (median project length: 2 km compared to 0.7 km), and bigger rivers (annual mean discharges: on average 87.70 compared to 14.84 m^3/s) than their rural counterparts. Owner and source of funding also differed with the context (rural or urban) of the project. Surprisingly, while restoration in rural contexts focused on the ecological restoration of the aquatic zone, urban projects combined social and ecological goals (Figure 15) and restored both riparian habitats and aquatic zones (Table 7 and Figure 16). Considering the five types of restoration presented above, *Flood protection RR* and *Human RR* were mostly implemented in urban contexts and *Fish RR* in rural contexts (Table 6). No significant differences were found for *Blue RR* and *WFD RR*. Moreover, no differences were found concerning the implementation of an evaluation procedure based on monitoring tools. In both contexts, less than 50% of the success of the restorations have been evaluated with metrics (all type of metrics were considered).

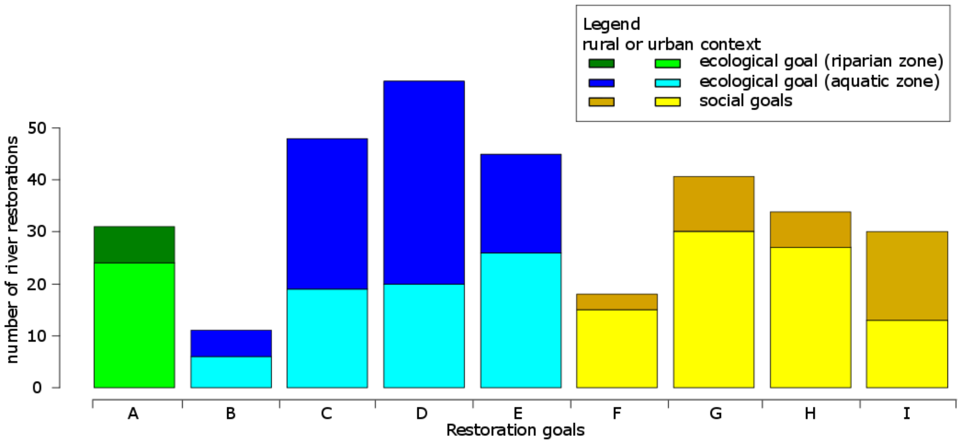

Figure 15 Distribution of the projects within each restoration goal considering their rural or urban context
A: Restoring riparian habitats; B: Improving the water quality; C: Restoring aquatic habitats; D: Reestablishing the longitudinal connectivity; E: Reestablishing near natural patterns of the river hydromorphology; F: Integrating the river into city structures; G: Improving the esthetics of the riverscape; H: Enhancing the recreational potential of the river; I: Improving flood protection potential. (published in Zingraff-Hamed et al. 2017a)

Table 7 Main differences and similarities (at p < 0,05) between rural and urban river restoration projects considering main project characteristics
(published in Zingraff-Hamed et al. 2017a)

Theme	**River restoration characteristics that are specific to:**		**River restoration characteristics found in both contexts (rural and urban)**
	Rural context	**Urban context**	
Project motivation	Reestablishment of the migration potential for fish	Improvement of the quality of life for citizens	Implementation of the WFD Improvement of the flood protection management strategy Nature conservation (Natura 2000) Restoration of (sensitive) habitats
Restoration goals		Restoring riparian habitats, Improving the esthetics of the riverscape Enhancing the recreational potential of the river Integrating the river into city structures	Restoring aquatic habitats Improving flood protection potential Reestablishing the longitudinal connectivity Improving the water quality Reestablishing near natural patterns of the river hydromorphology
	Projects have less than three goals	Projects have more than three goals	
	Projects rarely (24.6%) combine social and ecological goals	Projects often (60.5%) combine social and ecological goals	
River characteristics	Low annual mean discharges (on average 14.84 m³/s)	High annual mean discharges (on average 87.70 m³/s)	
	Restored natural river	Restored mostly HMWB	
Project costs	Median cost per meter of €95	more expensive (median cost per meter of €885)	
Funding	20.7% NGO funding 20% E.U funding	4.4% NGO funding 2% E.U funding	Local and national funding
Project size	Project median length 0.7 km	Project median length 2 km	
Evaluation procedure			Less than 50% of the projects

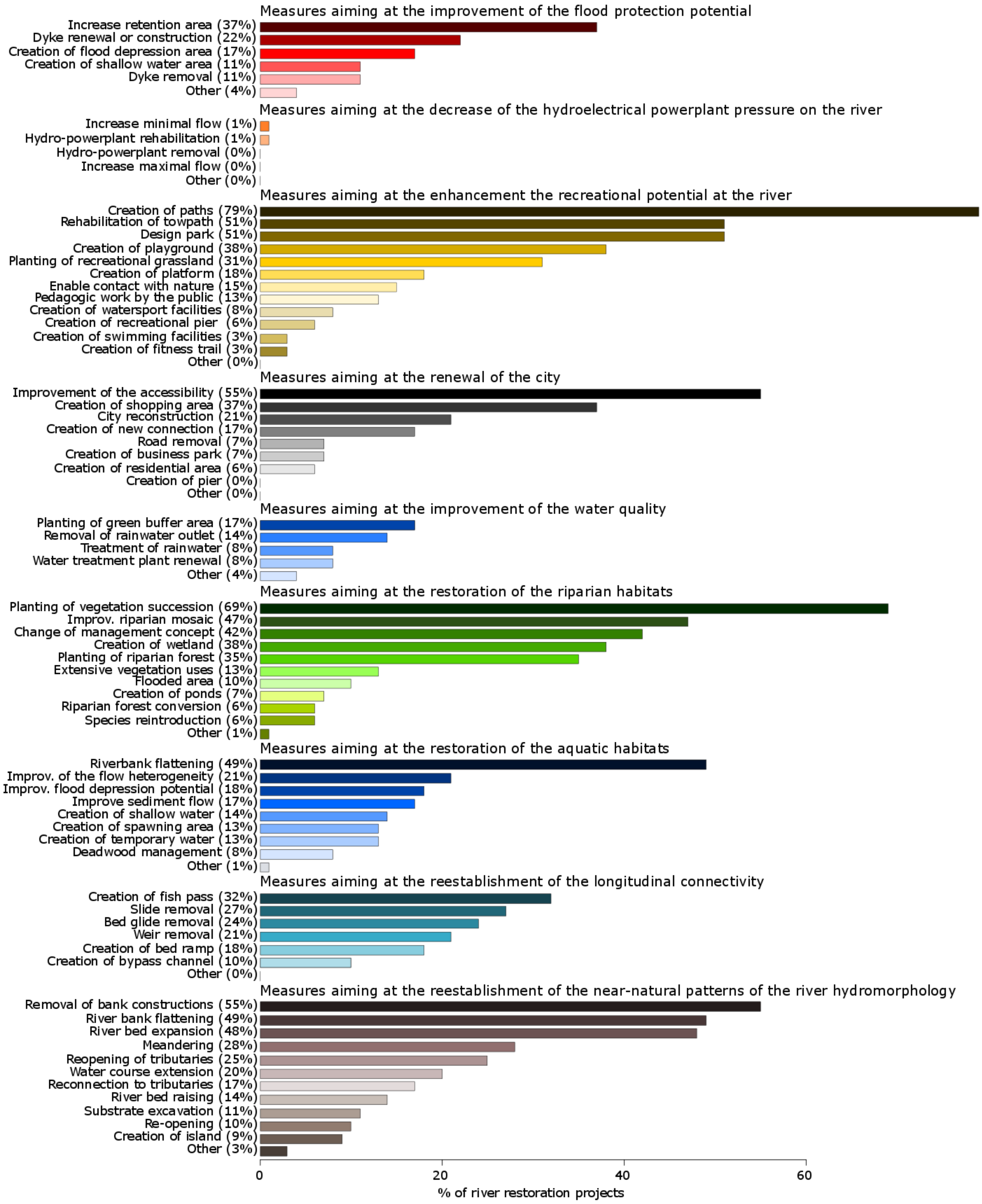

Figure 16 List of implemented restoration measures, ordered by restoration goals and by percent of urban projects concerned.

4.1.3. Drivers of the restoration (Paper A and B)

80% of the French river restoration projects were initiated to improve the ecological quality of the river, namely 40% have been implemented to satisfy the demands of the WFD, 32% to improve the migration potential of fish species, 6% to improve the quality of aquatic habitats, and 2% to conserve Natura 2000 habitats (Figure 17). Most of the river restoration projects (>80% of the projects) have been implemented after 2000, namely after the WFD came in force. However, the need for ecological improvement was not the single driver of the restoration effort. We found that 16% of the river restoration projects have been implemented to improve the quality of life for citizens, and 4% to improve the flood protection potential. Furthermore, we found that at least 25% of the projects initiated to improve the ecological quality of the river intend to achieve social goals, e.g. improve the aesthetic of the riverscape and improve the recreational potential of the river.

Interestingly, a great difference in motivation between projects implemented in urban and rural context was found. While most of the projects initiated to improve the quality of life for citizens were implemented in urban areas, project initiated to improve the longitudinal connectivity of the river to improve fish migration were mostly implemented in rural context. The other drivers (policies and flood protection) influenced the restoration in similar proportion within both contexts.

Differences also existed between urban projects located in France and in Germany. The main difference between French and German urban projects was the project motivation (Figure 17). 60% of the German urban river restoration projects were initiated to implement the WFD, as opposed to only 26% of projects in France, and 19% in Germany stated another ecological reason, as opposed to 9% in France. The project motivation of the majority (55%) of the French urban river restoration projects was the improvement in the quality of life for citizens. The improvement of the flood protection potential initiated projects in both country in similar proportions: 12% of the projects in Germany and 10% in France. In both countries, few projects have been implemented before the WFD came in force: only 5 in France and 8 in Germany. At this time, half of the German projects and only one French project were implemented to improve the ecological quality of the river.

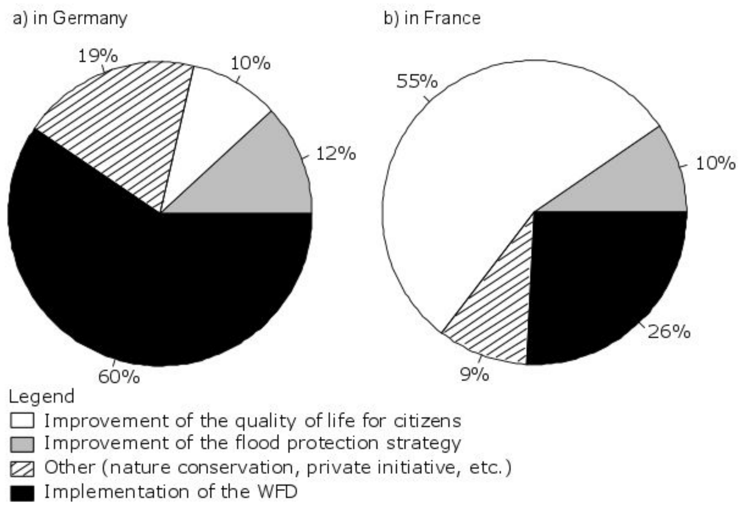

Figure 17 Pie chart of the main project motivations in each country (published in Zingraff-Hamed 2017c)

Projects were more often labelled *restoration* in Germany than in France. In both countries, projects labeled *restoration* intended to improve the physical habitats of the river. Projects with other labels differed from projects labeled *restoration* (Figure 10). The textual analysis of the short description of the restoration projects revealed that the relationship between the river and the city (as the citizen) was important in France (75% of the projects), while in Germany the projects were more often associated with the WFD (50% of the projects). The comparison of the morphological status of the rivers prior to restoration showed only one significant difference between the countries: in France 50% of the urban rivers were bordered by at highway or a road of national importance, while in Germany only 6% of the rivers involved this kind of infrastructure. However, road removal was not significantly more frequent in France than in Germany (Table 8).

Table 8 Synthesis of the differences and similarities between urban river restorations in France and Germany (published in Zingraff-Hamed et al. 2017b)

	River restoration characteristics that are specific to Germany	River restoration characteristics that are specific to France	River restoration characteristics found in similar proportion in both countries
Project motivation	Implementation of the WFD (60% of the projects in Germany)	Improvement of the quality of life for citizens (55% of the projects in France)	Improvement of the flood protection management strategy (10-20% of the project in both countries) Other motivations (10-20%)
Morphological status	Straightened channel (83%) Existence of highways or national roads along the riverbanks (6%)	Straightened channel (60%) Existence of highways or national roads along the riverbanks (50%)	Channelized (>87%) Impervious embankment (>97%) Impervious bed (66%) Longitudinal connectivity damaged (55-65%) Buried (13-16%) Navigable (20-27%)
Project date			Restoration boom after 2000
Project title	Restoration (51.2%)	Reclamation (18.7%), restoration (12.5%), or rehabilitation (9.4%)	
Discourse	Used of word pair River/WFD	Used of word pair City/River Importance of recreational goals	Mention of the WFD
Measures to improve the flood protection potential			Dyke removal Dyke renewal or construction Creation of shallow water area Creation of flood depression area Increase retention potential of the floodplain
Measures to improve the water quality			Construction of water treatment plant Planting of green buffer area Treatment of rainwater Removal of rainwater outlet
Measures to restore riparian habitats	Creation of flooded areas (18%) Planting of vegetation succession (58%)	Creation of flooded area (0%) Planting of vegetation succession (84%)	Creation of ponds Creation of wetland Improvement of the vegetation mosaic Change of the management concept Riparian forest conversion Planting of riparian forest Extensive uses of the riparian area Species reintroduction Invasive management

Measures to restore aquatic habitats	Deadwood management (15%) Improve the erosion or the sedimentation potential through morphological changes (25%)	Deadwood management (0%) Improve the erosion or the sedimentation potential through morphological changes (6%)	Riverbank flattening Creation of shallow water area inside the water course Creation of temporary water Improvement of the flow heterogeneity Improvement of the flood depression potential Creation of spawning area
Measures to reestablish near-natural patterns of the river hydromorphology	Removal of artificial bank constructions (68%) Connection of sidearm or tributaries (5%)	Removal of artificial bank constructions (39%) Connection of sidearm or tributaries (32%)	Substrate excavation River bed expansion Water course extension River embankment modeling Meandering Reopening of tributaries River bed raising Creation of island
Measures to renew city planning	Improvement of the accessibility (30%) Creation of shopping area (0%) Creation of recreational area (15%) City reconstruction (7%)	Improvement of the accessibility (87%) Creation of shopping area (13%) Creation of recreational area (65%) City reconstruction (39%)	Creation of new connection, e.g. bridge Road removal Creation of residential area Creation of business park Creation of pier
Measures to enhance the recreational potential at the river	Creation of paths (65%) Planting of recreational grassland (15%) Creation of playground (22%) Design park (35%) Rehabilitation of towpath (32%) Creation of watersport facilities (0%) Creation of recreational pier (0%)	Creation of paths (97%) Planting of recreational grassland (52%) Creation of playground (58%) Design park (71%) Rehabilitation of towpath (74%) Creation of watersport facilities (19%) Creation of recreational pier (13%)	Creation of platform Enable contact with nature Creation of fitness trail Creation of swimming facilities Nature protection and conservation pedagogic opportunities
Measures to reestablish the longitudinal connectivity	Bed glide removal (35%) Creation of bypass channel (17%)	Bed glide removal (9%) Creation of bypass channel (0%)	Weir removal Creation of fish pass Slide removal Creation of bed ramp
Measures to reduce pressures caused by hydropower plant			Increase residual water Decrease residual water Construction of hydropower plant Removal of hydropower plant

4.2. Assessment of social and ecological success

4.2.1. Conflicts between recreational uses and habitat suitability for target species

Three years after the reintroduction of *Myricaria germanica*, the overall survivor rate remained at 30%. However, the survivor rate was lower at the site with the high user density (21%) than at the site with the medium user density (38%). At both sites, the major loss occurred over the first summer (Figure 18). Plants were alive and showed frequent growth. After three years, the plants were flowering but no natural secondary establishments were found yet. No plant died because of unsuitable abiotic factors, e.g. dryness, competition or predation. Cause of death was related to flood events, and to the recreational pressure, e.g. plants were dug out. At the site with high user density, the likelihood of mortality by users was around 70%, while the likelihood of death by users in the site with medium user density was around 35%.

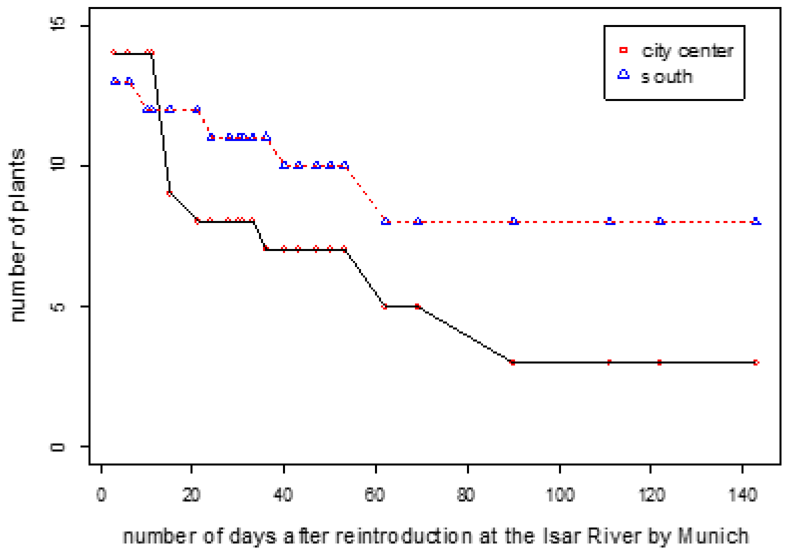

Figure 18 Graph of the temporal evolution of reintroduced *Myricaria germanica* (L.) Desv at each experimental site

At the restored stretch of the Isar river, high suitability occurred for four of the six habitats of *Chondostroma nasus* L. (Figure 19). For juveniles (HHS=0.39 to 0.29), pre-reproduction areas (HHS=0.27 to 0.19) and adults during the summer (HHS=0.27 to 0.25), the best suitability rates were found at low and mean discharges and when the recreational pressure was the highest. Suitable habitats for spawning activities and larval development were almost absent inside the restored stretch. Statistical analyses on 200 randomly chosen points showed that the quantity of suitable habitats and the habitat quality of the restored river section for *Chondostroma nasus* decreased when recreational pressure was integrated into the modeling procedure for three habitats, namely habitats for juveniles lost from 9 to 15.5% of the suitable area (Figure 20), habitats for adults spawning lost between 20 to 25% of the suitable area, and habitats for larvae lost between 71 to 76% of the suitable area, but no significant differences were found for the habitats for adults during the summer, the winter, and the pre-reproduction period.

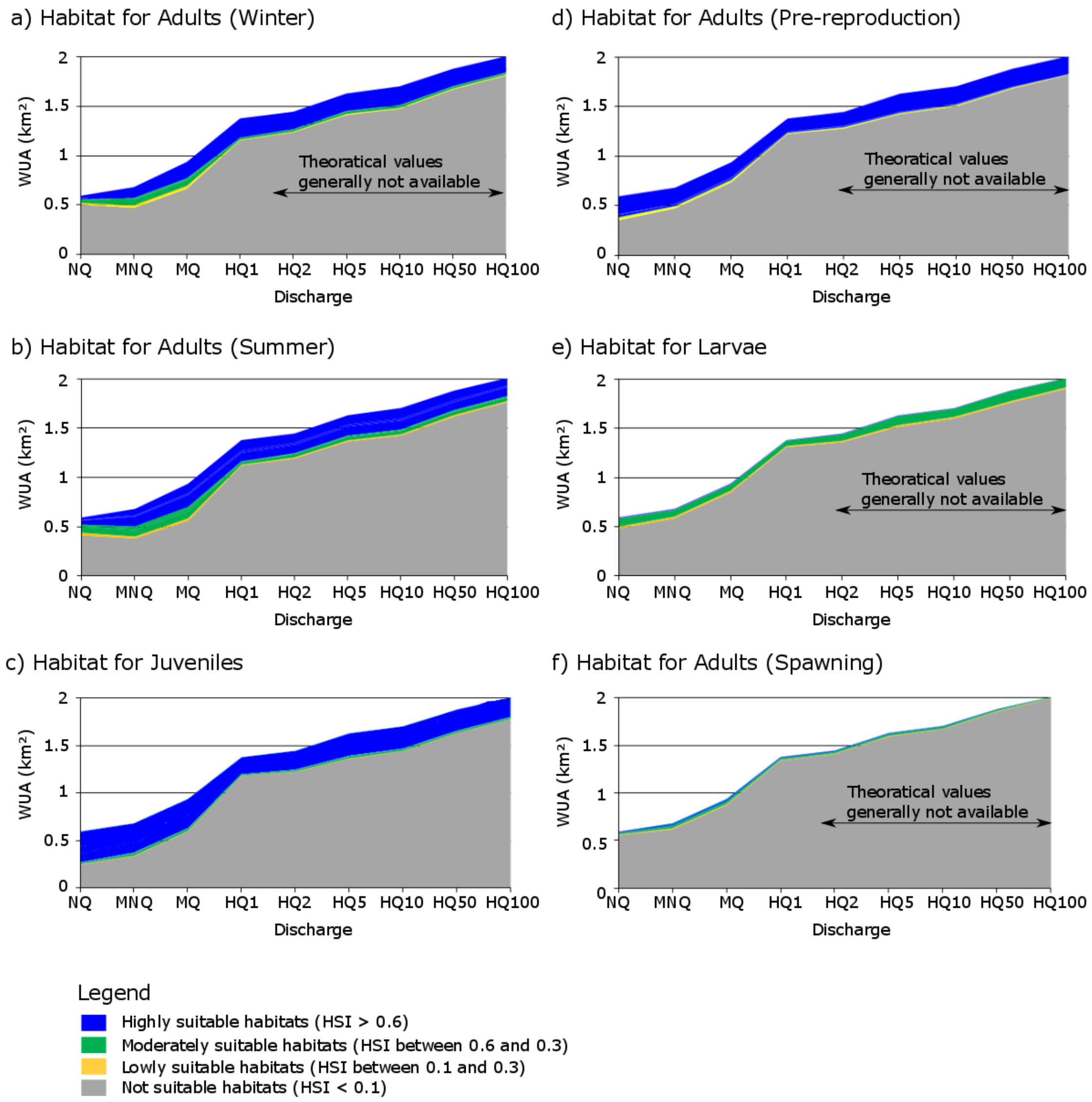

Figure 19 Weighted usable area a) for adults during winter, b) for adults during summer, c) for juveniles, d) for adults during the pre-reproduction period, e) for larvae, and f) for spawning adults
HSI: habitat suitability index, WUA: weighted usable area, NQ: minimum discharge (12 m^3/s), MNQ: mean low discharge (16.5 m^3/s), MQ: annual mean discharge (63.8 m^3/s), HQ1: annual mean maximum discharge (350 m^3/s), HQ2: biennial mean maximum discharge (405 m^3/s), HQ5: 5-year maximum discharge (550 m^3/s), HQ10: 10-year maximum discharge (650 m^3/s), HQ50: 50-year maximum discharge (880 m^3/s), HQ100: 100-year maximum discharge (1,050 m^3/s)
(published in Zingraff-Hamed et al. 2018b)

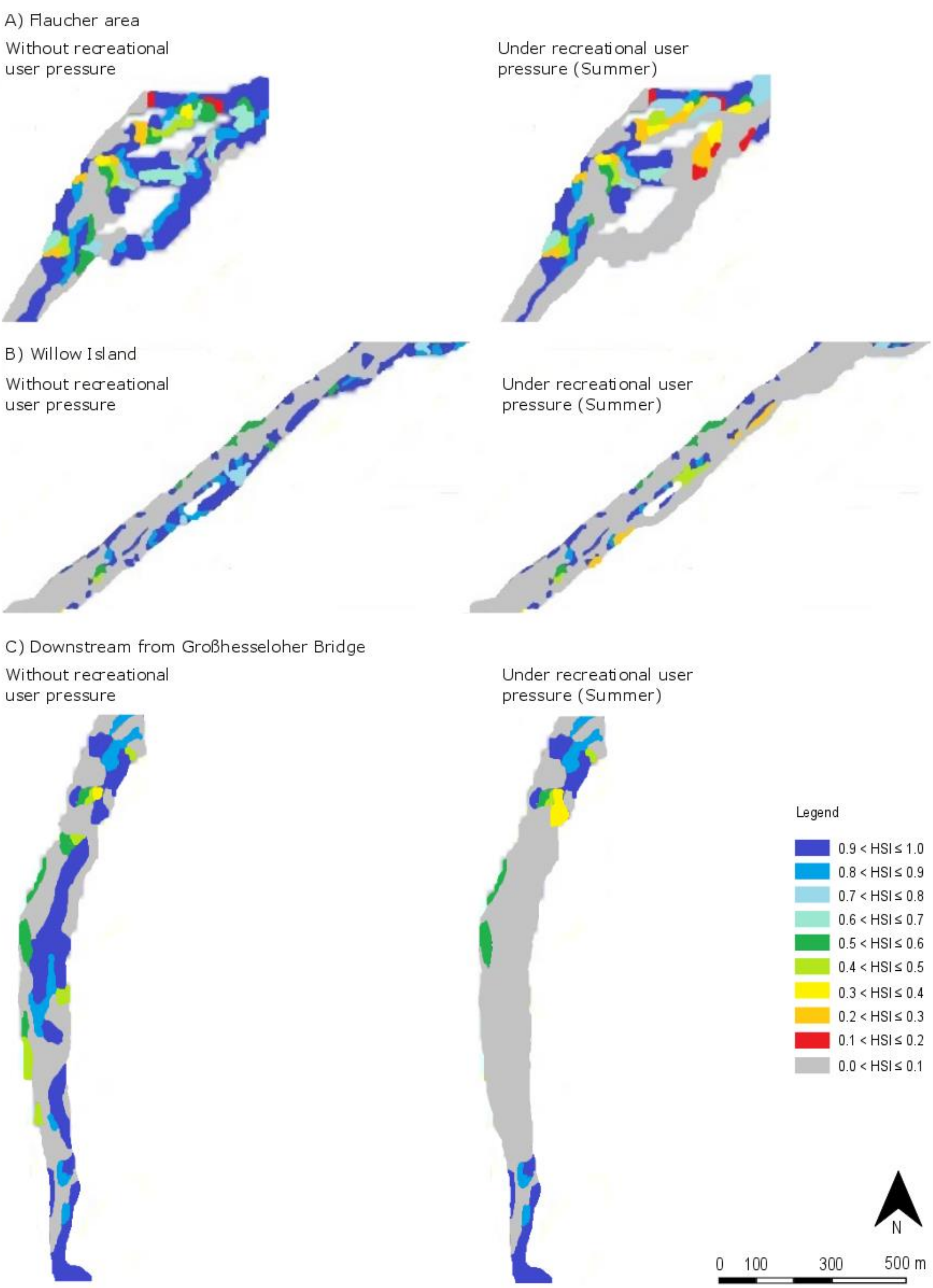

Figure 20 Habitat suitability map for juveniles of *Chondrostoma nasus* at mean annual discharge considering or ignoring recreational pressure
In the case of A) the Flaucher area, B) Willow Island, and C) the area near the Großhesseloher Bridge (HSI = Habitat Suitability Index)
(published in Zingraff-Hamed et al. 2018b)

4.2.2. Sharing the space between sensible species and recreational uses

We investigated the distribution of the suitable habitats for *Myricaria germanica* L. and *Chondostroma nasus* L. and compared their location with the recreational user distribution, density, and type of uses in the case of the restored Isar in Munich. The results were presented in Paper C and D. We found that spatial and temporal distribution of suitable habitats for sensible species partly matched with area and period with high user density.

Potential habitats for *M. germanica* occurred only at the eastern side of the river (Publication F: Scientific Report). The *Flaucher site*, the *Willow Island* and the 1,000m downstream from *Großhesseloher Bridge* were the best potential habitat for *Myricaria germanica* L. The habitat suitability model for *Chondostroma nasus* L. presented in Paper D showed that suitable habitats for adults during the winter and summer were mostly located at the west side of the river and in the southern two thirds of the restored stretch of the Isar in Munich (>80%). Especially, the *Flaucher* area had a high rate of highly suitable habitat. Areas with the lower suitability were upstream from weirs and the area surrounding the *Willow Island*. Habitats for juvenile and adult pre-reproduction periods occurred in the whole restored river stretch, but the *Flaucher* and the *Willow Island* areas had a higher density of spots with very high suitability (HSI>0.9). Suitable habitats for larval development and adult spawning were very rare, but a single spot with medium suitability (HSI from 0.4 to 0.7) occurred at the river bottom ramp.

Investigations of the recreational user distribution, presented in Paper C and D, showed that recreationists used the river intensely between mid-April to mid-September (Figure 21). Users in the northern part of the restored stretch of the Isar in Munich were walkers on paths (88%), users resting on gravel bars (10.5%), and bikers (1.5%). Users in the southern of the restored stretch of the Isar in Munich were mostly walkers on paths (41%), user resting on gravel bars (40%), and bikers (19%). Some of the users resting were also swimming (between 4 and 10%). User distribution was heterogeneous but concentrated at the eastern site of the study area. User density was higher at the *Willow Island*, the constructed stairs, the *Flaucher* area, the 1,000m downstream from *Großhesseloher Bridge*, and at the river bottom ramps (Figure 22). Investigations of the recreational user distribution inside the cross section of the river area showed that areas covered with pioneer vegetation, the typical habitat of *Myricaria germanica L.*, were used by less than 10% of the users and mostly as a form of lavatory. While users in the north were concentrated at paths and constructed stairs (almost 90%), users in the south were similarly distributed between the paths (48%) and the gravel bars (44%).

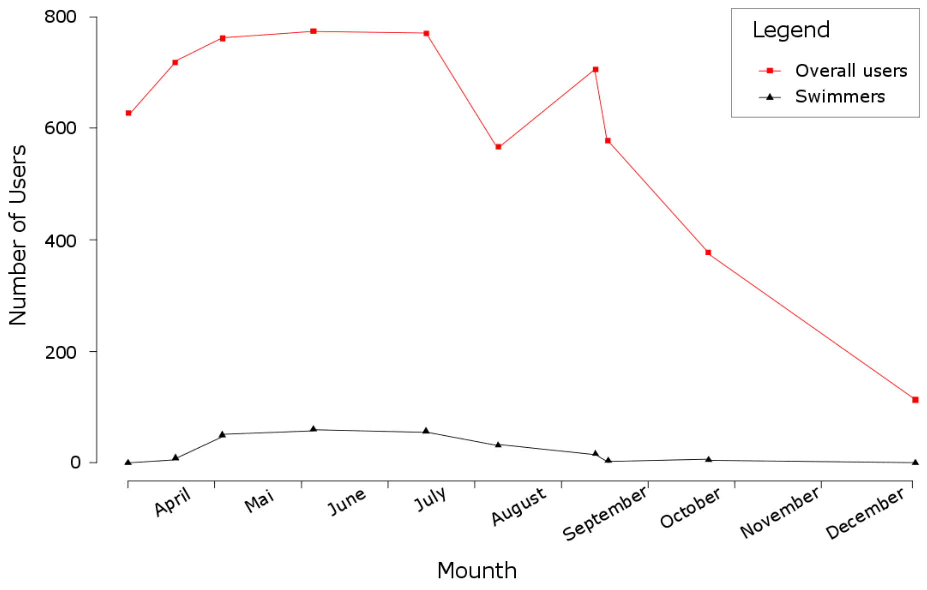

Figure 21 Cumulative user values for the entire Isar stretch over the ten investigated days. (published in Zingraff-Hamed et al. 2018b)

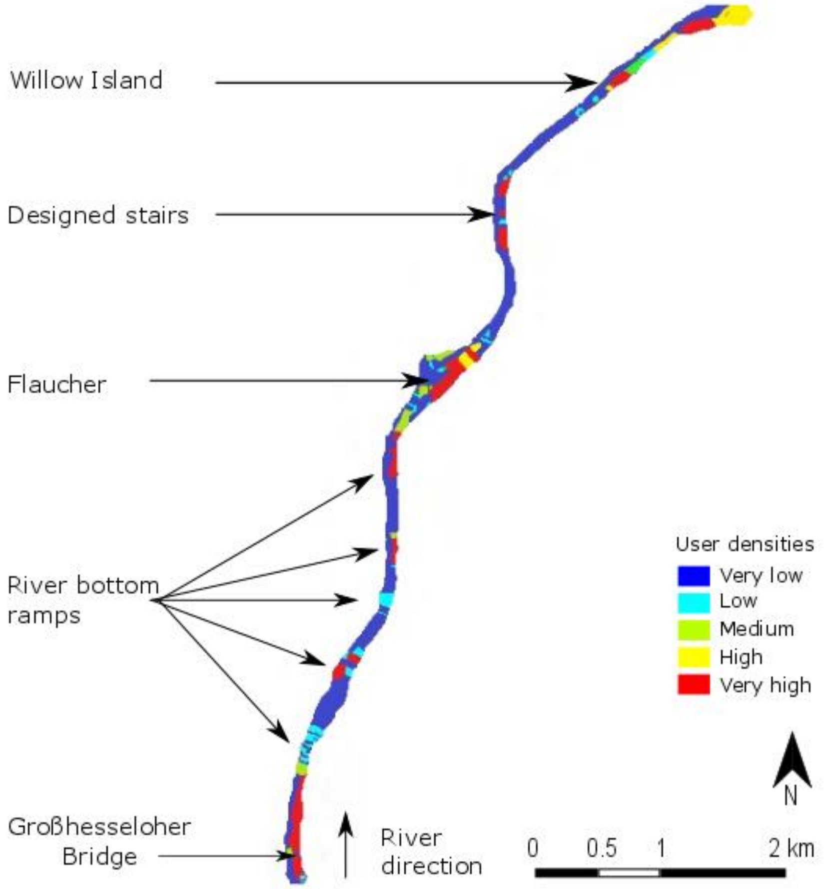

Figure 22 User density map of the Isar in Munich. (published in Zingraff-Hamed et al. 2018b)

4.2.3. Sharing water resources between hydropower production and fish

Scenario A, namely applying a minimum flow of 5 m^3/s into the river bed (situation before the restoration), is the best for three of the six habitats for *Chondostroma nasus* L.: habitats for larval development, juvenile growth and adults during the pre-reproduction period. All habitats of the other investigated fish species had the lowest suitability at this scenario (Table 9). Slight (scenario B) and medium (scenario C) increases in the minimal water flow, namely from 5m^3/s to 12 m^3/s or to 17 m^3/s, improves the habitat quality and quantity for all investigated fish species habitat types, except for juvenile and adults *Chondostroma nasus* L. during the pre-reproduction period. Habitat for larval development of *Chondostroma nasus* L. remained very low for all scenarios studied. All habitats investigated for *Chondostroma nasus* L. and *Hucho hucho* L. largely benefited more from medium than slight increase in the minimal water flow. Scenario D, namely without diversion, is the best only for adults *Hucho hucho* L., *Chondostroma nasus* L.

Table 9 Weighted Usable Area (WUA), Hydraulic Habitat Suitability index (HHS), and Mean Habitat Suitability Index value for each habitats and scenarios.
The best scenario for each habitat is highlighted. (to be published in Zingraff-Hamed et al. 2018a)

Habitat types	Indicators	Scenario A	Scenario B	Scenario C	Scenario D
***Thymallus thymallus* L.**					
TTA	WUA (1,000 m²)	183	274	**276**	233
	HHS	0.25	0.34	**0.29**	0.28
	Mean Habitat Suitability Index	Low	Low	Medium	Low
TTS	WUA (1,000 m²)	212	**255**	210	121
	HHS	0.29	**0.31**	0.22	0.14
	Mean Habitat Suitability Index	Low	Low	**Medium**	Very low
TTJ	WUA (1,000 m²)	229	**270**	222	128
	HHS	0.32	**0.33**	0.24	0.15
	Mean Habitat Suitability Index	Low	Low	Low	Very low
***Hucho hucho* L.**					
HHA	WUA (1,000 m²)	48	94	243	**384**
	HHS	0.07	0.12	0.26	**0.46**
	Mean Habitat Suitability Index	Very low	Low	Low	**High**
HHR	WUA (1,000 m²)	35	102	171	**277**
	HHS	0.05	0.13	0.18	**0.33**
	Mean Habitat Suitability Index	Very low	Very low	Very low	**Medium**
HHJS	WUA (1,000 m²)	31	79	**104**	88
	HHS	0.04	0.1	**0.11**	0.11
	Mean Habitat Suitability Index	Very low	Very low	**Low**	Very low
***Chondostroma nasus* L.**					
CNAS	WUA (1,000 m²)	72	167	241	**377**
	HHS	0.1	0.21	0.26	**0.45**
	Mean Habitat Suitability Index	Low	Low	Low	**Medium**
CNAW	WUA (1,000 m²)	30	100	182	**355**
	HHS	0.04	0.12	0.19	**0.42**
	Mean Habitat Suitability Index	Low	Low	Medium	**Medium**
CNR	WUA (1,000 m²)	**300**	277	207	118
	HHS	**0.42**	0.34	0.22	0.14
	Mean Habitat Suitability Index	**Medium**	Low	Low	Medium
CNJ	WUA (1,000 m²)	**341**	330	268	153
	HHS	**0.48**	0.41	0.29	0.18
	Mean Habitat Suitability Index	**Medium**	Medium	Medium	Low
CNS	WUA (1,000 m²)	11	27	32	**39**
	HHS	0.02	0.03	0.03	**0.05**
	Mean Habitat Suitability Index	Very low	Very low	Very low	**Low**
CNL	WUA (1,000 m²)	**60**	57	31	18
	HHS	**0.08**	0.07	0.03	0.02
	Mean Habitat Suitability Index	**Very low**	Very low	Very low	Very low

4.3. Research key findings

4.3.1. Understanding river restoration

- The restoration effort was composed of a great diversity of projects, with various project labels and motivations, multiple restoration goals, and a broad spectrum of implemented measures. However, five river restoration types were found in France: *Fish RR*, *WFD RR*, *Blue RR*, *Flood protection RR*, and *Human RR*. The restoration goals and the project motivations were the triggering variables differentiating the project types.
- Major differences existed between urban and rural river restorations. Urban projects were more comprehensive, combining social and ecological goals, rather than their rural counterparts, which focused on ecological goals, neglecting social function of the rivers and the restoration of the riparian zone.
- European policy, namely the Water Framework Directive have a major influence on the restoration effort. While the implementation of the WFD and the protection against flood risks were driving forces of both urban and rural projects, urban river restoration was also strongly driven by societal demand, e.g. the improvement of the quality of life. Interestingly, the WFD have more influence on the German that on the French urban restoration trend.

4.3.2. Conflicts between ecological success and human uses

- High recreational user density hindered the availability of the habitat for sensitive life stages of the targeted species, e.g. bud break and blooming, Spawning and Juvenile. Periods of high user density occurred during these critical life cycle stages.

- Spatial distribution of suitable habitats for sensible species partly matched with high user density. Potential suitable habitat for *Myricaria germanica* L. were located in areas with medium to high user density, but users preferred open gravel bar to closed area settled by pioneer species. Suitable habitats for spawning and larval development of *Chondostroma nasus* L. were very rare at the study area and matched with high user density area.
- Most of the aquatic habitats for fish benefited from a slight increase in the minimal flow, but change of discharge flowing into the river bed affected each habitat type differently. No one-size-fits-all scenario was found and interestingly, not all the studied endemic species or life-cycle phases will benefit from the historical discharges flowing into the current (post-restoration) river morphology.

5. Discussion

5.1. Restoration of the socio-ecological system

5.1.1. Characteristics and definitions of river restoration

Previous river restoration surveys showed that river restoration efforts are composed of a broad spectrum of practices (Bernhardt et al. 2005; Jenkinson et al. 2006; Nakamura et al. 2006; Bernhardt et al. 2007b; Brooks & Lake 2007; Kondolf et al. 2007; Aradóttir et al. 2013; Barriau 2013; Morandi et al. 2014). The wide range of restoration practices found in France and Germany is consistent with previously described trends in the U.S.A (Bernhardt et al. 2005; Kondolf et al. 2007), Australia (Brooks & Lake 2007; Fryirs et al. 2013), Iceland (Aradóttir et al. 2013), Brazil (Costa et al. 2010), Scotland (Gilvear et al. 2012), Korea (Kim et al. 2005), and Japan (Nakamura et al. 2006). This diversity suggests that river restoration efforts have multiple facets and the hierarchical multifactorial analysis grouped them under a finite number of restoration types with similar project design features. Five river restoration types were found and described establishing a river restoration typology: *Fish RR*, *WFD RR*, *Blue RR*, *Flood protection RR*, and *Human RR*.

Subcategories between restoration activities were already formulated, e.g. *rehabilitation* and *revitalization* (SER 2004) but distinctions are often fuzzy and may depend on the cultural use of terms (Morandi 2014), leading to misunderstanding and jeopardizing comparison. This study presents a practiced-oriented classification of river restoration projects considering their main characteristics and enabling a clear project categorization for better communication, and project comparison. Some common elements between this practice-oriented typology and previous conceptual definitions could be found. For instance, some authors may label Human RR *rehabilitation*. Interestingly, while previous conceptual definitions defined project type along an ecological gradient (Clewell et al. 1993), the main difference between the projects found in this study originated in the project motivation and the social rather than ecological quality goals. This finding suggests that the restoration types differ in the role of restoration as a social process. However, considering the socio-ecological approach *River Culture*, improvement for society may be achieved as a side effect of improvement of the ecological quality (Wantzen et al. 2016). Furthermore, societal benefits are often opportunistic, arising indirectly from actions intended to achieve ecological outcomes (Smith et al. 2016). For instance, the reestablishment of near natural morphological patterns increases both the ecological diversity of habitats and river aesthetics (Junker & Buchecker 2008). In this context, it is particularly important to consider all the social and ecological characteristics of river restorations and both targeted and unintended goals to identify projects, to compare and learn from them, and finally to formulate accurate frameworks and guidelines.

The concept of river restoration as defined by the Society of Ecological Restoration (1993; 2004) provides unity in the restoration community (Allison 2007) and groups all the restoration activities under the same umbrella, namely the intention to improve the ecological quality of the rivers. However, the study presented showed that the river restoration effort also intended to improve the quality of life for citizens and to protect them via nature-based solutions against flood risks. When projects only focused on the ecological quality, i.e. *Fish RR* and *Blue RR*, they intended more to mitigate local perturbation, e.g. re-establish the longitudinal connectivity removing a weir or creating a fish pass, rather than to reestablish the whole ecosystem functionality of the river. Furthermore, improvement of the fish habitat mostly focused on species of interest for hobby fishing and food provision. Accordingly, they are initiated by *pragmatic* rather than by *biotic* driving forces, namely the projects aimed for the maximal supply of natural services and products rather than the recovery of biological biodiversity (Clewell & Aronson 2006). Even if the SER definition was accepted at the international level, many definitions of *river restoration* were commonly used in international publications (Morandi 2014). The study showed that the RR effort surveyed meets rather the comprehensive definitions of river restoration e.g. definitions formulated by Palmer & Bernhardt (2006), that consider social functions of the river, minimize human constraints and targeted long-term river functions than ecological definitions that consider the return to prior human-degradation status.

5.1.2. Urban river restorations as show-piece of the socio-ecological approach

Urban river restorations were identified as more difficult than restoration in rural areas mostly because of high property values, diversity of owners, spatial limitations caused by dense human infrastructure, stronger degradations, and lower recovery potential (Bernhardt & Palmer 2007). Considering these limitations, the WFD set lower ecological quality goals for many urban rivers, namely for highly modified water bodies, than for natural rivers (EU 2000). Surprisingly, urban projects restored longer river sections, bigger rivers, and more often restored both riparian habitats and aquatic zones in comparison with their rural counterparts. Furthermore, urban and rural projects targeted similar ecological quality goals. This finding suggests that current trends in the urban areas exceed the current ecological expectations as those formulated by the WFD. Accordingly, urban river restorations are a show-piece of socio-ecological system tending to develop an effective and sustainable management of the resource.

The main differences between urban and rural projects were the project motivation and the diversity of restoration goals. Urban projects were more often driven by social motivations while rural projects were more often driven by ecological motivations. Furthermore, urban projects gathered and combined a broader spectrum of restoration goals, i.e. ecological and societal. One explanation for triggering interest in the social aspect of restoring urban rivers could be the high social value of urban rivers (Kondolf & Pinto 2016) and the need for public support for implementing projects in urban areas (Norynberg 2001). Urban river restorations may require citizen relocation and cause a short-term disruption in the quality of life, e.g. noise and temporary aesthetically damages. However, since human well-being is dependent on the ecological quality of its environment (Wantzen et al. 2016), public acceptance remains high when citizens perceive improvement in their quality of life (Macedo & Magalhães 2010). Consequently, social restoration is an important issue to assure public support. Furthermore, considering that short-term societal outcomes provide leverage for future ecological actions (Smith et al. 2016), taking the socio-ecological approach into account to develop a restoration strategy may be the best way to achieve high ecological quality goals. However, rediscovering the multiple values of rivers to society and modifying perception may take times. It is encouraging that societal demand for river restoration is already increasing, likely due to the increasing recognition of the benefits of the project for securing the recreational, spiritual and cultural ecosystem services (Gann & Lamb 2006; Suding 2011; Perring et al. 2015) and enhancing the water quality (Macedo & Magalhães 2010).

Another reason explaining the difference between urban and rural restorations could be the difference of stakeholders and institutions in charge of the projects. Ehrenfeld (2000) demonstrated that the different restoration trends result from different types of stakeholders and professions involved: Ecologists and biologists planned and designed the restoration of species, river managers the restoration of ecosystem functions, and geographers and landscape architects the restoration of ecosystem services. Morandi and Piégay (2014) also showed that the monitoring procedure chosen to assess the outcomes of the projects highly depend of the institution in charge. In this study, different stakeholders and institutions in charge of urban and rural projects have also been found. This finding highlights the importance of educating ecologists, hydrologists and landscapers, and the importance of findings outreach to secure good practices.

Surprisingly another major difference between urban and rural projects was the restored zone. Rural restoration focused on improving the aquatic zone, while urban projects more often included the restoration of the riparian zone as part of the ecological goals. Housing and infrastructure further limit the lateral spatial extension of the restoration project in urban as opposed to rural areas (Bernhardt & Palmer 2007). However, restoration aiming at the quality of life for citizens included the restoration of riparian areas, when available, because of their high recreational potential (Scott Shafer et al. 2013). Authors had critically described these restoration measures as urban greening rather than ecological restoration (Lane & Raab 2002; Moran 2007). However, the ecological value of the riparian restoration initiated to improve the recreational uses remain to be investigated.

Similarities between urban and rural projects were also found. For instance, the improvement of the water quality was the least frequent restoration goals in both contexts. This is an unexpected particularity because the improvement of the water quality is one of the most frequent goals of restoration efforts in many other countries, e.g. Brazil (Costa et al. 2010), Korea (Kim et al. 2005), and the U.S.A. (Bernhardt et al. 2005). Furthermore, the European Environmental Agency stated that the chemical status of the French and German rivers begs further improvement. For example, French river water quality is one of the six worst in Europe (EEA 2012). However, these findings are reliable on the macro-level of the degradation and the micro-level of the projects. While water quality degradation in France mostly originates from agriculture (EEA 2012), namely land use at the catchment area level, river restoration projects are limited to few kilometers of river long sections and few meters at the embankment. Unfortunately, the water quality is a precondition of ecological and social river recovery (Binder 2008; Castonguay & Samson 2010; PUB 2012; Chou 2016). This finding underscores the need to consider river restoration at the same level as the degradation causes. However, restoration of a longer river section or even of the whole catchment area may require further stakeholder cooperation.

5.1.3. The socio-ecological driving forces

The study informed about a clear increase in the number of restoration projects after 2000, namely after the implementation of the Water Framework Directive. Furthermore, according to the interviews and project surveys carried out for this study, the WFD was the main driver of a great proportion of projects. The WFD orchestrates the European restoration effort and river governance (Hering et al. 2010). According to the restoration driver typology defined by Clewell and Aronson (2006), the driver of restoration projects initiated to implement the WFD is *technocratic.* However, the main purpose of the WFD is the biotic restoration, namely the conservation and recovery of ecological quality. Consequently, it should be consider that projects initiated to implement the WFD have both *technocratic* and *biotic* drivers. This finding suggests that the restoration drivers have a more unified approach than previously described and illustrates the close interaction between the system components of the socio-ecological system.

The surveyed river restoration projects focused on the hydromorphological quality of the rivers. The emphasis on aquatic ecological quality goals can be explained by the European *technocratic drivers* of the restoration. The WFD puts the aquatic ecology at the center of restoration strategies (Hering et al. 2010) but pay little attention to the riparian zones or wetlands that are ruled by the Fauna–Flora–Habitat Directive (Council Directive 92/43/EEC), which demands more from their conservation than their restoration. This finding suggests that the *technocratic drivers* have a great influence on the river restoration effort, but that applicability of both European Directives, considering the riparian habitats, needs to be clarified.

The study presented here emphasized a major deviance between urban river restoration in France and in Germany. German urban projects were more influenced by the WFD than French urban projects, which were more often initiated to improve the quality of life for citizens. One explanation for this difference could be the historical and cultural context of the restoration practices in each country. Germany is an industrial country that faced major environmental issues in the early 1980s due to industrial pollution. For instance, the Sandoz Industry disaster at Basel, Switzerland (1986) caused major pollution of the Rhine River. Extreme pollution events trigger changes of the local environmental perception and governance, thus strengthening the political will for nature conservation and restoration (Prokopf 2016). Accordingly, in Germany, urban river restorations were already ecologically oriented before the WFD came in force and began with the emblematic Project Emscher restoration (1992–2020) (Petruck et al. 2003; Sommerhaeuser & Stemplewski 2015).

Another (related) explanation for this difference could be the different relationship between human and nature in each country. For instance, the estimation of the benefits of urban green spaces for and by urbanities vary between the countries (Madureira et al. 2015). A comparative study showed that Parisians appreciated nature-control more than Berliners and that citizen preferences highly influence planning policies (Skandrani & Prevot 2015). Accordingly, nature-based solutions and near natural riverscape may be preferred in Germany more than in France where designed waterfronts are preferred (Romain 2010a).

Finally, historical urban development and planning may also explain the difference between the countries. No relationship between driving forces and ecological degradations inside the river bed, e.g. morphological degradation, were found. Urban French and German rivers have a similar morphological status. However, expansion of the observation area to the urban structure near to the river, namely to the first housing area or road bordering the river side, suggest that in France, the existence of highways at the riverbank separating the river from the citizens successfully provides clues to understanding this difference between restoration practices in France and Germany. The observed difference of highways on the waterfront can be explained by different city development history and different schemes of ownership. Urban highways have been built in Europe post Second World War using vacant plots of land (Mumford 1953). In France, cities were densely built, and urban riverside was owned by the State and offered continuous plots of land which cross the city at its center and are almost free of construction (Lechner 2006). Engineering progress made the construction of riverine highway possible despite flood risks. The emotional and spiritual relationship between citizens and their rivers has been broken and its recovery highly influences the French restoration trend (Romain 2010b). In Germany, there was a tabula rasa caused by bombing during the Second World War, offering plenty of vacant plots of land to build urban highways (Sohn 2007). Four German cities of the investigated sample are bordered by an urban highway, i.e., Saarbrücken, Siegen, Darmstadt, and Frankfurt am Main. Interestingly, they are outliers of the German trend and are much like most of the French urban river restorations. These findings suggest that the lack of connectivity between urban areas and rivers caused by existence of highways strongly influences the nature of the restoration project. Interestingly, the highways were not removed during the restoration process. This can be again explained by the scale of the degradation and the scale of the project. Stakeholders in charge of the restoration are mainly local or regional, whereas the highway removal can only be ordered by national authorities. Taken together, these findings suggest that despite the common framework, E.U. countries developed different urban river restoration practices, which underscores the strength of micro-level societal drivers.

5.2. Conflicts within the restored socio-ecological system

5.2.1. Conflict between recreational users and habitats suitability

The Isar river restoration in Munich served as a case study to explore the relationships between ecological restoration and recreational uses. According to the results of modeling procedure and of the species reintroduction, the restoration partly succeeded in creating suitable habitats for sensitive species. First, the reintroduction of *Myricaria germanica* L. is partly a success, suggesting the reestablishment of a suitable habitat for this sensitive plant species. Another reintroduction of *Myricaria germanica* L. inside a unrestored stretch of the Isar near Freising, namely 34 kilometers downstream of the study area, failed (Koch & Kollmann 2012). However, despite flowering of the reintroduced plants at the Isar in Munich, no secondary establishment has been found yet, suggesting that it is still too early to declare a true success. Death rate was the highest the first year and survivor rates stabilized after the first summer. The death rate of reintroduced species is usually higher (> 60%) and stretches over a longer time period (around 5 years) (Edwards et al. 2004; Albrecht et al. 2011; Godefroid et al. 2011) than observed in this study. The findings suggest that the species has an important recovery potential and benefits from the restoration measures. Second, the simulation of the physical habitats for *Chondostroma nasus* L. at the Isar in Munich was conclusive: the restored river stretch may support suitable habitats. However, suitable habitats for species recruitment, namely for spawning activities and larval development, were almost absent. This result is coherent with the findings of Reinartz (1997), namely that the common nase preferred to spawn in tributaries to the Isar such as the Auermühlbach in Munich than in the main river channel. However, the physical habitat model suggested that near-natural man-made elements, e.g. river-bottom ramps with honeycomb structures, may locally improve the physical habitat suitability for spawning activities and larval development. Honeycomb river-bottom ramps are already recognized as efficient restoration measures providing sufficient habitats for sensitive benthic invertebrates and fish in gravel bar rivers for over 13 years (Goeller & Wolter 2015). However, the functionality of the created habitats remains to be proven for *Chondostroma nasus* L., which require recently deposited clean fine-gravel substratum for spawning and larval development (Lelek & Peñáz 1963).

Both studied species have in common that they require specific habitats that are sought after by humans using the river for their leisure activities. High user density occurred where potential habitats for *Myricaria germanica* L. were found. User density also increased in zones near islands, near natural bottom ramps, and at a braided area which are also the areas with many spots of highly suitable habitat for *Chondostroma nasus* L. In the case of rivers, the results of the study support the finding which states that for wetlands, attractiveness for recreational uses is in direct relation to the ecological value of the area (Cottet et al. 2013). This finding suggests that restoring habitats may increase both attractiveness for human and non-human species. This can be explained by the *River Culture* approach, namely that human well-being benefits from ecosystem health (Wantzen et al. 2016).

However, the increasing recreational user density may conflict with ecological restoration success because high recreational user density hinders the suitability of the habitat for both targeted species. First, recreational user activities decreased the overall habitat suitability for *Chondostroma nasus* L. Three habitats were particularly impacted: habitats for juveniles, for spawning activities and for larval development. Spatial distribution of suitable habitats and areas with high recreational user density partly matched. Furthermore, high user density occurred in spring and early summer, namely when these habitats should be used. Then, the survivor rate of *Myricaria gemanica* L. is lower in high user density areas than in medium user density areas. Recreational users negatively impact vegetation (Roovers et al. 2004; Grunewald & Schubert 2007; Rusterholz et al. 2009). However, the survivor rate in area with medium recreational user density is higher than similar reintroduction in another study area without or with very low recreational pressure (Egger et al. 2010). Species may be more or less tolerant of user disturbance, e.g. trampling (Roovers et al. 2004). *Myricaria gemanica* L. has a high degree of regenerative ability and supports repetitive light to major damages (Bill 2000). This finding suggests that because of its physiology, *Myricaria germanica* L. has a high degree of resistance, resilience and tolerance to recreational users that enable its settlement in habitats with high recreational user density. Interestingly, most of the deaths occurred the first year and were caused by recreational users, namely were due to out-digging. Consequently, lower death rates may be achieved by planting the seedling in autumn when the recreational pressure is lower enabling a better rootedness. The findings for both species taken together, the study emphasized conflicts between ecological and social functions post restoration. While recreational uses may be an important cause of potential ecological restoration failure, the existence of suitable habitats for sensitive species partly induced higher user density of the riverine area.

5.2.2. Sharing the space

Three tools of major importance for managers are identified in literature to mitigate recreation–wildlife interactions: regulations, public education, and a user-management plan (Manfredo et al. 1995). The first, may be difficult to implement. Public support for sustainable management and restoration projects is strongly driven by the usefulness of the restoration outcomes (Schenk et al. 2007). Regulations forbidding the recreational use of riverine areas may cause citizen disagreement and hinder public support. However, use regulation can gently influence user distribution indirectly participate to specific area protection. For instance, gravel bars with barbecue authorization were more densely used than the others. The second, namely public education, need long term work and show limited results. Study show that public education may increase the long term awareness of users for disturbance caused by recreational activities, but provide very limited short term recreationist behavior changes (Manfredo et al. 1995). The third, namely the design of user management plan, seems to be the most effective solution. A user management plan based on a motivational strategy to relocate users and enable fair sharing of the river between recreationists and ecological refuge for wildlife could be a useful tool. A good example for this are the periodically restricted access zones on gravel islands on the Loire, France, where kayak tourists have to respect the breeding areas for terns and other birds. However, while in the current situation, humans impact biodiversity, the species did not negatively affect use by humans. Strict user management plans risk changing this into a conflict situation and have to be wisely elaborated.

Users at the Isar were concentrated at emerged gravel bars. Visual values also drive user preferences for waterscape (Bulut & Yilmaz 2008; Junker & Buchecker 2008; Bulut & Yilmaz 2009; Bulut et al. 2010; Cottet et al. 2013), e.g., parameters of fascination, vividness, and naturalness (Bulut & Yilmaz 2008; Bulut & Yilmaz 2009; Bulut et al. 2010). However, user distribution cannot be only explained by these factors since not all the gravel bars were equally occupied by recreational users, suggesting that other parameters than the naturalness and vividness may explain the spatial distribution of the users. Morgan and Messenger (2009) stated that usability strongly influences user preferences. Users also respond positively to man-made design elements, e.g. constructed stairs to sit near the river or easily access the water. This finding suggests that the wise construction of man-made elements, e.g. seating possibilities, to attract users to an area with low ecological quality could play an important role for sustainable user distribution management plan, thus safeguarding area of ecological interest, namely with highly suitable habitats.

The accessibility of the area plays also an important role to determinate the density of recreational users. Most of the recreational users were located on the east side of the river, namely where the embankments are flat, bordered with gravel bars, and there are recreational grasslands with walker and biker paths. On the west side, accessibility is very limited because of a river wall and dense tree structures isolating the river from paths. Consequently, analysis of the spatial distribution of users resulting in user density maps should be an important tool in setting realistic conservation goals. An example is the model developed by Mc Kean and Johnson (2012) to estimate non-fishing recreational demands at the Snake River reservoirs' recreation area in eastern Washington state (U.S.A), the matrix established by Morgan and Messenger (2009) to explain visitors' motives for recreational activities at Eleven Point National Scenic River in southern Missouri, or the conceptual framework designed by Gilvear and Spray (2013) to assist the optimization of river rehabilitation in terms of benefits for humans.

5.2.3. Sharing the resource

Most of the aquatic habitats for the investigated fishes benefited from a slight increase in the minimal flow. However, no "one size fits all" solution was found. None of the four scenarios provided permanently suitable habitat conditions for all the three species, rather, different life stages of the fish species showed preferences for different scenarios. For instance, habitats for spawning activities benefited from low discharge, while habitats for adults benefited from higher discharge. Accordingly, a dynamic water management plan should reestablish near natural and seasonal discharge variations to ensure functionality of seasonal habitats, e.g. spawning areas. Furthermore, morphological restoration increases the diversity of physical habitats (Lepori et al. 2005; Pander & Geist 2010) and further restoration of the morphology should also provide higher diversity of habitats.

It is important to note that numerous hydropeaking occurred during the spring and summer. The restoration was partly designed to limit flood risk and succeed in containing the HQ100 discharge without permitting flood damage within the urban area. However, it failed to create refuges for juvenile fish and larvae, e.g. for *C. nasus*, during flood events. Even if most fish species may be the aquatic organisms the most able to adapt to long-term man-made hydropeaking by switching their habitat preferences (Capra et al. 2017; Holzapfel et al. 2017), larvae and young fish are particularly sensitive to drift during flood events (Lelek & Peňáz 1963; Keckeis et al. 1997; Maier 1997; Reinartz 1997). Slow-flowing anabranches and tributaries are important refuges for fish species during high-discharge events. Design of flood parks that support suitable habitats for aquatic species during flood events, that provide temporary wetland in spring and recreational grassland during the summer et dry season, as the Parc de Balzac in Angers, France (Gintrand 2012) and the flood or “polder” park in Bodenheim/Laubenheim south of Mainz, Germany (Dorsch 2000) are also very promising ecological-oriented landscape designs. Further advancement in fish friendly water regulation must furthermore be carried out to combine sustainable and efficient energy production and aquatic habitat protection.

Surprisingly, simulation of the scenario without diversion, namely with the full discharge flowing into the river bed, indicated that the restored morphology failed in this case to offer suitable habitats for some life stages of the investigated fish species. It was identified as the best scenario for Adult *Hucho hucho L* but it provided a too high discharge for *Thymallus thymallus* L. For *Chondostroma nasus* L., results strongly differed with the life stage. This finding suggests that the increase in the minimal flow to its historical conditions considering the current river morphology fail to recreate an aquatic habitat for all target species. The investigated river reach was hydromorphologically restored but considering the historical status for the last two centuries, the wetted area in the river corridor has been reduced by more than three-quarters (von Riedl 1808; Binder 2005; Düchs 2014). The floodplain has been urbanized and a return to historical condition is compromised.

Many authors agreed that the “historical conditions are therefore the ideal starting point for restoration design” (SER 2004) and that the reestablishment of the previous ecological status of the river, in many cases and especially in urban areas, cannot be achieved because of practical limitations, the complex trajectories of river systems, and new situations to face, e.g. climate change (Choi 2004; SER 2004; Eden & Tunstall 2006; Dufour & Piégay 2009; Bouleau & Pont 2015). Accordingly, restoration trends should follow realistic restoration goals rather than historical references. In morphologically stressed river systems with a strongly reduced diversity and expansion of habitats, artificial structures and discharge conditions that mimic the natural flow events may provide alternatively suitable habitats to those of the dynamically shifting habitat mosaic of the river/floodplain system (Tockner & Stanford 2002) that has been lost due to intensive river engineering.

5.3. Upgrading the river restoration in urban area: the case of the Isar restoration in Munich

Further advice for additional restoration measures can be formulated from this study and some of them were presented in the published papers. To list only the most important: There should be a better consideration of restoration of the riparian habitats as well as a preference for planting riparian characteristics species instead of ornamental plants and recreational grassland; restoration projects should be planned at the level of the catchment area to improve the water quality; longitudinal connectivity should continue to be a focus of the restoration but lateral obstacle removal should be integrated into the project to revitalize the riparian zone and reconnect habitats for adult fish and spawning areas; man-made elements such as row bottom ramps with honeycomb structure should be implemented to improve the aquatic habitats; minimal flow should be assured to enable fish recovery; river bed slopes should be designed to improve the habitat diversity; river such as the Isar should be meandered, braided and islands should be created; refuges should be created to protect sensitive species; attractive areas for recreational uses should be created outside of the area of importance for sensitive species and life cycle stages; pathways should lead to recreational areas without major ecological interest; and user management plans should focus on reducing the negative impact of users on sensitive ecosystem. It is worthy to note that all of these recommended measures concern only the improvement of the biological outcomes of the restoration, limiting the human impacts on the biota. Restoration measures should also intend on satisfying the social demands for river restorations, e.g. increasing the river aesthetic, fairness of the accessibility, and the recreational potential.

According to the concept of *River Culture*, improvement of the ecosystem quality and functions will improve the ecological services availability and satisfy the social demands (Wantzen et al. 2016). Previous studies also showed that improvement of the river health, e.g. improvement of the morphological pattern of the river, satisfies social demands (Bulut et al. 2010; Ozguner et al. 2012; van Marwijk et al. 2012). However, because of the human risks related to a natural river system, e.g. flood events, erosions, and diseases carried by mosquitos, some limits to the re-establishment of the full ecological health of the river remain. Furthermore, the exploitation of ecosystem services lead in the first place to ecological disturbance. Moreover, even if the perception by humans of nature changed in a more ecological and sustainable way (Cottet et al. 2008; Ozguner et al. 2012; Sagie et al. 2013; Skandrani & Prevot 2015), humans remain part of the ecosystem and will continue to impact it. Consequently, even without considerations of the spatial limits to the restoration, the return to a prior degradation status, namely an ecological restoration, is utopic. Accordingly, the river restoration trend should focus on a futuristic river restoration approach involving both social and ecological considerations.

Since the rivers were recognized as a socio-ecological system, humans and ecosystems interact. Their interactions could be positive, negative or neutral. Wantzen et al. (2016) already stated that aspects of the ecological quality may not have only positive effects on the humans. In the same spirit, humans may not have only a negative impact on the ecology and a futuristic restoration approach should consider the exploitation of the ecosystem service as a tool for management, restoration and conservation. However, there remains a need for further research investigating and estimating the positive effect of users on river ecology.

5.4. Methodological and practical contributions

5.4.1. Database

Previous European databases revealed that river restoration in urban areas represents a small share of the restoration effort. For instance, Morandi (2014) found only six urban river restorations implemented between 1970 and 2013 in France. The survey presented in this study and performed in 2013 considered only the 54 French major cities with more than 100,000 inhabitants, revealing the existence of 33 urban river restorations which were not yet recorded in the European database RiverWiki or the French database of the ONEMA. The database produced in this study will doubled the number of French river restoration projects recorded in RiverWiki (2013). Unfortunately, incomplete databases may result in an important bias to inform policies and to assess restoration efforts. This study therefore significantly increases knowledge about (urban) river restoration practices for policy makers and practitioners. Despite major efforts, the lack of knowledge of river restoration and the knowledge loss caused by poor databases as demonstrated by Jenkinson and Barnas (2006) remain. The report of restoration projects should use a secure, long-term, and open source archiving system, such as the standardized RiverWiki database. Yet, these findings revealed the limit of the participative survey protocol adopted by RiverWiki. The high response rate obtained in this study suggests that the survey protocol adopted is appropriate to fill these information gaps. However, the survey was very time-consuming and funding should be allocated to properly record the restoration effort.

5.4.2. Reintroduction of *Myricaria germanica* L.

The reintroduction of *Myricaria germanica* L. in the Isar in Munich provides important conservation benefits but also new insights for restoration sciences. First, another study was performed during the same time span and at the same sites at the Isar but using dead plant material, namely wood sticks of *Salix alba*, to estimate conflict between reintroduction measures and recreational uses. This affirms the failure of the potential reintroduction experience because of recreational pressure (Zagrodska 2014). The reintroduction presented here and using living material suggest the success of the procedure at least in an area with medium recreational user density. Second, the study suggested that the habitat preferences of same species may be different between population sources. Despite higher recreational pressure at the Isar, the survivor rate of

Myricaria germanica L. in the Isar was higher than in Kärnten (Austria). Both reintroduction procedures follow the method described by Egger and Angermann (2010) in great detail. The major difference between both experiments was the population source, namely, in each case, the nearest population source. Werth and Old (2014) identified genetic difference between nearby *Myricaria germanica* L. population which was separated by dams. This finding suggests that genetic differences may exist between the plants reintroduced in Kärnten and in the Isar. However, the influence of the genetic variations on the reintroduction success remains to be investigated. Furthermore, other unknown variables may affect the survivor rate. Finally, the reintroduction in medium to high recreational user densities provides new insights about conflict between recreationists and endangered species conservation strategy.

5.4.3. Model-based evaluation of projects

The physical habitat modeling procedure of the restored Isar in Munich provides important results to understand the missing recovery of the fish species target of the restoration. Findings could be use by authorities in charge of the river management to identify failure of the restoration and to establish an integrative river management plan.

The modeling procedure also provides a broader contribution to restoration science. The study presents how modeling procedures, such as CASiMiR, could help to identify the species and their life-cycle stage that may be the most affected by restoration measures, e.g. the increase in the minimal water flow. Models should be an important tool to define the best restoration measures considering the more realistic restoration goals. It also enables the simulation of side effects of measures on non-targeted species.

This study presents a novel method for evaluating habitat restoration projects. A major novelty of this study was the inclusion of recreational user pressure as a new parameter in the habitat suitability modeling procedure. This inclusion provides additional insight that can be used to determine potential causes of the failure of the river restoration projects and should be an important gain for future projects, avoiding risk of failure.

5.5. Limitations and further resarch

5.5.1. Project survey, comparison, and typology

The investigation on the difference between rural and urban river restorations showed a significant difference in restoration motivation and goals. However, all the river restoration projects similarly intended to improve the ecological quality of the project. The difference between urban and rural projects mostly depended of the higher social demands on the river in urban areas. However, since none of the variable assessed the ecological success of the project, the outcomes of the project can cannot be evaluated and compared.

The study presents a project typology based on the major project design features. The clustering procedure highly depends on the chosen variables. It is assumed that the broad set of variables used in this study covered all essential aspects of river restoration projects. A monitoring procedure typology based on the type of implemented monitoring, the duration of the monitoring, and the implementation of prior/ post-project monitoring has been developed partly on the same database (Morandi et al. 2014), namely on the projects recorded by the ONEMA. It defined four types of monitoring used and established a relationship between the metrics used and the authorities in charge. It should be of interest to investigate if both typologies could be put in relation to investigate the relationship between the monitoring procedure implemented and driving forces.

Furthermore, the project typology presented was established using a limited number of projects, and other project types may exist as, e.g. *Water RR* focusing on water sharing (Orthofer et al. 2007; Sagie et al. 2013), or *Climate RR* to face climate change (Kim et al. 2008; Olaya-Marín et al. 2012). The methodology of typology procedure should be applied to broader databases to make a more exhaustive listing of the project types.

The present study presents an original dataset of urban river restoration, a group of river restoration projects previously under-represented in national and in European databases and publications. Despite a high degree of significance of the presented results, they did not exclude the fact that other drivers accounted for country specific restoration trends.

5.5.2. Recreational user survey and impact

Recreational user surveys were performed on non-working and sunny days. Accordingly, the investigation based on these occasional observations were performed on much higher figures of riverbank-users than mean values recorded over the whole year. In order to reduce bias from the high fluctuation of users (driven by working time and weather conditions), more frequent and long-term surveys should be performed, including, for instance, the use of drones or aerial photographs. Long-term user monitoring should help to better estimate, simulate, and understand user distribution.

Furthermore, the type of uses, their distribution and the recreational user density were used to investigate the impact of recreationists on species. Other indirect pressures caused by recreational users may also influence the species distributions and habitat suitability. For instance, the conclusion of field observations suggests that use of the reintroduction areas as an outdoor lavatory by recreationists may be an important cause of decreasing the habitat suitability for *Myricaria germanica* L.

Furthermore, the user survey provided detailed information about user distribution and density but limited explanation on user behaviors. For instance, the analysis of the user distribution showed that recreational users preferred some gravel bars. This observation cannot be explained by vividness, aesthetics or river side accessibility, namely the existence of subway or parking and pathways. The lightness, namely sun exposure, may play a role in the choice of the gravel bar used by recreational users, but further observations remain to be done to support this suggestion. Understanding of user distribution is an important issue to simulate impact in light of different scenarios and to establish a user management plan.

5.5.3. Experimental study (reintroduction)

The study demonstrates the influence of recreational user densities on reintroduction measures. However, we cannot definitively affirm that the variables investigated alone accounted for reintroduction success and failures. Other drivers or other unknown variables may also have influenced our results. Furthermore, the study was performed at two sites, one with medium and the other with high user density.

Comparison with other sites with low and no user pressure could be of interest. The type of users also slightly differs between the sites, e.g. the proportion of users on paths and on gravel bars, making comparison difficult. Then, the number of plants reintroduced did not enable the use of strong statistical tests. Moreover, the success of the restoration can just be assessed regarding of the biology of the false Tamarisk. Finally, the reintroduction of sensitive species into areas under high user density raises ethical questions. This study was conducted under particular conditions. The residual plants of another reintroduction project were dedicated to die and through this project, they were given a new chance to life. We discourage relocation of endangered plants from protected areas to high user density area.

5.5.4. Habitat suitability model

The inclusion of recreational user pressure as a new parameter in the habitat suitability modeling procedure is a novelty. However, a critical point could be the evaluation of species tolerance limits, namely, tolerated usage intensities and frequencies. In this study, the habitat preferences and impacts of recreationists were estimated by expert statements of fish biologists because little scientific literature was available concerning these points. Despite the fact that expert evaluations of ecological quality may be as trustworthy as assessments made by experimental field investigations (Feio et al. 2016), future research designed specifically to evaluate the impact of recreationists on wildlife would be helpful.

Furthermore in this study, user distribution maps were integrated into the suitability model. It should be of interest to investigate different scenarios as well in order to create a predictive tool for helping to choose the best restoration design and the best user management plan. Simulation of user distribution change is an important issue to define refuges for species, and to investigate future scenarios, e.g. increases in user density. However, this area of scientific inquiry involves a broad range of disciplines and their respective fields of knowledge. More studies on recreational user preferences and recreational impacts on wildlife remain to be carried out to provide a strong baseline for the design of user-management plans based on an integrated framework for coexistence between recreationists and biodiversity.

Our study has demonstrated the existence of habitats with suitable flow velocities, depths, and substrate for the life cycle stage of *C. nasus* that were historically observed in this Isar section, despite occurrence of recreational pressure. The results suggest that other limitations exist, e.g. missing recruitment into tributaries, obstacles to the longitudinal connectivity. Spawning and juvenile habitats at the study area were very rare and their reduction or destruction by user pressure (on the juvenile habitats) may be responsible for the absence of recruitment, however, it does not explain fully the absence of *C. nasus* in the restored Isar section. Other habitat variables such as temperature, food sources, and predators as well as habitat availability on the scale of the catchment area could be taken into account to complete the picture.

The study on the minimal water flow requirement enables us to define the best restoration scenario in the case of the Isar in Munich for the three investigated fish species. However, the habitat suitability model remains at a theoretical level since the predictions have not be verified by field measurements. However, even field verifications, e.g. electrofishing, have shown limits in validating model prediction. In fact, false positive or negative predictions may not imply a model error (Mouton et al. 2008): Fish occurrence might also depend on other variables then those included in the habitat suitability model and suitable fish habitats may be present but not be settled.

Furthermore, despite extensive research, CASiMiR modeling procedure limitations remain. Further research on habitat modeling remains to be done to increase model robustness. For example, future models should consider the sediment dynamics leading to variations in the quality of substratum of the studied habitat type (Noack et al. 2016; Beckers et al. 2017) and correlate this dynamic to seasonal habitat change.

5.5.5. Socio-ecological evaluation of river restoration

The study presents methods to integrate user impact into an ecological evaluation and modeling procedure. However, the consideration of the socio-ecological system demands the integration of all kinds of interactions between human and ecology: this study has the major limitation that it considers human uses only as a pressure. Further studies should investigate the positive effect of human uses on ecology and integrate this observation into upgrading both the understanding of the restoration approach and the evaluation procedures.

Furthermore, the study did not integrate the benefit of the ecological health for human perception and uses. Many studies already stated that a healthier ecosystem increases human well-being, perception of the environment and potential recreational use. This statement was discussed in the paper discussion or present in the introduction as a background but the doctoral study did not intend to test it or even investigate which negative effect the healthy river could have on the social demand for restoration. Further studies should investigate the limit of the socio-ecological system, namely what is the threshold for considering that more ecological health will decrease the satisfaction of the social demand?

6. Conclusion

Riverine ecosystems are degrading at rates that jeopardize essential ecosystem services for human society. Ecological restoration was defined as our best chance to reestablish the ecological health of the river. River restoration was an “acid test” for human ecological and biological knowledge. Research focused worldwide on estimating the ecological deteriorations, the development of ecological solutions, and then the development of tools and metrics to evaluate the success of projects. The study established a clear project typology underscoring the diversity of the restoration effort. Interestingly, while previous sub-definitions of restoration distinguished the restoration activities according to their ecological quality goals, the five restoration types found in this study, i.e. *Blue RR*, *Fish RR*, *WFD RR*, *Flood protection RR*, and *Human RR*, were distributed on a social rather than an ecological gradient. The study also underscored that, while the rivers were identified as a socio-ecological system, the current restoration effort was dominantly driven by the environmental policies, i.e. the WFD, that demand the restoration of ecological form and functions and do not consider yet the whole socio-ecological system river. Unfortunately, current restoration approaches and tools resulted in limited success. Despite good intentions, attempts at restoring the freshwater body may fail when the consideration of the socio-ecological system is simplified to its ecological component.

The WFD expects lower ecological goals for urban rivers because of their highly impacted ecological status and accentuated limitations. Interestingly, societal driving forces are present in a greater degree in urban than in rural areas and innovative restoration approaches were developed to combine ecological and social quality goals. Urban projects intend to improve both aspects of the socio-ecological system but the interactions between social and ecological components of the system remain little considered. Accordingly, the study revealed potential conflicts between ecological and social restoration goals. The results also underscore that the restoration practices should not forget that the exploitation of the ecosystem service caused the ecological degradations in the first place and that even if human perception of nature and engineering evolve in a more sustainable way, ecological limits for the restoration of the ecosystem form, structure and functions remain. Accordingly, the understanding of the socio-ecological system, namely the better consideration of the interactions between human and nature, should be consolidated to develop a sustainable river restoration management and to preserve of the right balance system, and to formulate realistic restoration goals.

River restoration is a practical science that learns from success and failure. However, ecological as well as social responses to restoration measures take time and induce a learning process that needs long-term field observation and requires expensive study comparing prior and post restoration status. The modeling procedure as used in this study overpass previous methodological limitations and enabled a cost effective comparison of different scenarios. However, only field observation can affirm the success or failure of the scenario designed.

Finally, the study was carried out in France and Germany, but the research conclusions can be easily transferred to other locations to improve the sustainability and efficiency of urban river restorations. In the context of growing urbanization, these conclusions are an important step for future river management strategy, which should take a socio-ecological approach to restore freshwater ecosystems.

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Publications and Suplementary Material

Paper A

The first author, Aude Zingraff-Hamed, conducted the study, namely: Identify the knowledge gaps and research questions; Develop the conceptual idea and analytical framework; Design questionnaires; Conduct field survey; and Perform analyses and calculations. All these research steps were discussed with the research supervisors: Prof. Stephan Pauleit, Prof. K. Matthias Wantzen, and Dr. Sabine Greulich. Contribution was written by Aude Zingraff-Hamed in collaboration with all the co-authors.

French Abstract/Résumé en langue française :

L'article A intitulé *Urban and rural river restoration in France: a typology* (« La restauration des rivières rurales et urbaines en France : une typologie ») fut publié dans *Restoration Ecology* le 31 Mai 2017. Il expose les résultats de l'étude exploratoire et comparative portant sur 110 projets de restauration de rivières réalisés entre 1980 et 2015 en France métropolitaine. La publication a trois objectifs : a) Fournir une revue détaillée de l'effort de restauration en France. b) Comparer les projets en fonction de leur contexte urbain ou rural. c) Établir une typologie de projet basée sur des critères objectifs et transparents afin de faciliter les futures comparaisons de projets et les échanges de savoir.

Pour cette étude, la base de données produite et publiée par l'ONEMA (N=78) a été réalisée. Les fiche-projets ont été utilisées pour renseigner un questionnaire listant les variables étudiées. Cependant, elle ne contenait que huit projets réalisés en milieu urbain, dont seulement un dans une ville densément peuplée (ayant plus de 100 000 habitants). C'est pourquoi, elle a été complétée par base de données complémentaire de 33 projets réalisés en milieu urbain. Cette dernière a été obtenue par recensement téléphonique et interrogeant systématiquement les autorités de toutes les villes françaises de plus de 100 000 habitants (N=53). Le formulaire utilisé pour collecter les informations d'importance pour l'étude fut le même pour la procédure écrite basée sur les fiche-projets produites par l'ONEMA. Les variables utilisées pour comparer les projets ont été identifiées par une revue de la littérature internationale et classées sous huit thèmes : motivation du projet, objectifs de restauration, date de réalisation, coûts, dimensions, financement, débit annuel, et procédure d'évaluation. Pour établir une typologie, une Analyse Factorielle Multiple Hiérarchique a été réalisée utilisant le package FactoMineR 1.24. sous R version 1.31.3. Cette méthode permet une classification hiérarchique sur les composantes principales d'une analyse factorielle multiple utilisant la méthode de partitionnement en k-moyennes et se basant sur des variables numériques et catégorielles organisées en groupes.

Les résultats suggèrent, tout d'abord, que les pratiques de la restauration de rivière en France sont similaires aux pratiques observées dans de nombreux autres pays (États-Unis, Australie, Islande, Brésil et Japon). Cependant, elles se différencient par un manque d'intérêt pour l'amélioration de la qualité de l'eau et la restauration des habitats rivulaires terrestres (en milieu rural). Ceci peut s'expliquer par la législation européenne. Tandis

que la Directive Cadre sur l'Eau demande la restauration des milieux aquatiques, le programme Natura 2000 demande la conservation et non la restauration des habitats rivulaires d'intérêt. Davantage de concordance est attendue pour une gestion équilibrée de l'espace fluviale.

Ensuite, la comparaison de projets en fonction de leur contexte géographique montre que les projets de restauration de rivières urbaines sont plus grands, restaurent des rivières plus larges et à plus haut débit, et combinent davantage des objectifs sociaux et écologiques que les projets en milieu rural. De plus, les projets urbains incluent la restauration des habitats alluviaux tandis que les projets en milieu rural se limitent plus souvent aux milieux aquatiques. Les restaurations de rivières urbaines ont ainsi une approche plus complète que les projets en milieu ruraux et peuvent apporter des leçons pour la réalisation de futurs projets intégrant une approche socio-écologique

Enfin, les résultats proposent une classification en cinq types de projets : *Fish RR*, *Blue RR*, *WFD RR*, *Flood protection RR*, and *Human RR*. Même si toutes les variables contribuèrent à la classification, la principale différence entre les projets est leur motivation soit la raison qui a incitée leur réalisation. Ainsi, *Fish RR* sont réalisés pour rétablir la continuité fluviale pour la migration du poisson. Les projets de type *Blue RR* étaient précurseurs et poussés par le besoin d'améliorer les habitats aquatiques mais réalisés avant la signature de la Directive Cadre sur l'Eau (WFD). Les projets *WFD RR* sont initiés pour répondre aux exigences de qualité écologique imposées par la Directive Cadre sur l'Eau. Les projets de type *Flood protection RR* sont motivés par une meilleure protection contre les inondations utilisant des méthodes écologique et durable basées sur des solutions techniques inspirées par des structures naturelles. Et les projets *Human RR* sont initiés pour améliorer la qualité de vie des habitants. La transmission du savoir et la comparaison de projet sont nécessaires au transfert d'expérience et nécessitent une distinction claire entre les projets de restauration. La typologie de projet présentée ici peut permettre ceci. Toutefois, il est probable que davantage de types de projets existent. Ainsi, la méthode décrite devrait être reproduite utilisant une base de données plus importante.

Mots clefs : base de données, comparaison de projets, objectifs de la restauration, restauration de rivières, approche socio-écologique.

RESEARCH ARTICLE

Urban and rural river restoration in France: a typology

Aude Zingraff-Hamed[1,2,3,4], Sabine Greulich[1], Stephan Pauleit[2], Karl M. Wantzen[1,3]

River restoration (RR) is widely practiced in both rural and urban contexts by combining various goals and measures. The theoretical discourse on RR not yet adequately reflects this breadth of restoration practice. In this study, we investigated 110 French RR projects implemented between 1980 and 2015. We analyzed projects considering eight key design features, main project motivation, restoration goals, project dates, costs, size, funding, river annual discharge, and implemented evaluation procedures. The study (1) provides a detailed account of the French RR effort, (2) compares restoration efforts in urban and rural contexts, and (3) establishes a RR project typology. The results also show that urban RR comprises a wider range of goals and measures than its rural counterpart, includes restoration of riparian habitats, and integrates ecological and social goals. A hierarchical multiple factor analysis yielded five types of projects, Fish RR (14% of the urban and 53% of the rural projects), Blue RR (4%, 7%), Water Framework Directive RR (36%, 40%), Flood protection RR (14%, 0%), and Human RR (32%, 0%). We suggest that the restoration community needs databases that use a project typology as developed in this study. This approach would take into account the multiple facets of RR projects, enabling more transparency into their communication and allow more suitable project comparisons.

Key words: database, project comparison, restoration goals, river restoration, socioecological approach

Implications for Practice

- More specific project descriptions, definitions, and evaluation procedures are needed to enhance comparative learning processes and improve future restoration projects.
- River restoration (RR) in France focused on aquatic habitats as requested by the Water Framework Directive, but European environmental policies should improve emphasis on the importance of riparian habitat restoration.
- Reporting RR using more secure, long-term, and open source data archiving is needed. Practitioners should be strongly encouraged to enter project information into the RiverWiki database to fill the gap of documentation on restoration projects, improving the learning circle and providing more guidance for the formulation of policies.
- Urban RR is a showpiece of the "River Culture" approach and can provide some guidance for comprehensive RR projects.

Introduction

Rivers are hotspots of biological and cultural diversity (Arthington et al. 2010; Geist 2011; Wantzen et al. 2016). Centuries of human modifications have impacted rivers, causing negative effects on both ecosystems and humans (Vörösmarty et al. 2010). In recent years, restoration was recognized as essential to maintain or reestablish biodiversity and the ecosystem services provided by rivers (SER 2004; Jørgensen 2015). Restoration goals are therefore diverse (Bernhardt et al. 2005; Alexander & Allan 2006) and their categorization may help improve communication of restoration project aims.

A variety of restoration goals, e.g. channel reconfiguration, riparian management, and water-quality improvement, may drive river restoration (RR) projects (Bernhardt et al. 2005; Aradóttir et al. 2013), with different RR definitions, e.g. ecological restoration or rehabilitation, often overlapping in their content. Allison (2007) stated that "Restoration is a practice in which choosing the best language to describe that practice has been especially problematic." The term restoration has been applied since the 1990s to projects with different goals, dimensions, and motivations, and spanning a range of possibilities from *ecological restoration*, which focuses on the reestablishment of preexisting biotic integrity in terms of species composition and community structure, to *rehabilitation*, which focuses on reestablishment of ecosystem processes, productivity, and

Author contributions: AZH, SG, SP, KMW conceived and designed the research; AZH performed the survey; AZH analyzed the data; AZH, SG, SP, KMW wrote, edited, and revised the manuscript.

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services, *sensu* SER Primer (SER 2004). The 16 most commonly used definitions (Morandi 2014) can be grouped into four categories (Table S1, Supporting Information). Palmer and Bernhardt's definition is the only one of the 16 that adds the enhancement of social functions of rivers to the ecological approach. According to the Society for Ecological Restoration, ecological restoration differs from restoration that "includes reclamation, rehabilitation, mitigation, ecological engineering and various kinds of resource management" (SER 2004). The use of one single term for such a wide range of restoration activities may lead to misunderstanding, biases in comparison between projects and may jeopardize cross-fertilization between projects. For instance, comparison of previously published RR surveys shows that U.S. projects reported by Bernhardt et al. (2005) differ from those reported in France by Morandi et al. (2014) regarding the targeted ecological quality. Furthermore, several publications, such as Jenkinson et al. (2006) and Bernhardt et al. (2007), emphasized the need for clearer and more practice-oriented definitions and project characterizations. These could form the basis for more suitable guidelines and evaluation procedures for RR.

Increasing efforts have been made to synthesize results from RR (Bernhardt et al. 2005; Nakamura et al. 2006; Feld et al. 2011; Pander & Geist 2013; Morandi et al. 2014; Kail et al. 2016; Muhar et al. 2016; Speed et al. 2016) and enhance the transfer of experience. Several surveys were carried out as part of national and international research programs. For example, U.S. projects have been recorded by the National River Restoration Science Synthesis (NRRSS) (Bernhardt et al. 2005) and by the U.S. Environmental Protection Agency (http://wiki.epa.gov). Europe also developed two databases. The first was part of the EU REFORM project, dedicated to hydromorphological restoration (http://wiki.reformrivers.eu). The second is the RiverWiki database (https://restorerivers.eu/wiki/index.php?title=Main_Page), which is the major output of the EU LIFE+ RESTORE project (2010–2013). However, national databases often record more projects such as the ONEMA database in France (French RR in the ONEMA database, $n=85$; in RiverWiki, $n=38$).

Urban water bodies are in general more heavily modified than their rural counterparts and their dysfunctions have been described as the "urban river syndrome" (Walsh et al. 2005). In Europe, urban RR (URR) is supported by the increasing interest of the urban population in living on the borders of healthy rivers (Wantzen et al. 2016); however, the available space for URR is limited. With deindustrialization, the opportunities for URR have increased (Binder 2008). The NRRSS showed that URR in the United States mobilized a large share of the RR effort, 29% of all projects (Bernhardt et al. 2005; Bernhardt et al. 2007) and 50% of the funding (Hassett et al. 2005). In Europe, only 9% of the 906 projects recorded in RiverWiki (February 2015) are URR. In the European Union, the Water Framework Directive (WFD) adopted in 2000 is one of the most ambitious environmental policies (Hering et al. 2010) and has set quality goals based on ecological characteristics, that is, hydromorphological, biological, and chemical, for all water bodies. The WFD separates natural water bodies from heavily modified water bodies (HMWB) and artificial water bodies (AWB). According to the WFD, the first are required to achieve "*good ecological status*," whereas the second (HMWB and AWB) only need to achieve "good ecological potential," which is open to interpretation (Borja & Elliott 2007; Moss 2008; Hering et al. 2010; Cabezas 2012; Jørgensen 2015), and has less ambitious ecological quality goals (Hering et al. 2010). Therefore, we hypothesized that URR projects may have common characteristics and lower ecological quality goals that distinguish them from those in rural areas (rural RR (RRR)).

Given this background, the goals of our study are threefold. The study first aims to provide, for the case of France, a detailed account of the RR effort. Second, the study aims to compare RR in both rural and urban contexts. Third, the study targets the establishment of a project typology based on major project features, that is, project motivation, project goals, project dimensions, project costs and funding, project dates, river characteristics, and existence of an evaluation procedure, to satisfy the need for practice-oriented project characterizations. Such a typology may help, in the future, to develop practical guidelines and an evaluation procedure for each project type.

Methods

Dataset

We established a dataset of 110 RR projects (1980–2015) in France (Table S2; Fig. 1) aggregating both an existing public database produced by the French Water Agency (ONEMA) ($n=78$) and an additional database of URR produced by our research team ($n=33$). The overlapping cases were combined into a single record. Special care was taken to properly compile both databases in a single dataset, enabling project comparison analysis, e.g. same variables (number, type, and label), list of entries based on the existing database, same vocabulary used, and same form for recording data from both interviews and written sources (Appendix S1). To investigate the whole spectrum of restoration activities, studied projects fit to the approach defined by Bernhardt et al. (2005), namely, "No judgments were made of the validity of the terms restoration or project." Data were entered into an Excel spreadsheet. One person carried out the entire data collection.

The ONEMA database contained complete datasets for 78 RR projects (including 11 URR) in June 2015 (http://www.onema.fr/Hydromorphologie,510). Project managers from regional and interregional water agencies provided data, filling out standardized forms. Information from the ONEMA database was extracted and transcribed using the form used for the interviews (Appendix S1).

The additional database focused on URR. Data were collected via phone interviews with the staff of city planning departments and river management districts ("Syndicats de bassin versant"). This survey covered all 53 French urban areas with populations larger than 100,000, yielding a dataset of 33 URR projects. The remaining 20 cities either did not have URR projects ($n=9$) or did not reply ($n=11$). The phone interviews were performed using a direct closed technique

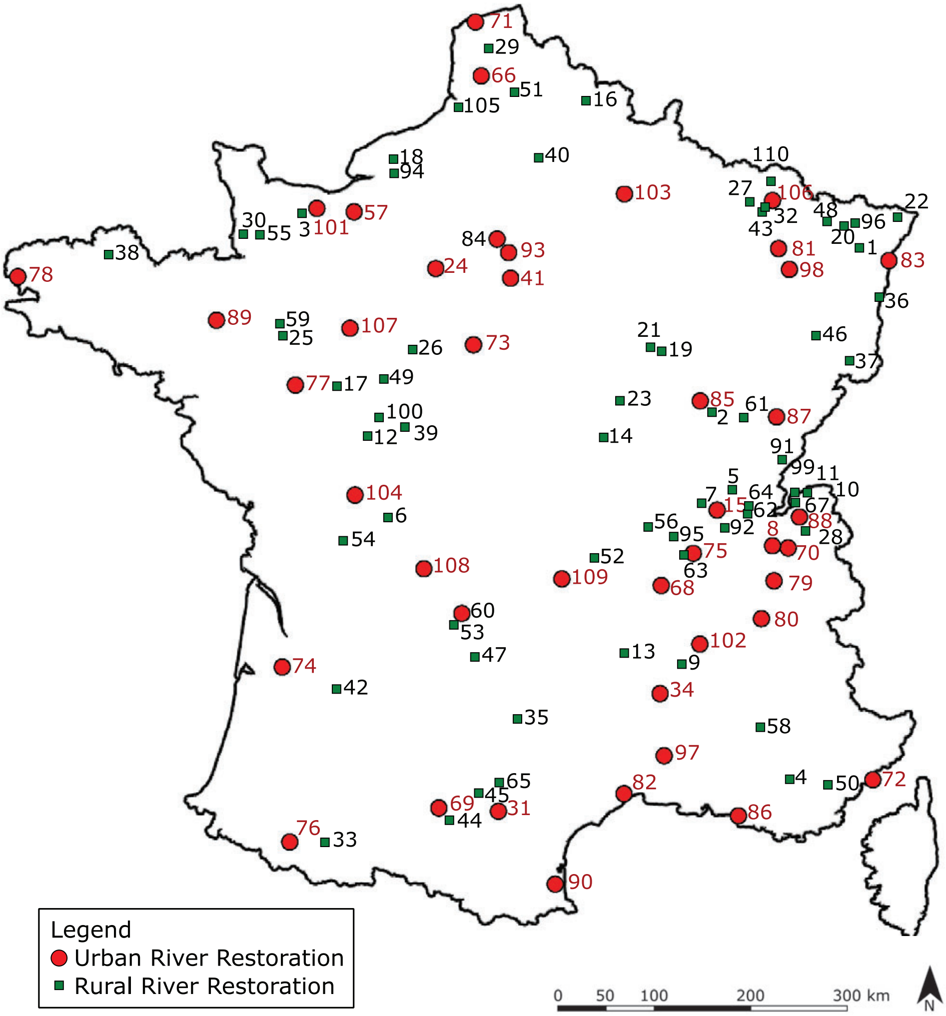

Figure 1. Location of the 110 investigated French RRs. Numbers correspond to city ID listed in Table S2.

(Kelley et al. 2003). The standardized multiple choice questionnaire (Appendix S1) listed questions to inform the seven themes: project motivation, restoration goals, project cost, project size, project dates, evaluation procedure, and source of funding, as e.g. Which motivation initiated the project (single answer)? What were the restoration goals of the project (multiple answers possible)? What were the characteristics of the project (size, cost, temporal aspect)? Which institution or program financed the project? Supplementary qualitative information about the implemented measures was collected to the best of our abilities during the interviews. Data on the eighth theme, river characteristics, was taken either from the ONEMA database or for the additional database focusing on URR from the HYDRO database (http://www.hydro.eaufrance.fr/). Hydrological gauging sites existed for most of the rivers nearby the restored sites. Missing data for small streams were entered as "NA." The ecological status of the restored river sections prior to restoration (HMWB and AWB, $n = 30$ or natural rivers, $n = 80$) were obtained online from the website of the water agencies. A total of 88% of the URR intended to restore HMWBs. Once filled, the questionnaire was sent to the interviewees to ensure proper reporting.

Variables

In order to describe and differentiate the 110 RR projects, we used eight themes (Table S3) defined by previous publications, as e.g. Jenkinson et al. (2006), and listed in the paragraph above. The main project motivation, which is the reason for the existence of the project, differs from the restoration goals. These have been identified by previous surveys (Table S3). For example, projects initiated for "implementation of the WFD" can have many diverse goals, such as improving aquatic habitats or/and water quality. We excluded descriptions of the implemented measures from the statistical analysis but these details were useful to qualitatively describe the projects and interpret the results.

In order to compare restoration projects in urban and rural contexts, we labeled each project either URR or RRR (supplementary variable *context*), considering the population density

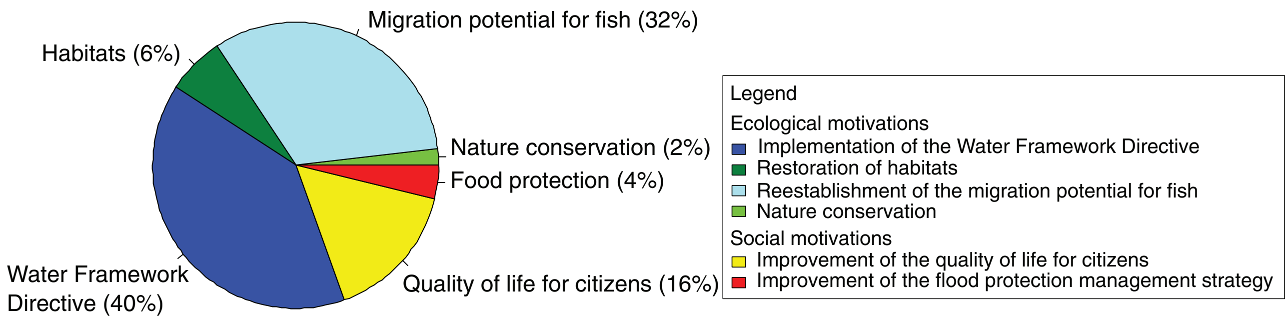

Figure 2. Pie chart of the distribution of project motivations for 110 French RR projects.

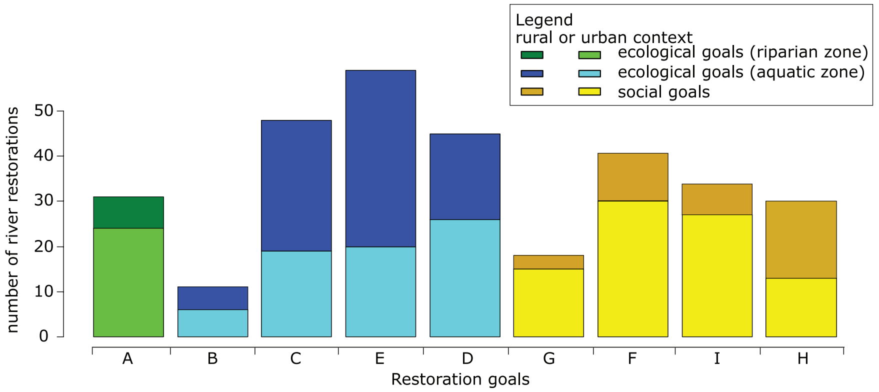

Figure 3. Distribution of the projects within each restoration goal considering their rural or urban context. A, restoring riparian habitats; B, improving the water quality; C, restoring aquatic habitats; D, reestablishing the longitudinal connectivity; E, reestablishing near natural patterns of the river hydromorphology; F, integrating the river into the city structures; G, improving the esthetics of the riverscape; H, enhancing the recreational potential of the river; I, improving flood protection potential.

and the number of city inhabitants in the urban area, merging under urban high-density (>1,500 inhabitants/km^2 and >50,000 inhabitants) and urban areas (>300 inhabitants/km^2 and >5,000 inhabitants) (EC 2011). Geographical characteristics (population density, number of inhabitants, and urban area) were obtained via the website of the French National Institute for Statistics and Economic Research (http://www.insee.fr/fr/bases-de-donnees/default.asp?page=recensement/resultats/2012/rp2012.htm).

Data Analysis

Statistical analyses was performed using R version 1.31.3. and followed two steps. All analyses were considered significant at $p < 0.05$.

To describe and differentiate the projects with similar characteristics, we performed a hierarchical multiple factor analysis (HMFA) with FactoMineR 1.24. This method allowed agglomerative clustering using the *k*-means method on multivariate data with numerical or categorical variables structured into themes (Husson et al. 2011). The output of the HMFA is a project typology that groups projects with similar characteristics into project types. We performed the HMFA on all variables in the eight themes.

To compare URR with RRR, we performed bivariate analysis on all the variables in the eight themes and the supplementary variable *project type* using the nonparametric Fisher's exact test, which is a test of equal or given proportions (McDonald 2014).

Results

The 110 RR projects (Fig. 1) represent 465 linear kilometers (sum of all restored river sections) with the overall project expenditure exceeding €0.5 billion between 1980 and 2015. The budgets ranged from €0 to €150 million (median cost €198,700) with a median cost per meter of restored river of €297 (median project length 1 linear kilometer). Projects had various motivations and multiple restoration goals. The great majority of projects had been carried out for ecological motivation, that is, implementing the WFD (Fig. 2). Almost all projects intended to improve the physical quality of the aquatic zone (hydromorphology, habitat diversity, etc.) but the improvement of water quality was the least common goal (Fig. 3). The restoration of riparian habitats was the second least common ecological goal (Fig. 3).

Project Typology

Despite this great variety of RR projects, the HMFA resulted in only five different project types, Fish RR, Blue RR, WFD RR, Flood protection RR, and Human RR. It is worthy to note that the project motivation explained most of the partitioning. Project type characteristics resulting from the HMFA are summarized in Figure 4 and Tables 1 and S4.

Type 1 projects ($n = 33$), labeled Fish RR, were mostly initiated to reestablish the migration potential for fish (91%). Most of them were found in a rural context (88%). Fish RR median cost per restored meter was €194. Numerous weirs and dykes were built in the past to satisfy industrial needs. Post deindustrialization Fish RR removed obstacles such as weirs to (1) re-establish the longitudinal connectivity (47%) and (2) improve the flood protection potential (17.5%). For example, the removal of the 2-m high weir in Régny (Loire, France) aimed to reestablish the ecological longitudinal connectivity of four river kilometers. Even if the reestablishment of longitudinal connectivity is part of the WFD, Fish RR differed from WFD RR, which (1) were comprehensive; (2) aimed for longitudinal as well as transversal improvement of the aquatic zone; and (3) restored longer sections of the rivers.

Type 2 projects ($n = 5$), labeled Blue RR, were initiated to restore (sensitive) habitats (100%). With a median cost of €66 per restored meter, projects focused on aquatic habitats and intended to improve the river hydromorphology through measures such as remeandering and riverbed remodeling. Most of the Blue RR were in a rural context (80%) and had three characteristics: (1) projects started between 1997 and 1999; (2) neglected social goals; and (3) lacked evaluation procedures. Blue RR projects were pilot projects to reestablish near natural patterns of river hydromorphology. For example, in Morsang-sur-Orge (Essonne, France) 1 km of the artificial embankment was removed, the embankments were flattened, and the river was remeandered to improve aquatic habitats. Blue RR are "closed cases" since the WFD came in force. They still may give some important information to understand the evolution of restoration trends in France.

Type 3 projects ($n = 32$), labeled WFD RR, were generally initiated to implement the WFD (93.8%). They cover a broad spectrum of measures, even social, despite the focus on aquatic zones, e.g. restoring aquatic habitats (21.7%), improving hydromorphology (17.5%) and longitudinal connectivity (15.5%). Another distinguishing characteristic is the implementation of evaluation procedures (75.0%). WFD RR median costs are €225 per restored meter. WFD RR are located in both urban (31%) and rural (69%) contexts. For example, the Bièvre in the Paris suburban area has been used as a sewer in the past by industry and the city. To avoid public health problems, the river was buried. Deindustrialization and the connection to a proper city sewer system increased the restoration potential. The project of daylighting the Bièvre aimed to improve the aquatic habitats, the esthetics of the riverscape, and the recreational potential of the river.

Type 4 projects ($n = 4$), labeled Flood protection RR, were the most expensive with a median cost of €3,468 per meter of restored river. They aimed at improving flood protection (100%) by designing new flood release zones. Similarly to WFD RR, they had a wide range of goals. For example, in Chambéry (Savoie, France), important industries, highways, and railways are located at the confluence of the two main rivers. To reduce the flood risk, the retention potential of the floodplain was increased by redesigning the floodable riverine park. The project increased at the same time the flood protection potential, the riverscape esthetics, and the recreational potential. In order to carry out this project type, land is required to serve as retention areas. Therefore, this approach may include expensive land acquisitions and even the relocation of residents.

Type 5 projects ($n = 9$), labeled Human RR, were initiated to improve the quality of life for citizens (100%). Human RR are located only in urban areas (100%). Projects are comprehensive and focused on both (1) social goals for improving the riverscape (20.45%), the recreational potential (20.45%), and the city structure (18.18%); and (2) ecological goals for improving the riparian habitats (15.91%). Most of those projects (66%) did not improve the aquatic zone. Human RR median cost was €1,250 per restored meter. Projects intended, as e.g. in Lyon, to improve the social value of the areas by designing green spaces along the waterfront. While WFD RR focuses on aquatic areas, Human RR focuses on riparian areas considering both human and nonhuman species.

Comparison of Urban and Rural Restoration Projects

URR had a higher total expense, restored longer river sections, were implemented on bigger rivers, targeted a broader variety of goals, and combined social and ecological goals more often (60.5%) than RRR (24.6%) (Table 2). Markedly, URR more often aimed at social and riparian improvement than RRR (Fig. 3). A great proportion of RRR focused only on improving the aquatic zone (49.2%). While RR in urban areas were to a large extent (>60% of the cost) paid by French city governments, French RR in rural areas were mostly paid by the French government via funding of the French Water Agencies (Table 2).

We found that the project types were partly related to the context of the project. While Flood protection RR and Human RR were mostly implemented in the urban context, Fish RR were only implemented in the rural areas. However, Blue RR and WFD RR were not significantly located in different contexts.

Discussion

The objectives of this study were to (1) review restoration efforts in France; (2) compare restoration projects in urban and rural contexts; and (3) establish a project typology. Our results showed that the French RR effort was strongly driven by public policies, especially the WFD, varied in the context of the project (urban or rural), and included at least five restoration types.

French RR Effort

In the spirit of previous surveys carried out as part of national and international research programs aimed at sharing experiences (Jenkinson et al. 2006), this study investigated the French restoration effort. The wide range of restoration goals and measures implemented in France is consistent with previously described trends, as e.g. in the United States (Bernhardt et al. 2005; Kondolf et al. 2007), Australia (Brooks & Lake 2007;

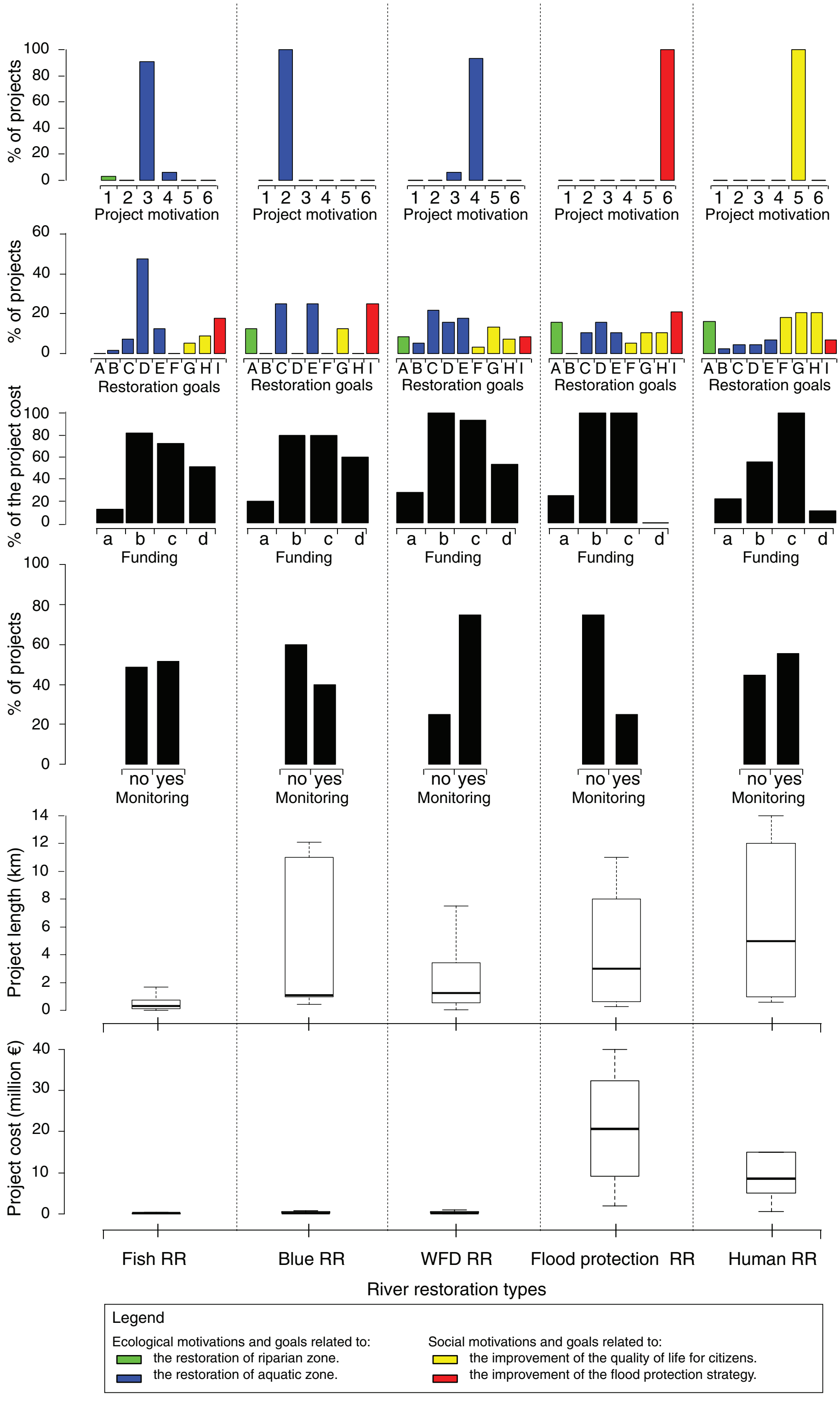

Figure 4. Description of the main variables for the five types of RR projects. 1, Nature conservation (Natura 2000); 2, reestablishment of the migration potential for fish; 3, improvement of the flood protection management strategy; 4, restoration of (sensitive) habitats; 5, improvement of the quality of life for citizens; 6, implementation of the WFD; A, restoring riparian habitats; B, improving the water quality; C, restoring aquatic habitats; D, reestablishing the longitudinal connectivity; E, reestablishing near-natural patterns of the river hydromorphology; F, integrating the river into the city structures; G, improving the esthetics of the riverscape; H, enhancing the recreational potential of the river; I, improving flood protection potential; a, European Union; b, State and Water Agency; c, city government; d, non-governmental organization.

Table 1. Main project-type characteristics and context (rural and/or urban) to which project types are associated (at $p < 0.05$). Full project-type characteristics in Table S4.

Project Type	*Type Label*	*Main Characteristics*	*Localization*
1	Fish RR	Projects (1) are initiated to reestablish the migration potential for fish; (2) focus on the reestablishment of longitudinal connectivity; and (3) are short (mean project length, 960 m).	Rural
2	Blue RR	Projects (1) are initiated to improve the ecological status of the river; (2) were implemented before the WDF came into force; and (3) aim for the restoration of (sensitive) habitats and the reestablishment of the longitudinal connectivity.	Rural
3	WFD RR	Projects (1) are initiated to implement the WFD; (2) aim for the restoration of aquatic habitats, the reestablishment of longitudinal connectivity and near natural patterns of river morphology; and (3) implement an evaluation procedure according to WFD expectations.	Rural and urban
4	Flood protection RR	Projects are initiated to improve the flood protection strategy.	Urban (rural)
5	Human RR	Projects (1) are initiated to improve the quality of life for citizens; (2) aim for the restoration of riparian habitats, the integration of the river into the city structures, the improvement of the esthetics of the riverscape, the enhancement of the recreational potential at the river, and ecological improvement; and (3) are long and expensive.	Urban

Fryirs et al. 2013), Iceland (Aradóttir et al. 2013), Brazil (Costa et al. 2010), and Japan (Nakamura et al. 2006). However, French RR is distinct because of its focus on the aquatic zone rather than on the improvement of the water quality and the riparian zone. First, despite the fact that achieving good water quality is also part of the WFD, this was surprisingly the least frequently reported restoration goal in this study, yet was the most frequent in other countries such as Brazil (Costa et al. 2010), Korea (Kim et al. 2005), and the United States (Bernhardt et al. 2005). In Europe, improving water quality mostly depends on changing the use and management of land in the catchment area (EEA 2012), yet only short river sections were restored in projects. Consequently, these projects attempt to improve the water quality by changing only the river morphology. Furthermore, because water quality is a precondition of river recovery (Binder 2008), we believe that many French RR managers assume that the improvement of water quality has been achieved prior to the restoration project and/or is implemented at a larger scale. Second, French RR projects focused on restoring the aquatic zone, that is, reestablishing near natural patterns of the river hydromorphology, reestablishing the longitudinal connectivity, and improving the aquatic habitats. The emphasis on aquatic ecological goals can be explained by the WFD that puts the aquatic ecology at the center of restoration strategies (Hering et al. 2010). Third, it is worthy to note that in France, improving riparian habitats is not a common RR goal, at least not in rural areas. Conversely, improving the riparian zone was one of the most frequent goals in other countries, such as in the United States (Bernhardt et al. 2005) and Australia (Brooks & Lake 2007; Fryirs et al. 2013). This finding can be explained by European policies. On the one hand, the WFD pays little attention to the riparian zones and wetlands in favor of the river channels. On the other hand, another directive, the Fauna–Flora–Habitat Directive (Council Directive 92/43/EEC) deals with riparian habitats and promotes their conservation rather than their restoration. These findings show that the WFD drives the French national effort; however, the applicability of both European Directives, considering the riparian habitats, needs to be clarified. We plead for the formulation of an ambitious amendment of the WFD demanding also the restoration of riparian habitats.

Comparison of RR in Rural or Urban Contexts

According to the WFD, ecological quality goals are lower for many urban rivers, namely HMWBs, than for natural rivers (EU 2000). Furthermore, urban rivers have a limited restoration potential (Bernhardt & Palmer 2007). Surprisingly we found no significant difference between RR in rural or in urban context regarding ecological quality goals. However, we found that French RR projects in an urban context differ from rural counterparts based on (1) the diversity of restoration goals; (2) the project motivation, namely ecological for RRR and social for URR; and (3) the restored area (aquatic or riparian). While RRR focused on the ecological restoration of the aquatic zone, URR are multifaceted emphasizing not only human well-being but also aiming for ecological restoration, at least of the riparian habitats, albeit with “domesticated” ecosystems (Tockner et al. 2011). There may be several reasons for the difference in motivation between URR and RRR. One of them could be the high social value of urban river reaches in comparison with the rural areas (Kondolf & Pinto 2016). Another reason could be the need for public support for project implementation in urban areas (Norynberg 2001). Because city dwellers suffer from relocation, noise, and temporary damage to the cityscape, their quality of life post project has to be improved to ensure public support (Macedo & Magalhães 2010). A third reason could be, as argued by Ehrenfeld (2000) and supported by our findings, that different restoration trends may be explained by the different types of stakeholders and professions involved. City governments often own riversides, but not the riverbed, and mostly restored the riparian zone of urban rivers, unlike state agencies support and

Table 2. Main differences and similarities (at $p < 0.05$) between rural and URR projects considering main project characteristics.

Theme	*RR Characteristics That Are Specific to Rural Context*	*RR Characteristics That Are Specific to Urban Context*	*RR Characteristics Found in Both Contexts (Rural and Urban)*
Project motivation	Reestablishment of the migration potential for fish.	Improvement of the quality of life for citizens	Implementation of the WFD, Improvement of the flood protection management strategy, Nature conservation (Natura 2000), Restoration of (sensitive) habitats.
Restoration goals		Restoring riparian habitats, Improving the esthetics of the riverscape, Enhancing the recreational potential of the river, Integrating the river into the city structures.	Restoring aquatic habitats, Improving flood protection potential, Reestablishing the longitudinal connectivity, Improving the water quality, Reestablishing near natural patterns of the river hydromorphology.
	Projects have less than three goals Projects rarely (24.6%) combine social and ecological goals	Projects have more than three goals Projects often (60.5%) combine social and ecological goals	
River characteristics	Low annual mean discharges (on average 14.84 m^3/second) Restored natural river	High annual mean discharges (on average 87.70 m^3/second) Restored mostly HMWB	
Project costs	Median cost per meter of €95	more expensive (median cost per meter of €885)	
Funding	20.7% NGO funding 20% EU funding	4.4% NGO funding 2% EU funding	Local and national funding
Project size	Project median length 0.7 km	Project median length 2 km	
Evaluation procedure			Less than 50% of the projects

financed the restoration of the rural river channels avoiding payback measures and relocation of agricultural plots of land.

While previous findings in the United States (Bernhardt et al. 2005; Hassett et al. 2005; Bernhardt et al. 2007) highlighted the importance of URR as part of the national RR effort, it is noteworthy that URR is underrepresented in European databases. Our study showed both (1) that URR projects are important in France, considering the projects number, size, and cost; and (2) that URR effort is larger than currently represented by the ONEMA and RiverWiki databases. We suggest two reasons for this lack of documentation of URR, miscommunication and data loss (Brooks & Lake 2007). It is worrying that these incomplete databases may be used to inform policies and assess restoration efforts. Reporting RR using more secure, long-term, and open source data archiving is needed. The approach adopted in this study seems appropriate to fill these gaps. Ideally, all European institutions should use the standardized RiverWiki database.

The results also showed that URR represents a trend toward socioecological restoration. It therefore provides examples of "River Culture" (Wantzen et al. 2016), that is, harmonizing the needs to reestablish biodiversity and ecosystem services with the interests of the local human population, and creating sites for being in and learning from nature. This finding suggests that URR exceed WFD expectations and that future European policies should build on a review of current URR to provide more guidance for urban rivers, considering both ecological and social restoration.

Practice-Oriented Definitions of RR

Definitions of RR, as the ones formulated by Palmer and Allan (2006) or Clewell et al. (1993), were intentionally broad enough to group all the restoration activities under the same umbrella, namely the aim of improving the ecological quality of rivers, and providing unity in the restoration community (Allison 2007). Our results showed that RR projects in France attempt to meet the definitions related to the intent of minimizing human constraints and targeting long-term ecological functions (Rosgen 1994; Stanford et al. 1996; FISRWG 1998; Palmer & Bernhardt 2006) rather than the ecological definitions focusing on the return to prior degradation status (Clewell et al. 1993; Brookes & Shields 1996; Amoros 2001; Shields et al. 2003). The results of the HMFA showed that French RR efforts are comprised of at least five different restoration types. Previous definitions have defined subcategories of restoration along an ecological gradient (Clewell et al. 1993), but the differences between the project types are sometimes fuzzy. Our typology is transparent and allows a clear project categorization for better communication, comparison, and development of a suitable evaluation procedure. We believe that the typology can be widely applicable and provides the basis for RR comparison. Furthermore, because evaluation of RR should depend on the restoration goals (Morandi et al. 2014), monitoring tools and evaluation procedures should be project-type specific.

It should be noted although that the clustering procedure highly depends on the variables chosen. However, the broad set of variables used in this study covered all essential aspects of RR, from project motivation to project funding. Furthermore, the typology was defined based on a limited number of projects, and other project types may exist as, e.g. Water RR focusing on water sharing (Orthofer et al. 2007; Sagie et al. 2013), or Climate RR to face climate change (Ares & Serra 2008; Kim et al. 2008). However, the legitimacy of Human RR, which were initiated to improve the quality of life for citizens, as restoration could be questioned because according to most of the definitions, RR focus on the restoration of ecological quality (Cairns 1991; NRC 1992; Gore & Shields 1995; Brookes & Shields 1996; Amoros 2001; Bradshaw 2002). Despite the fact that Human RR may be labeled rehabilitation by other authors, we suggest that they are part of the restoration effort because (1) according to Clewell et al. (1993), the term restoration includes many activities such as reclamation, rehabilitation, and mitigation; (2) modern approaches treat social functions as equally important as ecological functions (Palmer & Bernhardt 2006); and (3) even if none of the Human RR changed the hydromorphology of the river as demanded by the WFD, they implemented other ecological restoration measures such as improving the riparian zones. These measures are common in other countries, e.g. in the United States (Bernhardt et al. 2005), and of great ecological value when the planted vegetation consists of endemic riparian plant species (Anderson & Ohmacht 1985). Because none of our collected data informs us about the ecological success of the projects, the ecological value of the RR types cannot be estimated. Finally, evaluation procedures should be project-type specific but we suggest that a set of parameters should be used for evaluation of all the RR to enable comparative studies. Furthermore, more attention should be given to the short-term social outcomes that generate public support and can be leveraged to achieve long-term ecological objectives. However, the potential conflict between recreational uses and the ecological recovery in terms of the return of rare species and increase of the biodiversity should also be investigated.

Our study is a continuation of the worldwide effort to synthesize and publish information about RR. The definition chosen, the method used to create the database, and the major features of the projects investigated are consistent with similar studies (Bernhardt et al. 2005; Jenkinson et al. 2006; Bernhardt et al. 2007; Brooks & Lake 2007; Kondolf et al. 2007; Aradóttir et al. 2013; Morandi et al. 2014). What makes our study unique is that beyond providing a detailed account of the restoration effort, we present a typology of RR projects, which (1) highlights the multiple facets of RR efforts; (2) enables more transparency for communication of RR projects and more suitable project comparison; and (3) contributes to a wider socioecological concept of RR.

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Supporting Information

The following information may be found in the online version of this article:

Appendix S1. Questionnaire form.
Table S1. Synthesis of the main definitions of river restoration published.
Table S2. Project list (*unclear location, #extended clustering).
Table S3. Variables of the database and their modalities.
Table S4. Project type characteristics.

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Paper B

"Zingraff-Hamed, A.; Greulich, S.; Wantzen, K.M.; Pauleit, S. Societal Drivers of European Water Governance: A Comparison of Urban River Restoration Practices in France and Germany. Water 2017, 9, 206." (MDPI and ACS Style)

The first author, Aude Zingraff-Hamed, conducted the study, namely: Identify the knowledge gaps and research questions; Develop the conceptual idea and analytical framework; Design questionnaires; Conduct field survey; and Perform analyses and calculations. All these research steps were discussed with the research supervisors: Prof. Stephan Pauleit, Prof. K. Matthias Wantzen, and Dr. Sabine Greulich. Contribution was written by Aude Zingraff-Hamed in collaboration with all the co-authors.

French Abstract/Résumé en langue française :

L’article B publié dans *Water* le 10 Mars 2017 et intitulé *Societal Drivers of European Water Governance: A Comparison of Urban River Restoration Practices in France and Germany* (« Les forces motrices sociétale de la gouvernance Européenne de l’eau : Une comparaison des pratique de restauration des rivières urbaines en France et en Allemagne ») expose les résultats de l’étude comparative entre 75 projets de restauration de rivières urbaines réalisés entre 1980 et 2015 dans les villes de plus de 100 000 habitants en France métropolitaine et en Allemagne. L’étude a trois objectifs : a) Examiner les différentes forces sociétales influençant les pratiques de la restauration. b) Identifier différente perception du concept de restauration des rivières urbaines. c) Étudier l’influence des aménagements passés sur les pratiques actuelles de la restauration.

Considérant les composants du système socio-écologique, deux forces sociétales ont été identifiées et étudiées : la gouvernance européenne de l’eau et la demande citoyenne pour une meilleure qualité de vie marquée par l’intérêt croissant pour une esthétique des vitrines fluviales et leurs aménagements récréatifs. Les projets de restauration ont été identifiés sans jugement de leur valeur écologique effectuant un recensement téléphonique et interrogeant systématiquement les autorités de toutes les villes de plus de 100 000 habitants (N=132). Des interviews directes ont été menées utilisant un questionnaire à choix multiple afin d’apporter la même qualité de données pour chaque projets. Cette étude comparative utilisant R version 1.31.3 a été réalisée se basant sur les caractéristiques principales des projets telles que l’élément initiateur du projet, ses objectifs, les mesures réalisées, l’état morphologique de la masse d’eau avant les travaux de restauration et les dates de début et de fin de projet. De plus, afin d’obtenir des données qualitative, les interviewés ont également fourni une courte description du projet expliquant l’élément déclencheur du projet, ses objectifs et ses particularités. Une analyse textuelle basée sur ces données qualitatives formulées par le maître d’œuvre ou l’autorité responsable des travaux a été réalisée en utilisant le logiciel IRaMuTeQ 0.7 alpha 2 combinable avec R

Les résultats suggèrent que malgré un cadre législatif européen commun, les pratiques de restauration varient entre les pays étudiés. La Directive Cadre sur l’Eau influence davantage les projets urbains réalisés en Allemagne qu’en France. Ces derniers sont davantage inspirés par la demande social pour une meilleur qualité de vie et une

(re)connexion entre les habitants leur rivières. En France, la variété de projets est plus importante qu'en Allemagne, où la restauration passe principalement par des changements de la morphologie fluviale. Enfin, la morphologie urbaine, l'aliénation de la rivière au tissu urbain et l'histoire de la relation homme-nature au sein des pays influence fortement les tendances de restauration.

Pour conclure, la directive cadre a établi les standards de la restauration et influence les pratiques. Cependant, cette étude met en avant les limites de la gouvernance européenne au profit des moteurs locaux notamment sociaux. Ces derniers sont en partie définis par les gouvernances passées et différentes perceptions de la relation homme-nature entre les pays mais de nombreuses raisons socio-culturelles peuvent expliquer les différences de pratiques entre les pays. Il est important de les considérer afin d'éviter une rupture entre gouvernance, demande des usagers et pratiques de la restauration.

Mots clefs : relation homme-nature, objectif de la restauration, socio-écosystèmes fluviaux, écologie urbaine, Directive Cadre sur l'Eau water

MDPI

Article

Societal Drivers of European Water Governance: A Comparison of Urban River Restoration Practices in France and Germany

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Abstract: The European water governance took a decisive turn with the formulation of the Water Framework Directive (WFD), which demands the restoration of all water bodies that did not achieve sufficient ecological status. Urban rivers are particularly impaired by human activities and their restorations are motivated by multiple ecological and societal drivers, such as requirements of laws and legislation, and citizen needs for a better quality of life. In this study we investigated the relative influence of socio-political and socio-cultural drivers on urban river restorations by comparing projects of different policy contexts and cultural norms to cross-fertilize knowledge. A database of 75 projects in French and German major cities was compiled to apply (a) a comparative statistical analysis of main project features, i.e., motivation, goals, measures, morphological status, and project date; and (b) a qualitative textual analysis on project descriptions and titles. The results showed that despite a powerful European directive, urban river restoration projects still keep national specificities. The WFD drives with more intensity German, rather than French, urban river restoration. This study showed the limits of macro-level governance and the influence of micro-level governance driven by societal aspects such as nature perception and relationships between humans and rivers.

Keywords: human-nature-relationships; restoration targets; riverine socio-ecosystems; urban ecology; Water Framework Directive

1. Introduction

Water governance refers to political, social, economic, and administrative systems that intend to improve water resource management [1]; for example, promoting sustainable development of water resources and services. In an urban context, rivers have been pervasively modified for various uses and to reduce flood risks [2,3]. This development has resulted in severe ecological dysfunctions described as the "urban stream syndrome", which is characterized by flashier hydrography, elevated concentrations of nutrients and contaminants, altered channel morphology, reduced biotic richness, and increased dominance of tolerant species [4]. River restoration aims to re-establish ecological functions of running water ecosystems [5–7]. According to the definition formulated by Clewell [7] a broad spectrum of restoration activities, e.g., rehabilitation, reclamation, and revitalization, are gathered under the term "restoration" and differ in their ecological quality goals. Urban river restorations (URR) generally need to integrate ecological goals, physical constraints [8], flood protection for close-by areas, as well as increasing demands for recreational uses by citizens [9,10]. URR are motivated by multiple ecological and societal drivers, especially (a) governmental interventions setting new requirements of legislations and laws, such as the ecological quality goals demanded by the Water Framework Directive [11,12]; and (b) citizens' increasing demands for a better quality of life, e.g., improvement of the recreational potential of the riverine area [11]. While many urban river restoration projects have been initiated [13,14], a review of published articles from the Web of Knowledge carried out by Francis [15] showed that scientific studies on urban freshwater body restorations remain rare, especially in the case of major cities. However, the publication of feedback is an important issue to fertilize restoration governance, sciences, and practices. When studies on URR exist, they focused on the success of the restoration in terms of ecological recovery [16] and chemical quality improvement [15]. Little concern has been given to societal aspects [17–19], e.g., how social, cultural, recreational, political, and historical contexts influence water governance and practices in the case of urban river restorations.

The European water governance took, in 2000, a decisive turn with the signature of the Water Framework Directive (WFD). The WFD is one of the most ambitious environmental legislations [12,20] and intends to ensure a good ecological quality [21] of all water bodies inside the European Union, considering biological, hydro-morphological, and chemical characteristics. However, the European political landscape is heterogeneous. Authorities in each European member state incorporate rights and obligations of European directives into their own law. Historic-cultural differences are important inside Europa and each country has developed in the past its own policies for slightly different purposes [22,23]. Hence, Europe showed a wide variation of water governance, e.g., policies, before and after the WFD came into force [20,24,25]. This background suggests that, despite the fact that the WFD is a powerful tool, it may differently influence the national water governance failing in homogenizing the restoration effort. The understanding of the country-specific differences of water governance may help to cross-fertilize systems, and to formulate effective E.U. policies.

Cross-national comparative research is an effective tool to understand different societal responses to common issues [26], and to cross-fertilize knowledge [27]. This study investigates the variability of URR in different policy and cultural contexts by choosing the cases of projects in major cities in France and Germany to (a) cross-fertilize knowledge; and to (b) investigate the influence of macro-level water governance on micro-level restoration practices in these European countries. The comparison between France and Germany is particularly interesting since they both have a long-standing tradition of restoration and, therefore, a large number of projects. Furthermore, they developed in the past similar strategies in environmental policies as, for example, in flood risk reduction [22]. However, major differences exist. First, a Europe-wide comparative study showed that fundamental parts of landscape planning policies and landscape approaches differ between France and Germany [28]. German approaches are usually more ecologically-oriented than French, which underscore human needs and usages. Social concerns and cultural understanding of nature also differ between both countries [26,29,30] and influenced the formulation of planning strategies, as well as the design and management of urban green spaces [31–34]. Studies showed that, in France, citizen preference for controlled nature is higher than in Germany, where urban parks have a more natural design comparing, for example, major parks in Paris and Berlin [30]. Since urban riverine areas are commonly used as urban green spaces, urban river restoration practices may also mirror this difference of nature preferences. Accordingly, we expect to find, in France, restoration projects of the "rehabilitation" type, according to the definition formulated by Clewell [7] namely focusing on the reestablishment of ecosystem processes, productivity, and services, whereas German projects may target a more ecologically-oriented river restoration. Additionally, water governance prior signature of the WFD differed between the countries, e.g., concerning water quality control policies [23], and different river management and planning strategies [20]. These differences may have contributed to the achievement of different river ecological status at the date of the ecological inventory of European freshwater in 2004 [35]. Different river status in the past may influence the current river restoration strategy. The understanding of country-specific and historical-cultural influence on the restoration practices may provide valuable information for further development of the water governance strategy avoiding disconnection between policy, practices, and governance.

Accordingly to this background, this study aims to investigate the limit of the common framework caused by the influence of socio-cultural drivers on national water governance by comparing urban river restoration projects in France and Germany. We hypothesized that, despite a common framework orchestrating the ecological restoration of the European rivers, between both investigated countries: (1) the driving forces for the restoration effort, e.g., the influence of the WFD, differ; (2) the restoration approaches differ, namely, that the German approach may be more ecologically-oriented than the French, which may be more human-oriented, mirroring higher preferences for nature-control; and (3) antecedent conditions influence different restoration strategies.

2. Materials and Methods

2.1. Sampling of Restoration Projects

The study has been carried out on all the German and French major urban areas (n = 132) with population sizes larger than 100,000 inhabitants at the last demographic census; in France, counted in 2013 and published online via the Institut National de la Statistique et des Etudes Economiques [36] and, in Germany, counted in 2011 and published via the Statistisches Bundesamt [37]. Since existing cross-national databases of river restoration projects were highly fragmented, often relying on voluntary entries, and contained poor information about URR, we collected data through direct phone interviews. We identified 153 contact persons, i.e., stakeholders or officers in regional urban planning agencies, water management offices, river basin district offices, local governments, staff of consulting or planning firms, and non-governmental organizations, using the staff listing of river basin districts and city governments. We asked them if urban river restorations have been or will be implemented into the 132 urban areas and if they could provide contact information. The overall response rate was 65% (Table 1). We found that more than a half of the surveyed major urban areas (>58%, at least n = 76) had implemented URR. However, considering the cities which did not participate to the survey may also have implemented a project, the urban river restoration effort could reach 90% of the French and German major urban areas. We recorded all of the projects with no prior judgment about their legitimacy as restoration following the approach used for the U.S. river restoration survey [13]. Only implemented projects, or those in an advanced state of planning, were recorded. We established a database of 75 URR implemented between 1980 and 2015 (Figure 1, Table A1), namely 32 French urban river restorations (FURRs) and 43 German urban river restorations (GURRs).

Table 1. Overview of the participation rate at the survey.

Country	Number of Urban Rivers	Number of Cities with URR		Number of Cities without URR	Number of Cities without Answer
France	n = 53	n = 32	60.37% of French urban rivers	n = 10	n = 11
Germany	n = 79	n = 43	54.43% of German urban rivers	n = 1	n = 35

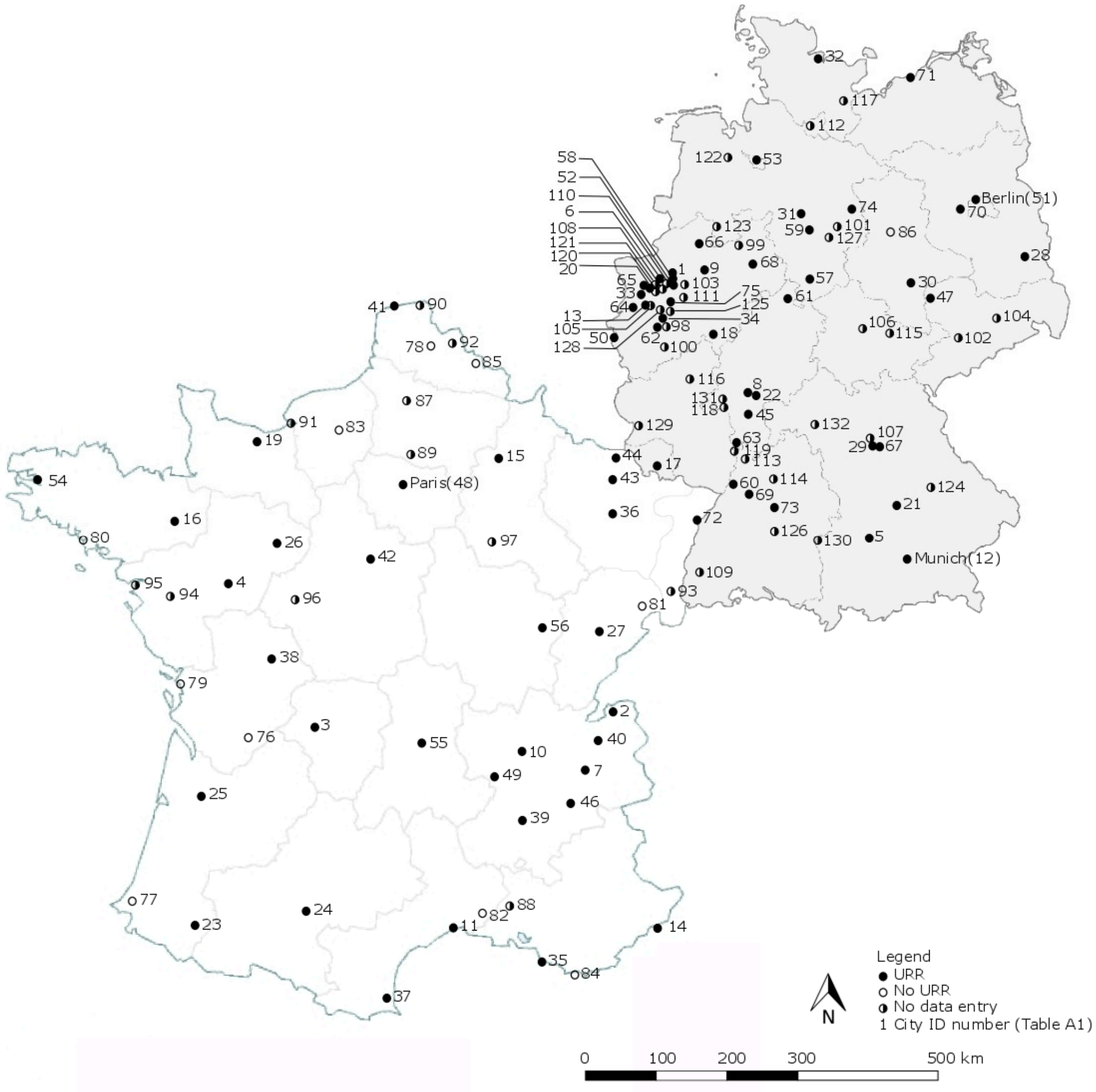

Figure 1. Map of the 75 urban river restorations (URR) in France and Germany, 11 urban areas without river restorations (no URR), and 46 urban areas without an entry.

2.2. Data Collection

The contact people recommending specific urban river restoration projects were contacted between 10 April 2013 and 10 November 2013. According to guidelines for river restoration survey, each contact person was directly called [13,38,39]. The competence of the contact person was previously checked by a preliminary short interview to assure in-depth political, administrative, and technical knowledge of the restoration project. Finally, interviewees were asked either (a) to fill out the questionnaire and to return it per email or per post; or (b) to arrange an interview by phone. Contact persons who agreed to fill the questionnaire received follow-up calls to encourage a response after two weeks. One researcher carried out the entire procedure to avoid operator bias. Interviewees received the filled form per mail to ensure proper reporting. The 75 project entries of the database resulted from 34 oral and 98 written responses.

2.3. Variables

The interview form (Form A1) was direct, structured, and composed of partly closed questions [40]; namely, few questions were asked, were formulated in the same order, and interviewees mostly had to choose from a restricted list of answers. We used the same form for both oral and written procedures. To introduce the interview, the interviewee should be given a short description of the project (2–3 sentences) mentioning the project context and the restoration goals. Then the interview consisted of the following five groups of questions: What is the project title? When was the project implemented? What is the project motivation? What was the morphological status of the river before the project? Which measures have been implemented? The variables are listed in Table A2. The list of restoration measures and goals have been obtained by reviewing previous publications on river restoration surveys [11,13,38,41–43]. We gathered similar goals under broader labels as, for example, grouping channel reconfiguration, bank stabilization, dam removal, etc., under the goal "reestablishment of near-natural pattern of the river hydromorphology". We identified nine project goals: improvement of the flood protection potential, improvement of the water quality, restoration of the riparian habitats, restoration of the aquatics habitats, reestablishment of the near-natural pattern of the river hydromorphology, renewal of the city, enhancement of the recreational potential of the river, reestablishment of the longitudinal connectivity, and reduction of pressures caused by hydro power plants. We kept all of the mentioned measures. Since implemented measures could meet diverse goals, interviewees had to choose the purpose of the mentioned implemented measures. It should be also noted that the project motivation, namely the single main reason of existence of the project, differs from the restoration goals, which could be multiple. The project title and the short project description were translated into English.

We verified the answers about morphological status of the rivers against aerial photographs to ensure that the interviewees' responses reflected the actual state of the rivers. We found no differences. Since chemical status had been assessed for less than 50% of the E.U. rivers [35] and local sampling did not match with the studied areas, we ignored this variable.

2.4. Data Analyses

We applied a comparative analysis between projects in France and Germany to assess (dis) similarities between the projects combining statistical analyses using R [44] version 1.31.3 and textual analysis using IRaMuTeQ 0.7 alpha 2 supported by R [45], which is a qualitative lexical data analysis software developed by the research team LERASS from the Universities of Toulouse and of Montpellier, France. All analyses were considered significant at $p < 0.05$.

First, to investigate the difference of socio-cultural drivers of the restoration effort, such as the implementation of the WFD or the increasing recreational demands (hypothesis 1) we performed tests for equality of proportions on the variables project motivation (Figure 2), restoration goals, and the date of implementation (before or after 2000). Results were synthesized into Table 2. Furthermore, an analysis of word co-occurrences on project short descriptions informed more deeply about the restoration drivers.

Second, to investigate the different understanding of the restoration approach (hypothesis 2), we compared the frequencies of the term into the project titles. We also performed a comparison of frequencies of implemented measures for each restoration goal between (a) projects located in France or in Germany; and between (b) projects including or not the term restoration into their title. The results of this analysis are presented in Figure 3.

Third, to investigate the difference of antecedent conditions mirroring different historical relationships between citizens and urban rivers (hypothesis 3), we performed tests for equality of proportions between the countries on the variables related to the morphological status of the river prior to the implementation of the restoration, i.e., straightened channel, existence of highways along the riverbank, channelization, impervious embankments, impervious river beds, longitudinal connectivity damage, buried rivers, and navigable rivers. Results of this comparison are synthesized into Table 2. Furthermore, we performed an analysis of word co-occurrences on project short descriptions, excluding articles, conjunctions, and prepositions, and gathering similar words, e.g., restore and restoration. The words which did co-occur within statements indicate meaningful associations [46].

Table 2. Synthesis of the differences and similarities between urban river restorations in France and Germany.

Themes	River Restoration Characteristics that Are Specific to Germany (% of the projects in Germany)	River Restoration Characteristics that Are Specific to France (% of the projects in France)	River Restoration Characteristics Found in Similar Proportion in Both Countries (% of the project in both countries)
Project motivation	Implementation of the WFD (60%)	Improvement of the quality of life for citizens (55%)	Improvement of the flood protection management strategy (10%–20%), Other motivations (10%–20%)
Morphological status	Straightened channel (83%), existence of highways or national roads along the riverbanks (6%)	Straightened channel (60%), existence of highways or national roads along the riverbanks (50%)	Channelized (>87%), impervious embankment (>97%), impervious bed (66%), continuity damaged (55%–65%), buried (13%–16%), and navigable (20%–27%)
Project date			Restoration boom after 2000
Project title	Restoration (51.2%)	Reclamation (18.7%), restoration (12.5%), or rehabilitation (9.4%)	
Discourse	Used of word pair River/WFD	Used of word pair City-River, and importance of recreational goals	Mention of the WFD
Measures to improve the flood protection potential			Dyke removal, dyke renewal or construction, creation of shallow water area, creation of flood depression area, and increase retention potential of the floodplain
Measures to improve the water quality			Construction of water treatment plant, planting of green buffer area, treatment of rainwater, and removal of rainwater outlet
Measures to restore riparian habitats	Creation of Flooded areas (18%), and planting of vegetation succession (58%)	Creation of Flooded area (0%), and planting of vegetation succession (84%)	Creation of ponds, creation of wetlands, improvement of the vegetation mosaic, change of the management concept, riparian forest conversion, planting of riparian forest, extensive uses of the riparian area, species reintroduction, and invasive management
Measures to restore aquatic habitats	Deadwood management (15%), and improvement of the erosion or the sedimentation potential through morphological changes (25%)	Deadwood management (0%), and improvement of the erosion or the sedimentation potential through morphological changes (6%)	Riverbank flattening, creation of shallow water area inside the water course, creation of temporary water, improvement of the flow heterogeneity, improvement of the flood depression potential, and creation of spawning area
Measures to reestablish near-natural patterns of the river hydromorphology	Removal of artificial bank constructions (68%), and connection of sidearm or tributaries (5%)	Removal of artificial bank constructions (39%), and connection of sidearm or tributaries (32%)	Substrate excavation, river bed expansion, water course extension, river embankment modeling, meandering, reopening of tributaries, river bed raising, and creation of island
Measures to renew city planning	Improvement of the accessibility (30%), creation of shopping area (0%), creation of recreational area (15%), and city reconstruction (7%)	Improvement of the accessibility (87%), creation of shopping area (13%), creation of recreational area (65%), and city reconstruction (39%)	Creation of new connections, (e.g., bridge), road removal, creation of residential areas, creation of business parks, and creation of piers
Measures to enhance the recreational potential at the river	Creation of paths (65%), planting of recreational grassland (15%), creation of playground (22%), design park (35%), rehabilitation of towpath (32%), creation of watersport facilities (0%), and creation of recreational pier (0%)	Creation of paths (97%), planting of recreational grassland (52%), creation of playground (58%), design park (71%), rehabilitation of towpath (74%), creation of watersport facilities (19%), and creation of recreational pier (13%)	Creation of platforms, enable contact with nature, creation of fitness trails, creation of swimming facilities, and nature protection and conservation pedagogic opportunities
Measures to reestablish the longitudinal connectivity	Bed glide removal (35%), and creation of bypass channel (17%)	Bed glide removal (9%), and creation of bypass channel (0%)	Weir removal, creation of fish pass, slide removal, and creation of bed ramp
Measures to reduce pressures caused by hydropower plant			Increase residual water, decrease residual water, construction of hydropower plant, and removal of hydropower plant

3. Results

The investigation of the restoration driving force (hypothesis 1) showed major differences between the countries. French and German authorities restored their rivers with the same intensity (between 50% and 60% of the FURR and GURR). Most of the projects (>80%) in both countries were implemented after 2000, the date of signature of the WFD. However only 45% of the projects were initiated to implement the WFD. Differences between countries existed with regard to most variables and are summarized in Table 2. The most frequent project motivation in Germany was the implementation of the WFD (60%), while the desire for a better quality of life for the citizens was the most declared motivation in France (55%) (Figure 2). Accordingly, measures intending to improve the recreational potential and the integration of the river into the city are more often implemented in France than in Germany (Table 2), i.e., planting of recreational grassland (52% of the FURR against 15% of the GURR), creation of playgrounds (58% of the FURR against 22% of the GURR), improvement of the river accessibility for recreational users (87% of the FURR against 30% of the GURR). Before the WFD came into force, few projects had been implemented in both countries: n = 5 in France and n = 8 in Germany. However, already at this time, an important part of GURR were initiated to improve the ecological status of the rivers (50%), whereas this motivation was mentioned only once in France. Textual analysis on the project descriptions also showed that communications about projects in Germany referred more often to the term "restoration" and the WFD than communications about French projects (51.2% of GURR against 12.5% of FURR).

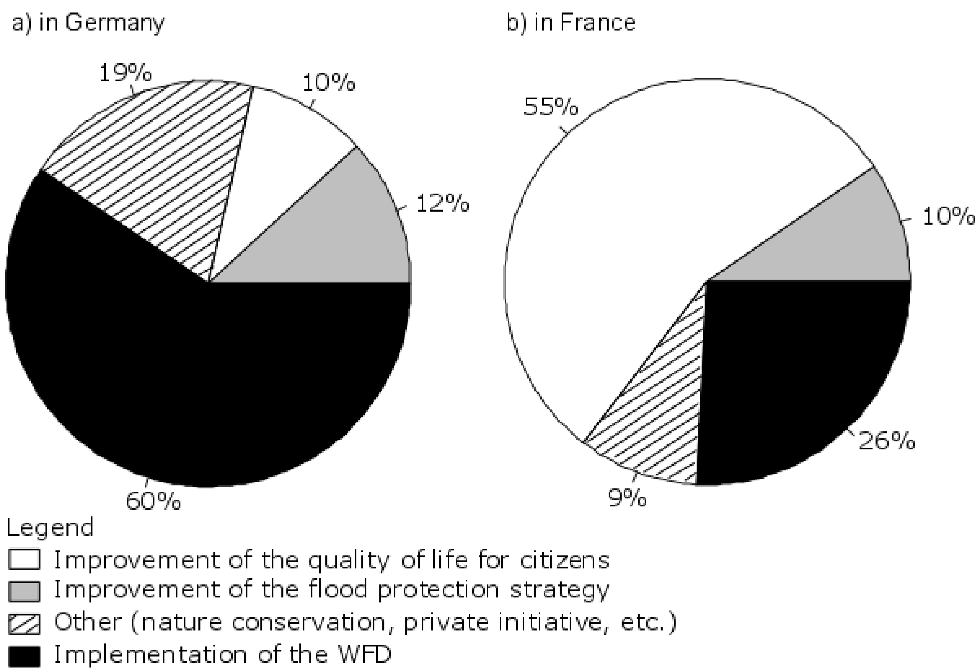

Figure 2. Pie chart of the main project motivations (**a**) in Germany, and (**b**) in France.

The comparison of the understanding of the restoration approach between the countries (hypothesis 2) showed that the French approach is broader than the German approach, which focuses on the ecological improvement according to the WFD. The comparison of the terms used in the project title showed that the word "restoration" was the most frequent in Germany (51.2% of the projects, n = 22) whereas, in France, the diversity of terms was higher, e.g., reclamation (18.7%, n = 6), restoration (12.5%, n = 4), and rehabilitation (9.4%, n = 3). The analysis of word co-occurrences on the short project descriptions showed that, in France, the relationship between the city (used for 46% of the projects) and the river (used for 75% of the projects) is meaningful with a co-occurrence for 32% of the projects, whereas in Germany the terms WFD (used for 50% of the projects), restoration (used for 42% of the projects), and ecological (used for 35% of the projects) are the most frequent terms of the project descriptions and have a high degree of co-occurrence (46% of the projects). The investigation on the relationship between the project title and the implemented measures showed that: (a) in both countries, projects labelled "restoration" implemented similar measures and with similar frequency (Figure 3). For example, French and German projects labelled "restoration" intend to improve physical habitats by reestablishing (i) near-natural patterns of the river hydromorphology through artificial bank removal, embankment remodeling, and bed expansion; and (ii) the longitudinal connectivity through river bed glide removal and construction of fish friendly solution, such as ramps and fish passes; (b) the main differences between projects in France and Germany concerned projects with title other than "restoration", e.g., rehabilitation. French projects not labelled "restoration" significantly differed from French projects labelled "restoration" and German projects. The difference between the German projects labelled "restoration", or not, is less significant than in France. The differences concern ecological and social measures.

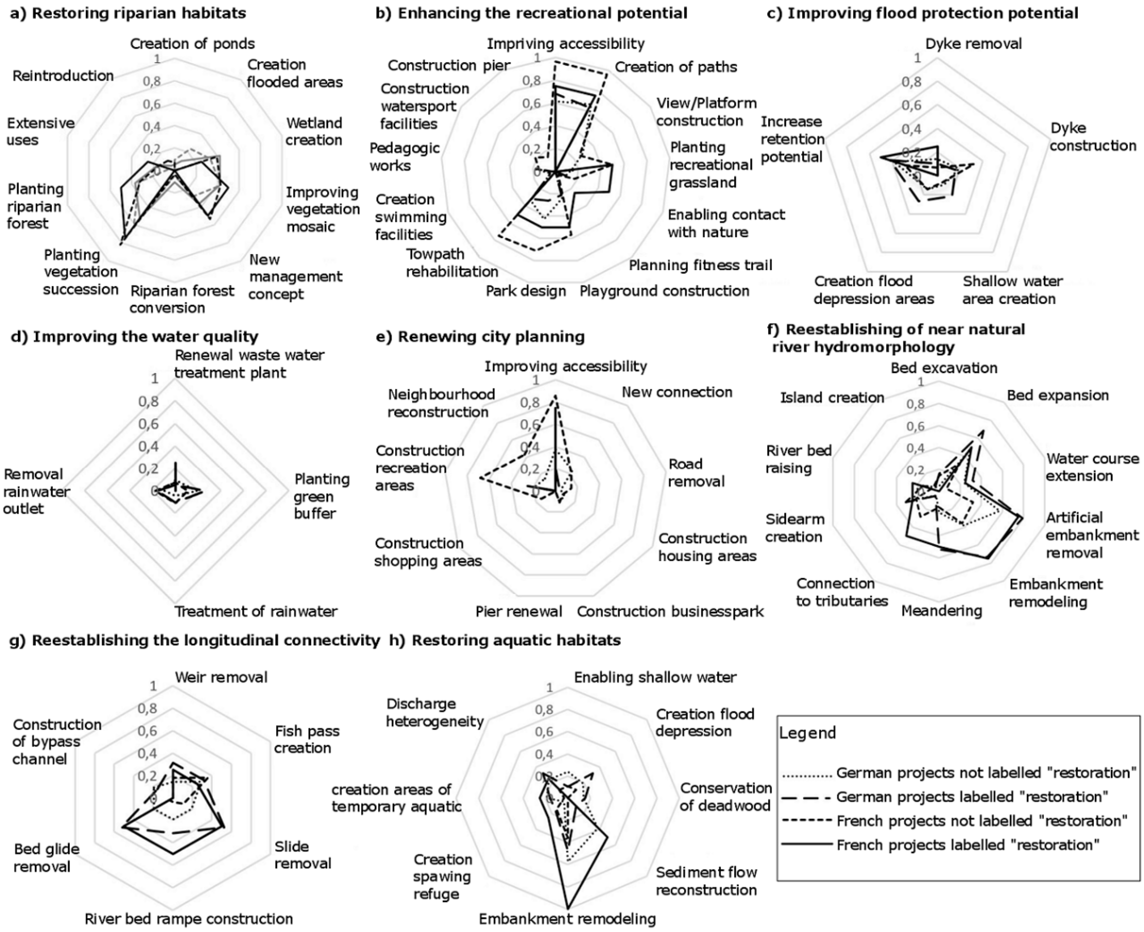

Figure 3. Frequency of implementation of the restoration measures regarding restoration goals, title of the project and the country where the project was implemented.

The investigation of different antecedent morphological conditions between the countries (hypothesis 3) was conclusive. The morphological pattern of the rivers prior to restoration differed with regard to two characteristics (Table 2): the straightened river channel and the existence of highways or national roads along the riverbanks. German rivers were straighter than French rivers (83% of the restored urban river sections in Germany against 60% in France) and highways more often bordered restored river sections in France (50%) than in Germany (6%). Removal of roads at the riverside as part of URR was not significantly more frequent in France than in Germany. The analysis of the short project descriptions showed that the relationship between citizens and their rivers is an issue in France (46%), but not in Germany.

4. Discussion

The objectives of this study were to provide a detailed account of the French and German urban river restoration efforts, comparing projects in both countries and focusing on their political and socio-cultural drivers. Our results showed that: (a) in both countries, the urban river restoration effort is partly driven by EU policy, but with different intensity; (b) the understanding of the restoration approach in both countries is similar, but differs for projects that are not labelled as restoration; and (c) historical relations between citizens and their rivers highly influence the restoration strategy and consequently practices.

The WFD is one of the most ambitious environmental EU policies and is a driver of the European restoration effort and river governance [12]. The WFD intends to homogenize the EU water policy and demands to protect and/or restore all EU water bodies. France and Germany qualified the demands of the WFD as obligations of results [47]. However, the study showed that the influence of the WFD on the restoration practices is limited. In particular, in France, where only a quarter of the URR has been directly motivated by the implementation of the WFD, the improvement of the quality of life for citizens was the most frequent project motivation. This finding shows a disconnection between macro-level policy and micro-level governance and practice. However, despite the fact that Aradóttir [11] stated in the case of Iceland, that policies have limited impact on restoration practices and governance, the WFD seems to be a great value to set ecological standards of the European restoration effort. The study showed that, despite this common framework, both countries developed different URR practices and approaches underscoring the strength of micro-level societal drivers. German URR is ecologically oriented, as defined by the WFD, which places aquatic ecology in the center of river restoration [12]. In France, the restoration approach is understood more broadly and projects were both ecologically and societally oriented. The differences between the countries may have several socio-cultural reasons and indicate the importance of national contexts.

First, according to a Europa-wide comparative study of landscape planning policies and landscape approaches [28], our results showed that the German urban river restoration approach focuses more on ecological improvement than French projects, which are more comprehensive. Germany is, historically, an industrialized country with high population density [26] and related pollution problems. The Sandoz Industry disaster (1986) causing major pollution of the Rhine River initiated in Europe, and more particularly in Germany, changes of environmental perception and governance strengthening policy for nature conservation and (river) restoration [48]. According to this background, the German ecological river restoration trend was initiated long before the WFD came into force, for instance, with the emblematic Project Emscher restoration (1992–2020) [49,50]. This circumstance may explain why German water governance is particularly related to an ecological approach similar to the one formulated by the WFD. This finding underscores the difficulties of changing water governance trends as also described in the Philippines [51].

Second, previous study showed that recreational demands are, since the 1990s, increasingly important motivations of restoration [11]. Citizens value the benefits of urban green spaces according to various subjective parameters, such as their perception of the area [29]. However, a comparative study between France and Germany showed that nature perceptions of city-dwellers differ between both countries in their preference for nature-control, namely, that it is higher in France than in Germany [30]. As expected from this background we found that French URR implemented measures quite well for the improvement of the recreational potential via man-made recreational facilities (e.g., playgrounds) in comparison with German URR. On the contrary, measures, such as the keeping of deadwood, at the river banks could not be observed in France, probably because it did not fit with the perception of a well-kept urban landscape. We assume that, in the context of socio-ecological change perceptions of nature, may evolve apace and that educational work should guide perception changes, ensuring public support to ecologically-oriented projects.

Third, urban-crossing rivers have social values beyond the ecological [52]. The emotional and spiritual relationship between human beings and the rivers impact the governance and drivers of river conservation and restoration [9] . We suggest that the historical relation between citizens and their rivers influenced the project motivation and related implemented social measures. This can be evidenced by the morphological development of the river. We found that French and German urban rivers had similar morphological status prior to restoration. The single significant difference between the restored urban river sections in these countries was the more frequent existence of urban express road or highways on the riverbanks in France. Urban highways have been built in Europe, as in post Second World War North America, during the auto city trend using vacant plot of land [53]. German urban riversides are relatively free from urban highways, in comparison with France, even if exceptions exist. While the French state owned the major part of the urban riverside that offers a convenient plot of land for the urban highway construction [54], neglecting social and ecological values of the river, construction of most of the German major cities infrastructure benefited from the tabula rasa caused by U.S. bombing during the Second World War, offering vacant plots of land [55]. Interestingly, the four German URR of our sample bordering an urban highway, i.e., Saarbrücken, Siegen, Darmstadt, and Frankfurt am Main, are outliers of the German trend and have been initiated to improve the quality of life for citizens, much like most of the French URR. The finding suggests that the existence of highways on the riverside strongly influences the ecological and social restoration potential. However, we found that highways have not been removed during the restoration process. This is understandable considering that the URR stakeholders are mainly local or regional, whereas the highway removal can only be decided by national authorities.

Our study presents an original dataset of URR, a group of river restoration projects previously underrepresented in national, as well as European databases, and in publications. The extensive survey and the high participation rate led to a high significance of our results. However, we cannot definitively affirm that studied societal drivers, i.e., political and socio-cultural, alone accounted for country specific restoration trends. Other drivers or other unknown variables may also have contributed to this effect. Finally, according to the goals of the study, we presented an overview of the trends. Exceptions exist in the dataset.

5. Conclusions

This study explored the influence of some societal drivers, i.e., political and socio-cultural, on the urban river restoration trends in France and Germany. We found that the WFD assures an ecological standard and the same understanding of river restoration in Europe, but drives with more intensity urban river restoration efforts in Germany than in France. The study showed that micro-level drivers still overtake E.U. policy. The differences of practices between the countries may have several socio-cultural reasons and indicate the importance of considering national and local contexts to avoid disconnection between policy, practices, and governance.

First, our results highlighted the historical ecologically-oriented water governance in Germany. However, even if the French urban river restoration effort is more often motivated by the improvement of the quality of life for citizens than by the implementation of the WFD, ecological improvements are still a major concern.

Second, national urban river restoration trends mirror different relationships between humans and nature. Understanding the implications of city dwellers' perceptions and expectations for urban open space planning is an important issue to estimate public endorsement, orchestrate public participation, support educational work, and ensure coherence in the water governance strategy.

Third, previous water governance strategies indirectly, but strongly, drive the current river restoration effort. Reversing historical morphological changes and restoring social and ecological functions need cooperation between stakeholders working in different agencies and government.

Taken together, our findings demonstrated that, despite powerful European legislation, the urban river restoration efforts still maintain strong national specificities. The study demonstrates that socio-cultural differences challenge the unity of E.U. water governance. Despite common requirements for ecological quality of the freshwater bodies within the European Union, the variation of societal driving forces and other contextual conditions would make it difficult if not impossible to develop a “silver bullet” approach for urban river restoration. However, a comparison of projects based on rigorous analytical frameworks, as initiated with this study, is helpful for supporting further development of guidelines for urban river restorations.

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Appendix A

Table A1. List of the surveyed urban areas with, first, those with urban river restoration project(s); second, those without urban river restoration projects; and, third, those that did not answer the survey.

	City Name	Country	Project Title (Original Language)
Cities with URR			
1	Recklinghausen	Germany	Wiederherstellung der Durchgaengigkeit des Baerenbachs
2	Annemasse	France	Contrat rivière
3	Limoges	France	Contrat rivière
4	Angers	France	Rives Nouvelles
5	Augsburg	Germany	Wertach Vital
6	Bottrop	Germany	Emscher Zukunft
7	Chambéry	France	Confluence Leysse et Hyeres
8	Frankfurt am Main	Germany	Main 2015
9	Hamm	Germany	Lippeaue
10	Lyon	France	Berges du Rhône
11	Montpellier	France	Lez Vert
12	Munich	Germany	Neues Leben fuer die Isar
13	Neuss	Germany	Pilotprojekt Gnadenthal
14	Nice	France	Coulee verte
15	Reims	France	Trame verte
16	Rennes	France	Prairies Saint-Martin
17	Saarbruecken	Germany	Stadtmitte am Fluss
18	Siegen	Germany	Siegen zu neuen Ufern
19	Caen	France	Parc periurbain Orne Odon
20	Duisburg	Germany	Rhein Park in Duisburg
21	Ingolstadt	Germany	Stadt Park Donau
22	Offenbach am Main	Germany	Mainuferpark
23	Pau	France	Parc naturel urbain du Gave de Pau
24	Toulouse	France	Parc Garonne
25	Bordeaux	France	Plan Garonne
26	Le Mans	France	Programme de lutte contre les inondations
27	Besançon	France	Amenagement des bords du Doubs
28	Cottbus	Germany	Umgestaltung der Spree
29	Fürth	Germany	Neugestaltung der Gewaesser Talraum in Pegnitz
30	Halle	Germany	Umgestaltung der Saale
31	Hannover	Germany	Umgestaltung der Ihme
32	Kiel	Germany	Naturnahe Umgestaltung des Gewaessersystems Hasseldieksau und Struckdieksau
33	Krefeld	Germany	Deichsanierung an der Rhein
34	Leverkusen	Germany	Naturnahe Umgestaltung der Dhuenn
35	Marseille	France	Réamenagement de l’Huveaune
36	Nancy	France	Aménagement de la rivière Meurthe
37	Perpignan	France	Réamenagement de la Têt
38	Poitiers	France	Aménagement des berges du Clain
39	Valence	France	Aménagement des canaux
40	Annecy	France	Requalification du Fier
41	Calais	France	Revalorisation des canaux et berges

Table A1. *Cont.*

	City Name	Country	Project Title (Original Language)
Cities with URR			
42	Orléans	France	Requalification de la rive Sud
43	Metz	France	Renaturation de la Seille
44	Thionville	France	Renaturation des berges de Moselle
45	Darmstadt	Germany	Offenlegung des Darmbachs
46	Grenoble	France	Reouverture du Verderet
47	Leipzig	Germany	Offenlegung der Pleisse und des Elstermuehlgrabens
48	Paris	France	Réouverture de la Bièvre
49	Saint-Etienne	France	Réouverture du Furan
50	Aachen	Germany	Renaturierung der Wurm
51	Berlin	Germany	Renaturierung der Panke
52	Bochum	Germany	Renaturierung der Emscher
53	Bremen	Germany	Renaturierung Weserufer
54	Brest	France	Restauration de la Penfeld
55	Clermont-Ferrand	France	Restauration de la Tiretaine
56	Dijon	France	Restauration de continuité écologique au Lac du Tir
57	Goettingen	Germany	Renaturierung der Leine
58	Herne	Germany	Renaturierung der Emscher
59	Hildesheim	Germany	Renaturierung Grabens
60	Karlsruhe	Germany	Renaturierung der Alb
61	Kassel	Germany	Renaturierung Ahna
62	Köln	Germany	Renaturierung des Flehbachs
63	Ludwigshafen am Rhein	Germany	Renaturierung des Altrheingrabens Isenach Moerschbachs
64	Moenchengladbach	Germany	Renaturierung des Bungtbachs
65	Moers	Germany	renaturierung der Moersbach
66	Muenster	Germany	Renaturierung der munstersche Aa
67	Nurenberg	Germany	Renaturierung der Pegnitz
68	Paderborn	Germany	Renaturierung der Pader
69	Pforzheim	Germany	Renaturierung der Enz Wurm Nagold
70	Potsdam	Germany	Renaturierung Nuthe
71	Rostock	Germany	Renaturierung des Carbaek
72	Strasbourg	France	Restauration du Muhlbach de Koenigshoffen
73	Stuttgart	Germany	Renaturierung der Nektar
74	Wolfsburg	Germany	Renaturierung Allerniederung der Kästorf bei Warmenau
75	Wuppertal	Germany	Renaturierung der Wupper
Cities without URR			
76	Angoulême	France	
77	Bayonne	France	
78	Béthune	France	
79	La Rochelle	France	
80	Lorient	France	
81	Montbéliard	France	
82	Nîmes	France	
83	Rouen	France	
84	Toulon	France	
85	Valenciennes	France	
86	Magdeburg	Germany	
Cities without answer			
87	Amiens	France	
88	Avignon	France	
89	Creil	France	
90	Dunkerque	France	
91	Le Havre	France	
92	Lille	France	
93	Mulhouse	France	
94	Nantes	France	
95	Saint-Nazaire	France	
96	Tours	France	
97	Troyes	France	
98	Bergisch Gladbach	Germany	
99	Bielefeld	Germany	
100	Bonn	Germany	
101	Braunschweig	Germany	
102	Chemnitz	Germany	
103	Dortmund	Germany	
104	Dresden	Germany	
105	Düsseldorf	Germany	
106	Erfurt	Germany	
107	Erlangen	Germany	
108	Essen	Germany	
109	Freiburg im Breisgau	Germany	
110	Gelsenkirchen	Germany	
111	Hagen	Germany	
112	Hamburg	Germany	
113	Heidelberg	Germany	
114	Heilbronn	Germany	
115	Jena	Germany	
116	Koblenz	Germany	
117	Lübeck	Germany	
118	Mainz	Germany	
119	Mannheim	Germany	
120	Mülheim an der Ruhr	Germany	
121	Oberhausen	Germany	
122	Oldenburg	Germany	
123	Osnabrück	Germany	

Table A1. *Cont.*

	City Name	Country	Project Title (Original Language)
Cities without answer			
124	Regensburg	Germany	
125	Remscheid	Germany	
126	Reutlingen	Germany	
127	Salzgitter	Germany	
128	Solingen	Germany	
129	Trier	Germany	
130	Ulm	Germany	
131	Wiesbaden	Germany	
132	Würzburg	Germany	

Form A1. Interview form.

City:

… .

1) Project

Did river(s) inside the city territory have been restored since 1980?

☐ Yes
☐ No

What is the project title? …

Could you please shortly describe the project mentioning context elements and main goals?

… .

… .

… .

2) Status

How was the morphological status of the river/stream before the project?

☐ Channelized river course
☐ Straightened channel
☐ Impervious riverbank
☐ Artificial river bed
☐ Longitudinal connectivity damaged
☐ Existence of national road or Highway at the river side
☐ Buried river

Is the river navigable?

☐ yes
☐ no

3) project motivation

What is the project motivation (single answer)?

- ☐ Implementation of the WFD
- ☐ Ecological (ante signature of the WFD), e.g., Reestablishment of the migration potential for fish, Nature conservation (Natura 2000), Restoration of (sensitive) habitats
- ☐ Improvement of the flood protection strategy
- ☐ Improvement of the quality of life for citizens
- ☐ Other . . . .

4) project cost and funds

How expensive was the project (€):

. . . .

Which institution or program financed the project?

☐ European Union

If yes, which program? . . . .
If yes, which percent of financing? . . . .

☐ State and Water Agency

If yes, which percent of financing? . . . .

☐ City government

If yes, which percent of financing? . . . .

☐ NGO

If yes, which percent of financing? . . . .

5) Restoration measures

Which measures have been implemented to:

a) improve the flood protection potential

- ☐ Dyke removal
- ☐ Dyke renewal or construction
- ☐ Creation of shallow water area
- ☐ Creation of flood depression area
- ☐ Increase retention potential of the floodplain

b) to improve the water quality

- ☐ Construction of water treatment plant
- ☐ Planting of green buffer area
- ☐ Treatment of rainwater
- ☐ Removal of rainwater outlet

c) to restore riparian habitats

- ☐ Creation of ponds
- ☐ Flooded area
- ☐ Creation of wetland
- ☐ Improvement of the vegetation mosaic
- ☐ Change of the management concept
- ☐ Riparian forest conversion
- ☐ Planting of vegetation succession
- ☐ Planting of riparian forest
- ☐ Extensive uses of the riparian area
- ☐ Species reintroduction

d) to restore aquatic habitats

- ☐ Deadwood management
- ☐ Improve the erosion or the sedimentation potential through morphological changes
- ☐ Riverbank flattening
- ☐ Creation of shallow water area inside the water course
- ☐ Creation of temporary water
- ☐ Improvement of the flow heterogeneity
- ☐ Improvement of the flood depression potential
- ☐ Creation of spawning area

e) to reestablish near-natural patterns of the river hydromorphology

- ☐ Substrate excavation
- ☐ River bed expansion
- ☐ Water course extension
- ☐ Removal of artificial bank constructions
- ☐ River bank flattening
- ☐ Meandering
- ☐ Connection of sidearm or tributaries
- ☐ Reopening of tributaries
- ☐ River bed raising
- ☐ Creation of island

f) to renew the city planning

- ☐ Improvement of the accessibility
- ☐ Creation of new connection, e.g. bridge
- ☐ Road removal
- ☐ Creation of residential area
- ☐ Creation of business park
- ☐ Creation of pier
- ☐ Creation of shopping area
- ☐ Creation of recreational area
- ☐ City reconstruction

g) to enhance the recreational potential at the river

- ☐ Improve accessibility
- ☐ Creation of paths
- ☐ Creation of platform
- ☐ Planting of recreational grassland
- ☐ Enable contact with nature
- ☐ Creation of fitness trail
- ☐ Creation of playground
- ☐ Design park
- ☐ Rehabilitation of towpath
- ☐ Creation of swimming facilities
- ☐ Nature protection and conservation pedagogic opportunities
- ☐ Creation of watersport facilities
- ☐ Creation of recreational pier

h) to reestablish the longitudinal connectivity

- ☐ Weir removal
- ☐ Creation of fish pass
- ☐ Slide removal
- ☐ Creation of bed ramp
- ☐ Bed glide removal
- ☐ Creation of bypass channel

i) to reduce pressures caused by hydropower plant

- ☐ Increase residual water
- ☐ Decrease residual water
- ☐ Construction of hydropower plant
- ☐ Removal of hydropower plant

Table A2. Variables of the database and their possible entries.

Variables	Sub Variables	Entries
Project		Implementation of the WFD
Motivation		Ecological but not WFD related (prior WFD, nature conservation, Natura 2000, agenda 21, etc.)
		Improvement of the flood protection strategy
		Improvement of the quality of life for citizens
		Other
Morphological status	Channelized river course	Yes/No
	Straightened channel	Yes/No
	Impervious riverbank	Yes/No
	Artificial river bed	Yes/No
	Longitudinal connectivity (for fish migration) damaged	Yes/No
	Existence of national road or highway at the river side	Yes/No
	Buried river	Yes/No
	Navigable	Yes/No

Table A2. *Cont.*

Variables	Sub Variables	Entries
Implemented measures	to improve the flood protection potential	listed in Form A1 and Figure 3
	to improve the water quality	
	to restore riparian habitats	
	to restore aquatic habitats	
	to reestablish near-natural patterns of the river hydromorphology	
	to renew city planning	
	to enhance the recreational potential at the river	
	to reestablish the longitudinal connectivity	
	to reduce pressures caused by hydropower	
Public participation		Yes/No
Project implementation		Before 2000 After 2000
Short project description		Qualitative variable (text)
Project label		Qualitative variable (text), e.g., restoration of the Aa in Münster

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Paper C

"Zingraff-Hamed A., Greulich S., Egger G., Pauleit S., Wantzen K.M. (2017) Urban river restoration, evaluation and conflicts between ecological and social quality. In Deutsche Gesellschaft für Limnologie (Hrsg.): Erweiterte Zusammenfassungen der Jahrestagung in Wien 2016; Hubert & Co., Göttingen, ISBN 978-3-9818302-0-1. pp 144-149".

The first author, Aude Zingraff-Hamed, conducted the study, namely: Identify the knowledge gaps and research questions; Develop the conceptual idea and analytical framework; Design questionnaires; Conduct field survey; and Perform analyses and calculations. All these research steps were discussed with the research supervisors: Prof. Stephan Pauleit, Prof. K. Matthias Wantzen, and Dr. Sabine Greulich. The identification of the reintroduction sites was realized in cooperation with Prof. Gregory Egger (WWF-Auen Institut KIT). The contribution was written by Aude Zingraff-Hamed in collaboration with all the co-authors.

French Abstract/Résumé en langue française :

L’article C intitulé *Urban river restoration, evaluation and conflicts between ecological and social quality* (“Restauration des rivières urbaines, évaluation et conflits entre qualité social et écologique”) fut publié en mai 2017 dans les actes du congrès German Limnological Society (Société Limnologique allemande) ayant eu lieu à Viennes en Autriche du 26 au 30 septembre 2016. Il rapporte les résultats d’une étude expérimentale, soit la réintroduction d’une espèce végétale pionnière sur les rives d’une rivière restaurée. Cette étude a pour objectifs de : a) Évaluer le succès écologique d’un projet de restauration, et b) Estimer les conflits entre la recolonisation des habitats sensible et l’usage du secteur restauré pour le loisir de proximité.

L’étude a été réalisée dans le cas de l’Isar à Munich (Allemagne). La restauration hydromorphologique de huit kilomètres de la rivière dans sa traversée urbaine de la métropole de Munich a eu lieu entre 1999 et 2011. Le projet avait de nombreux objectifs dont, rétablir le bon état écologique demandé par la Directive Cadre sur l’Eau, permettre le retour d’espèce emblématique telle que *Myricaria germanica* L. (Tamarin d’Allemagne) et accroître les potentiels récréatifs de la zone fluviale. *M. germanica* est une espèce d'arbrisseau pionnière des bancs de gravier des rivières et torrent de montagne. Son aire de répartition s’étend des pyrénéens jusqu’aux bords Est de la mer adriatique. En Allemagne, le Tamarin d’Allemagne occupait les berges d’affluents du Danube, mais leur population est actuellement limitée à quelques exemplaires en amont des principaux barrages et ouvrages hydraulique alpins. Deux ans après clôture du projet, le bilan est positif, mais le tamarin d’Allemagne n’a pas recolonisé les berges de l’Isar. Une réintroduction de 27 plantes a été réalisée sur deux sites à différentes densités d’usage récréatif (moyenne et élevée). Le protocole de réintroduction suit la méthode décrite par Egger et al. (2010). La transplantation des plantes matures ayant eu lieu tardivement, soit en mai 2014, un arrosage de 100 ml d’eau par jour a été assuré les deux premiers mois. Les spécimens n’ont pas reçu davantage de soin. Leur survie, leur croissance et la densité des usages ont été documentées pendant trois ans.

Le taux de survie de 30% laisse supposer que l’habitat créé par la restauration ait une qualité suffisante pour permettre la recolonisation de l’espèce. De plus, aucune perte n’a été causée par des facteurs abiotiques. Cependant, malgré la fructification des plantes, aucun établissement secondaire n’a été recensé à ce jour. Les observations faites sur les

populations naturelles montrent qu'une nouvelle génération s'installe environs tous les sept ans. L'étude ne permet donc pas encore d'affirmer ou réfuter le succès de l'expérimentation.

Le taux de survie diffère autre les deux sites : 21% dans le secteur à haute densité d'usage récréatif et 38% par densité moyenne. Les pertes observées ont été causées en partie par les usagers côtoyant les sites d'expérimentation pour prendre des bains de soleil, se baigner et faire des grillades sauvages. Cependant, la plante a un fort potentiel de régénération et supporte un haut degré de perturbation et des dommages majeurs de son matériel végétatif. La plupart des pertes ont eu lieu le premier été par arrachage des plantes nouvellement transplantées. Ces résultats suggèrent que l'usage récréatif limite le succès de la réintroduction, mais ne l'exclus pas. Cependant, des mesures doivent être appliquées pour limiter les pertes, sont par exemple, la protection des sites expérimentaux et la sensibilisation des usagers à la protection et le respect de la biodiversité.

Mots clefs : réintroduction d'espèce végétale, *Myricaria germanica* L., usage récréatif.

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Urban river restoration, evaluation and conflicts between ecological and social quality

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Keywords: plant species reintroduction; *Myricaria germanica*; recreational uses

Introduction

Urban rivers often suffer from global ecological damages, described as the "urban stream syndrome", characterized by flashier hydrograph, elevated concentrations of nutrients and contaminants, altered channel morphology, reduced biotic richness, and increased dominance of tolerant species (Walsh et al., 2005). When urban rivers restoration projects are planned, they generally need to integrate physical constraints (Bernhardt & Palmer, 2007), flood protection for close-by areas, as well as increasing demands for recreational uses by citizens (Wantzen et al., 2016). Projects therefore often seek to combine ecological and social goals that can be conflicting. Recreational uses, for example, have been shown to negatively impact butterfly communities (Bennett et al., 2013), bird behavior (Huhta & Sulkava, 2014), mammal reproduction (Pineiro et al., 2012), and soil and vegetation structures (Sarah & Zhevelev, 2007). When both ecological and social goals are integrated in a restoration project, both should be taken into account to evaluate restoration success.

However, most of the metrics used to evaluate river restorations concern only biological, chemical, and hydromorphological parameters (Morandi et al., 2014). When social indicators are used, they only evaluate the aesthetical improvement (Bulut et al., 2010; Ozguner et al., 2012) or the project public acceptance (Macedo & Magalhães, 2010). Social metrics and monitoring procedures are generally missing.

The objective of this study is to investigate both the ecological and social success of urban river restoration and the potential conflicts between ecological and social restoration outcomes, for the case of the Isar River restoration (1999-2011) in Munich, Germany. The project had re-created a close-to-natural river morphology in the center of Munich and a range of typical piedmont floodplain habitats. One of the restoration goals was the re-establishment of pioneer sand and gravel bars, which are the habitat of various endemic species, such as the endangered floodplain plant *Myricaria germanica*. In this study, we simultaneously monitored the survival of re-introduced *M. germanica* and the pressure from recreational uses. We investigated whether (a) the Isar River restoration can support a sensitive plant species in floodplain pioneer habitats, and (b) to what extent recreational pressure is compatible with a survival of *M. germanica*.

Material and Methods

Study area

We studied the case of the Isar River restoration in the city center of Munich named “New life for the Isar” (1999 - 2011). The Isar is a 292 kilometer long (pre)Alpine river with a catchment area of 2.838,40 km^2 and crossing the city of Munich at the river kilometer 32 (NQ 8,63 m^3/s, MQ 63,8 m^3/s, HQ 1050 m^3/s). The Bavarian Water Agency collaborated with the Munich city government to re-stored eight kilometers of the Isar river from the south limit of the city territory (48° 4'29.59"N, 11°32'25.83"E) to the city center (48° 7'41.42"N, 11°34'46.88"E). The project had multiple goals, e.g., restoring ecological status, and increasng the recreational activities (Rädlinger, 2012).

Species

Myricaria germanica (L.) Desv. (Tamaricaceae), named False Tamarisk, is a pioneer shrub on sand to gravel bars, historically found in almost all the (pre-)Alpine rivers, including the Isar (Oberdorfer, 1992; Bill, 2001). The current distribution is scattered throughout the Alps (Müller, 1988; Kudrnovsky, 2013). *M. germanica* is an endangered species and indicator of the good ecological functions of (pre-)Alpine gravel bar rivers, influenced by floods. Study has shown that the plant has a high degree of regenerative ability, an important adaptation to natural river dynamics that continuously alters the sites and repeatedly shifts gravel banks (Bill, 2000). The most vulnerable part of the plant’s life cycle is germination (Benkler & Bregy, 2010).

Reintroduction

For another research project, 200 seedlings stemming from the same population in the Pupplinger Aue (47° 55′ 55″ N, 11° 26′ 19″ E) has been cultivated in the same conditions. However, because of missing funding and authorization, the project aborted and the plants did not received any care during three years. Our project gave a new chance to the 27 residual plants. The authorization from the competent authorities, namely the local government of Upper Bavaria, has been delivered the 9th May, 2014, and the reintroduction took place the day after. The five year old plants were mature but in poor conditions at the day of the transplantation. We introduced *M. germanica* in two sites. The experimental area in the south (48°7'39.49" N, 11°34'44.82" E) is a dry secondary channel formed by flood in 2013. The area is by regular discharge approximatively 20 centimeters from groundwater and 40 meters from the river, it is between the HQ1 and HQ5 flood line and it is covered by scattered willow settlement (mostly *Salix alba*) on gravel and sand. The experimental area in the north (48° 4'47.70"N, 11°32'31.52"E) is a 100 meter long and 20 meter wide island of gravel and sand, and scattered cover by one meter high willow settlement (mostly *Salix alba*). The island is 40 centimeters to one meter high by regular discharge. We transplanted 14 plants into the north (in the city center) and 13 in the south. The plants and the precise location of the transplantation into each experimental site were both randomly chosen. However, a minimum of 20 centimeters between the plants was set. The reintroduction protocol followed the method described by Egger et al. (2010). Importantly, since the transplantation took place after the start of the vegetation period, a minimal watering was required the two first months. Each plant was watered with 100 ml water from the river every day, after 3 days without rain, and then left without any care.

Collected Data

We collected data related to both a) the recreational pressures, counting users, and b) the success of the reintroduction, monitoring survivor rate and the cause of death (Tab. 1). The counting took place for both experimental sites during eleven sunny summer days, every 40 minutes, and for 20 minutes in order to include users crossing the experimental areas. For each user, we recorded his location and type (Tab. 1). We monitored the plants each second weekend during the first year, once a month in the second year, every two months in the third year, and after major flood events in order to document flood damages.

Table 1 Variables collected

Individual	Aspect	Variables	Entry
User	Recreational pressures	Area	Experimental area Near to the experimental area (100m gravel bar around the experimental area) Area of influence (nearest path)
		Type of use	Laying Walking Biking Other (ex. barbecuing)
Plant	Success of the reintroduc-tion	Survive	Yes/No

Statistical analysis

We applied the Welch test to compare survivor rate and user number and type between both sites.

Results

Recreational pressure

We found different number of user (p-value < 0.01) between the sites. We found similar usages, i.e. walking, laying in the sun, but in different proportion (p-value < 0.01). In the north, users were mostly walker (88%), some users laid in the sun (10.5%), and the rest were bikers (1.5%). In the south, users were equally walkers (41%) or laying in the sun (40%). In the south, a higher proportion of user were bikers (19%) than in the north.

The location of the users differed between both sites (p-value < 0.01). The experimental area is used by less than 10% of the users in both sites (north 3%, south 8%). Users in the north mostly used the influence area (88%), while in the south, both area were similarly used: 44% into the area near to the experimental area, and 48% into the influence area.

Plant survival

The survivor rate differed between both sites. We observed an overall survivor rate of 30%. However, in the north (city center), the survivor rate was lower (21%) than in the south (38%). In both sites, the number of plants mostly decreased the first year (2014). Three summer after the reintroduction, a stable population survives and flowers but no secondary establishment, namely natural reproduction by seeds, has been found yet.

We observed similar causes of death in both sites but with different intensities. We found no loss due to abiotic factors (death from by dryness or dieback) but loss due to natural events, namely floods, that caused the sudden disappearance of plants in each site every years, and loss due to users that caused dig out of plants during the first summer. During the monitoring procedure, we observed how toddler dug out transplanted plants playing into the sand that is *M. germanica* habitat. Observed types of damages suggest that death in the north (close to the city center) is more likely to be caused by users (72% of the death rate), than in the south (37% of the death rate).

Discussion

The results of our study partly support the hypotheses of a successful restoration of *M. germanica* habitats. After three years, reintroduced plants growth and flower, however, it is too early to affirm the success of the reintroduction. We observed a higher survivor rate than those of the single published experimental reintroduction of mature seedlings (20% the second year) which took place in Kärnten, Austria (Egger et al., 2010). Despite the fact that survivor rate cuttings are higher than those of mature seedlings (Nikowitz, 2010), our experiment showed better results than the reintroduction of cuttings in Freising, a periurban area north to Munich, that had a survivor rare of 0% (Koch & Kollmann, 2012). Other reintroductions had better survivor rates but used cuttings und monitored the survivor rate during the first summer (Staffler, 1999). Since no secondary establishment has been found, we cannot yet affirm that the restored habitats are suitable for the expansion of the reintroduced population.

The results of our study support the hypotheses that users have a negative impact on sensitive species reintroduction. Great loss during the first year post reintroduction is a common issue (Edwards et al., 2004). However, in our case, a great number of losses could have been avoided by better reintroduction conditions. We reintroduced the plants when the vegetation phase already began, plant were in a poor condition before the reintroduction, and the four week-ends following the reintroduction were particularly sunny and warm causing high recreational pressures. If the reintroduction has took place earlier, the root system should be strong enough to survive toddler play. Further studies on the impact of riverine users on species survive and development should help to understand the potential conflict between social and ecological restoration.

The study demonstrates the influence of recreational uses on reintroduction measures. However, we cannot definitively affirm that the variables investigated alone accounted for reintroduction success and failures. Other drivers or other unknown variables may also have influenced our results. Then, the number of plants reintroduced did not enable the use of strong statistical tests. Furthermore, the success of the restoration can just be assessed regarding of the biology of the false Tamarisk. Finally, the reintroduction of sensitive species into areas under high user density cause ethical questions. This study was conducted into particular conditions. The residual plants of another research project were dedicate to die and have through this project a new chance to life. We discourage relocation of endangered plants from protected areas.

Conclusion

Thanks to a man-made re-introduction we overcame the dispersal limitation and found that: 1) The biophysical and chemical habitat conditions are suitable to support a reintroduced population at least on the three-year scale. However a secondary establishment remains to be found to affirm the ecological success of the Isar restoration in Munich, Germany. 2) In the case of the Isar river restoration, even if the recreational uses impact the development of sensitive species, they did not cause reintroduction failure. Rather, high user pressure slows and decreases the establishment success. A user management plan has to be considered during the design and planning of the restoration project to passively secure ecological refuge. Furthermore, it is necessary to monitor users before the project and simulate user increase to predict damages and conflicts. Pedagogic works has to be done but would not replace a good user management plan.

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Paper D

“Zingraff-Hamed, A., Noack, M., Greulich, S., Schwarzwälder, K., Wantzen K. M., Pauleit, S. (2018) Model-based evaluation of urban river restoration: conflicts between sensitive fish species and recreational users, Sustainability *10*(6), 1747; https://doi.org/10.3390/su10061747”

The first author, Aude Zingraff-Hamed, conducted the study, namely: Identify the knowledge gaps and research questions; Develop the conceptual idea and analytical framework; Design questionnaires; Conduct field survey; and Perform analyses and calculations. The 2D hydromorphological model, which was used as input data for the habitat model procedure CASiMiR as presented in Paper D and E, was simulated by Dr. Markus Noack (University Stuttgart) and SKI GmbH + Co.KG. The hydromorphological field survey at the Isar was conducted by Aude Zingraff-Hamed in collaboration with Dr. Kordula Schwarzwälder (Technical University of Munich) and associated staff. All these research steps were discussed with the research supervisors: Prof. Stephan Pauleit, Prof. K. Matthias Wantzen, and Dr. Sabine Greulich. The contribution was written by Aude Zingraff-Hamed in collaboration with all the co-authors

French Abstract/Résumé en langue française :

L’article est intitulé Model-based evaluation of urban river restoration: conflicts between sensitive fish species and recreational users (“Évaluation des conflits entre habitat propice au poisson et usage récréatif fondée sur un modèle ”) et rapporte les résultats d’une modélisation des habitats physique propice au poison intégrant la pression relative causée par l’usage intensif de la zone fluviale pour l’usage récréatif en milieu urbain. Cette étude a pour objectifs de : a) Évaluer le succès écologique d’un projet de restauration, et b) Estimer les conflits entre restauration des habitats aquatiques sensibles et l’usage du secteur restauré pour le loisir de proximité.

L’étude a été réalisée dans le cas de l’Isar à Munich (Allemagne). Huit kilomètres de rivières ont été hydromorphologiquement restaurés entre 1999 et 2011. Le projet avait pour but, entre autres, de rétablir le bon état écologique demandé par la Directive Cadre sur l’Eau (2000) et d’accroître le potentiel récréatif de la zone fluviale. Chondrostoma nasus L. est une espèce indicatrice du bon état écologique de la rivière et n’a pas recolonisé les huit kilomètres restaurés malgré l’implantation de mesures cibles pour cette espèce. De plus, une population source fut localisée à environ 10 kilomètres en aval et le poisson est un bon migrateur qui peut parcourir de très grande distance et a un grand potentiel de recolonisation. L’absence du poisson suggère un échec du projet de restauration. Cependant, l’objectif du projet était de reconstruire son habitat physique et de nombreuses raisons peuvent en partie expliquer le non-rétablissement de l’espèce. La pression récréative intensive propre au milieu urbain est supposée expliquée en partie l’absence du poisson sur le tronçon restauré.

Afin d’étudier la qualité des habitats physiques pour les différentes phases du cycle biologique de Chondrostoma nasus L. un modèle hydromorphologique à haute résolution a été créé informant pour chacune des 160 000 cellules de 1m x 1m sur les trois variables clefs décrivant les habitats du poisson : vélocité, profondeur de la colonne d’eau et type de substrat à la surface du lit. La morphologie fluviale post restauration a été établi utilisant le logiciel SMS 10 (Surface Modeling System, Aquaveo, USA) utilisant les données topographiques fournies par le bureau d’ingénierie hydraulique ayant assisté la réalisation du projet de restauration. La vélocité a été calculée utilisant le logiciel Hydro_AS-2D version 3 résolvant le modèle spectral par les équations Sait-Venant et utilisant la méthode de discrétisation des volumes finis. Le modèle a été calibré pour quatre débits allant de 65 m^3/s à 782 m^3/s. Le substrat superficiel du lit a été documenté par relevé de terrain lors des basses eaux en 2013 et identifiant visuellement la taille du

grain dominant. Le substrat de chaque cellule a été identifié utilisant les catégories suivantes: 1) matière organique; 2) limon ou argile; 3) sable fin (<2 mm); 4) sable moyen (2–6 mm); 5) sable grossier (6–20 mm); 6) gravier (2–6 cm); 7) pierres (6–12 cm); 8) rochers (>20 cm); ou 9) roche lisse ou béton. La densité des usages a été estimée par relevés systématiques de terrain réalisé de 10h à 20h et ayant été répété 10 fois pendant des journées ensoleillés. Les huit kilomètres de rivière étudiés ont été parcourus en utilisant un intervalle de 10 mètres entre chaque relevé. La description des habitats a été estimée par la littérature et l'interaction des variables par estimation d'experts interviewés.

L'analyse du modèle montre que des habitats propices pour Chondostroma nasus L. existent en quantité pour les trois habitats types des Adultes et l'habitat type des Juvéniles : 182,838 m², 238, 322 m², 268,028 m², et 177,645 m² à débit annuel moyen. Cependant, peu d'habitats propices au recrutement existent: 32,198 m² pour les habitats de frayère et 33,331 m² pour les habitats nécessaires au développement des larves. Ces derniers sont localisés au sein des sites à forte densité d'usagers utilisant l'espace pour le loisir : natation, bain de soleil, regroupement sociaux et grillades sauvages. Un conflit direct existe. D'un côté, l'usage non régulé des frayères pour le loisir de proximité limite les possibilités de reproduction de l'espèce. D'un autre côté, la régulation du loisir sur les sites de frayère risque de causer le désaccord des usagers, financeur du projet. Cependant, historiquement Chondostroma nasus L. frayent dans les structures annexes de manière préférentielle. Ces dernières ont été au 20ème siècle isolées du lit principal de la rivière limitant considérablement le potentiel de reproduction de l'espèce. Depuis, la population est vieillissante. Ainsi, une restauration des structures annexes devraient apporter plus de succès que la limitation des usages récréatifs sur le tronçon urbain.

Mots clefs: évaluation des restaurations de rivière, gestion des conflits, modélisation des habitats, system socio-écologique, river culture, Chondrostoma nasus L.

sustainability

MDPI

Article

Model-Based Evaluation of Urban River Restoration: Conflicts between Sensitive Fish Species and Recreational Users

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Abstract: Urban rivers are socioecological systems, and restored habitats may be attractive to both sensitive species and recreationists. Understanding the potential conflicts between ecological and recreational values is a critical issue for the development of a sustainable river-management plan. Habitat models are very promising tools for the ecological evaluation of river restoration projects that are already concluded, ongoing, or even to be planned. With our paper, we make a first attempt at integrating recreational user pressure into habitat modeling. The objective of this study was to analyze whether human impact is likely to hinder the re-establishment of a target species despite the successful restoration of physical habitat structures in the case of the restoration of the Isar River in Munich (Germany) and the target fish species *Chondostroma nasus* L. Our analysis combined high-resolution 2D hydrodynamic modeling with mapping of recreational pressure and used an expert-based procedure for modeling habitat suitability. The results are twofold: (1) the restored river contains suitable physical habitats for population conservation but has low suitability for recruitment; (2) densely used areas match highly suitable habitats for *C. nasus*. In the future, the integrated modeling procedure presented here may allow ecological refuge for sensitive target species to be included in the design of restoration and may help in the development of visitor-management plans to safeguard biodiversity and recreational ecosystem services.

Keywords: conflict management; habitat modeling; river culture; socioecological system; urban case study

1. Introduction

Centuries of human activities have directly or indirectly degraded, damaged, transformed, or entirely destroyed aquatic ecosystems [1], threatening worldwide riverine ecosystem services [2], e.g., water security for fauna, flora, and humans [3]. Restoration activities are essential to re-establish the functional capacities of ecosystems for providing and maintaining biological and cultural diversity [1,2,4]. River restoration is a term applied to a wide range of activities concerned with "repairing waterways that can no longer perform essential ecological and social functions" [5]. Project surveys in the United States, Japan, Australia, Germany, and France have shown that improving instream physical habitats through hydro-morphological changes is one of the most common goals of restoration [6–11]. Hydro-morphological river restoration intends to recreate natural forms of the river course or at least mitigates the human impact, for instance removing artificial embankments and meandering the river bed. However, despite significant hydro-morphological changes, indicator species may not recover [12–15], which suggests that stressors other than hydro-morphological degradations still affect the biota in restored river sections [10,12].

Urban rivers are showpieces of a socioecological system [11], and their restoration often faces conflicts between ecological quality and recreational uses. They are particularly impoverished in habitat diversity and quality [16,17], and their dysfunctions have been described as the "urban river syndrome" [18]. At the same time, urban rivers have important cultural functions [19], and their restoration (or rehabilitation) is often driven by citizens' demands for more near-natural landscapes and for a greater recreational potential [11,20]. Rather than ecological restoration in the sense of a return to pre-disturbance conditions, which is unlikely in urban areas [21], urban river restoration often aims at integrating ecological demands into urban planning [20]. According to the socioecological approach of the "River Culture Concept" [2], improvements in ecosystem functions and biodiversity will have a positive effect on human culture, e.g., riverine recreational activities [22]. Junker and Buchecker [23] also showed that users respond very positively to morphological river restoration. With population growth and increasing demands for recreational opportunities in urban areas, an increase in the use of river beaches for leisure activities has been predicted since the 1990s [24], especially on urban rivers with improving water quality [2]. However, recreational activities cause pressures on ecosystems; for example, they negatively impact wildlife, soil, and vegetation [25–30]. Therefore, conflicts between ecological restoration and recreational uses are likely to exist [31,32], but impacts of recreational users have been overlooked in comparison to those of other perturbations [33–35].

While project assessment is an important procedure for feedback and guidance, few river restoration projects implement an evaluation procedure. Studies showed that in the United States, less than 10% of river restorations have been monitored [6]. Similar observations have been made in Bavaria, Germany [36]. Recent studies identified five difficulties faced in the evaluation of river-restoration projects:

1. Requisite data are missing because pre- and post-restoration monitoring is absent for many projects or occurs over a very short period [9,36].
2. Control sites are inappropriate for assessing the success of restoration [9,37].
3. Biological indicators have serious limitations [38–40], such as a lack of identification of the causes of failures in restoration.
4. Current evaluation procedures investigate ecological responses, but social evaluation remains lacking [9,36,41]. Few studies have performed parallel investigations into both social and biological aspects, e.g., water quality and project acceptance, but without the integration of both aspects into a single evaluation method, the resulting conclusions remain speculative.
5. The time span needed for the re-establishment of a target species is often longer than the monitoring period [9,12,13].

Furthermore, the evaluation method should inform about potential conflicts, integrate social and ecological assessments, and investigate the quality of the physical habitat.

Habitat models are very promising tools and may contribute to solving this part of the problem. Habitat models are appropriate tools to investigate physical habitats and their ecological functions. Habitat simulation models are increasingly used in water management and the investigation of habitat changes caused by hydropeaking [42–44], weir removal [45,46], and the presence of reservoirs. The models also help in the decision-making process for choosing the most efficient restoration design [47]. The Physical Habitat Simulation (PHABSIM) model was the first widely available physical habitat model and was used in the 1990s to assess restoration measures [48], but it uses univariate functions and ignores interactions among physical habitat variables, which cause major limitations [49]. The Computer Aided Simulation Model for Instream Flow Requirements (CASiMiR) solves these limitations by using an approach based on fuzzy logic, sets, and rules to integrate interactions between physical habitat variables and enable the prediction of habitat selection for different fish species and life cycle stages in defined river types [49–53]. However, habitat models such as CASiMiR are solely based on physical hydro-morphological variables that affect the ecological function of habitats, whereas human impacts by recreational uses of river banks on the availability of instream habitats for the target fauna has not yet been considered.

Fish habitats are a common indicator of the quality of and richness in aquatic habitats [9,54–57]. Modeling of physical fish habitats is a suitable tool for assessing the impact (positive or negative) of hydro-morphological changes on physical instream habitats. While impacts of hydro-morphological changes on fish habitats are well described in the literature, little information exists about the response of fish to nonfishing recreational pressure. Some studies showed that anthropogenic noise negatively affects the functions of fish habitats; for example, road traffic (around 85 dB) disturbs fish migration [58], piling sounds (>120 dB) disturb communication [59] and cause total dispersion of fish schools or a drift in their habitat from a depth of 15–20 m [60], and ship noise (around 85 dB) inhibits larval development and increases rates of larval death due to predators [61]. However, we found no study that investigated the impact of recreationists along or in rivers on fish habitats.

Through a novel methodological approach, our study made a first attempt at integrating social aspects (human use of riverbanks) into habitat modeling for a sensitive fish species to detect potential conflicts between physical fish habitats and recreational uses. We investigated, in the case of the common nase (*Chondrostoma nasus* L.) in the restored section of the Isar River in the center of Munich, (i) whether hydro-morphological urban river restoration succeeded in providing physical habitats for different life-cycle stages of the target species, (ii) how urban recreational pressure is distributed with regard to fish habitats and how it modifies the availability of highly suitable habitats, and (iii) whether urban recreational pressure is likely to explain the absence of *C. nasus* from the studied restored river section.

2. Study Area

2.1. Study Area

The Isar River drains part of the Karwendel Mountains (Northern Alps), crosses the Munich conurbation (Germany), and joins the Danube River (Figure 1). The pre-alpine river has been used since prehistoric times as a trade route from the Alps, but only using rafts. Major environmental issues began in the 1920s with the construction of 28 hydroelectric power plants. The whole river has been canalized, river water has been diverted several times, and the Sylvenstein Reservoir (1954–1959) has been built in the upstream part of the river to mitigate flood risk.

The discharge of the Isar River in Munich (Figure 2) is minimal during the winter (11–202 m^3/s between 1959 and 2012; www.hnd.bayern.de), although brief and slight increases in water quantity may occur, which are mostly due to rain events (annual mean maximum discharge (HQ) in winter = 450 m^3/s). In spring, the discharge increases due to snowmelt (>63.8 m^3/s), although substantial decreases (to as little as 8.63 m^3/s) may happen sporadically due to late freeze and snowfall. During summer, minor flash flood events (mean maximum discharge (HQ) in summer = 395 m^3/s) caused by summer storms in the Alps are frequent but they only occasionally reach a very high discharge (650–1050 m^3/s). Dry periods may also cause minimal discharges during summer, although regulation by the upstream Sylvenstein Reservoir usually avoids these to ensure water supply for hydroelectric power plants and cooling water for the nuclear power plant. At the gauging site in Munich, NQ locally occurred because of important water diversion to supply hydropower plants (Figure 2).

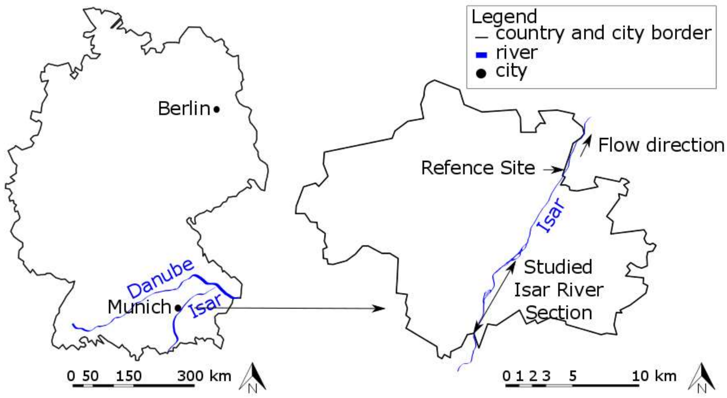

Figure 1. Locations of Munich, of the study area, and of the reference site for the habitat suitability model.

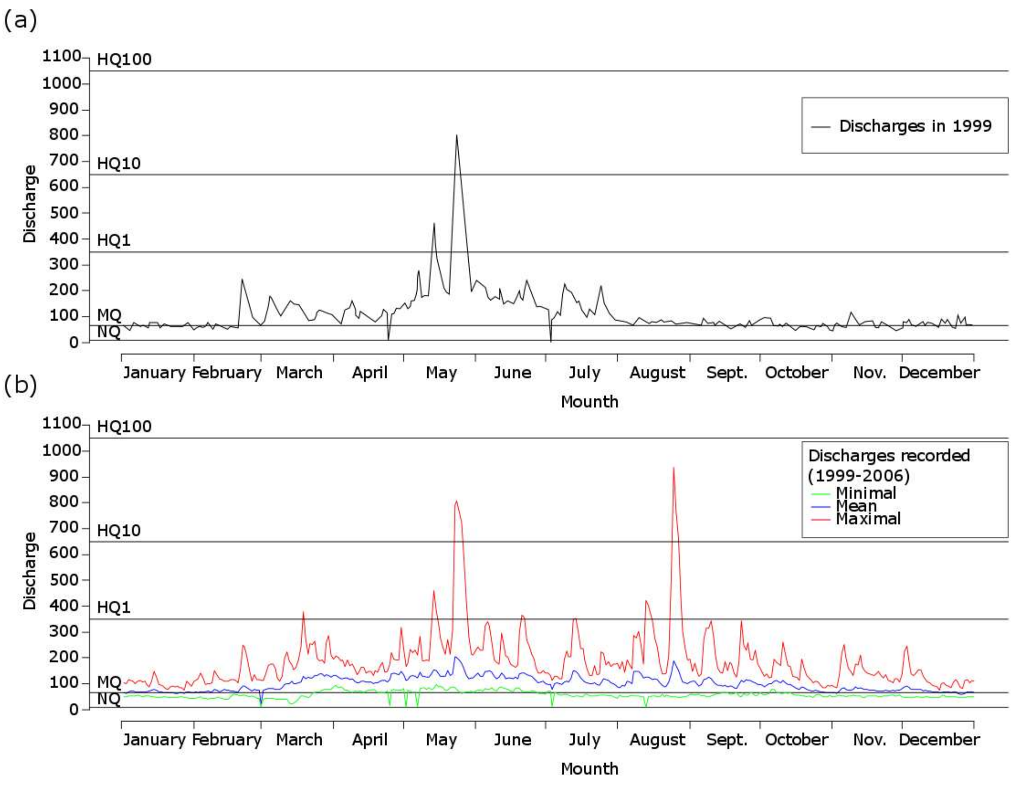

Figure 2. Discharges of the Isar River in Munich recorded at the gauging station inside the study area (**a**) in 1999 and (**b**) between 1999 and 2006 by the Bavarian Water Agency. HQ100, HQ10, and HQ1: 100-, 10-year, and 1-year maximum discharge; MQ: mean discharge; NQ: minimum discharge.

Since the 1990s, restoration projects have been carried out to improve the ecological status of the river and the esthetics of its riverscape in order to decrease flood risk and to increase recreational potential. For example, the project "New Life for the Isar" (1999–2011) (Figure 3) was carried out by the Bavarian Water Agency in collaboration with the Munich city government to restore 8 km of the Isar River crossing the city of Munich in such a manner that high ecological quality could be expected in the future [62,63]. The project extended from the Großhesseloher Bridge (48°4′29.59′′ N, 11°32′25.83′′ E) to Museum Island (48°7′41.42′′ N, 11°34′46.88′′ E). The restoration focused on the eastern side of the river, while the western side remained unchanged because of topographic limits, namely, a very steep wooded slope ending at a stone wall in the river that separates the river from the housing area. One of the goals of the restoration project was the improvement of the habitats for the endemic fish species, such as the emblematic common nase (*C. nasus*). The project focused on hydro-morphological improvements such as the removal of the concrete embankment, the creation of seminatural fishways (Figure 4) at the 400 m long Flaucher site (Figure 4), and the construction of near-natural river-bottom ramps (Figure 4). Special care was also taken to reproduce a near-natural waterscape, and one island (Willow Island) (Figure 4) was created to satisfy citizens' esthetic demands. Long-term monitoring confirmed that the good chemical and biological (macrozoobenthos) conditions required for the re-establishment of *C. nasus* had been achieved. However, electrofishing showed no recovery of *C. nasus* despite the potential for rapid recovery of the species [64–66].

Figure 3. Photograph of the restored Isar River section in Munich (Aude Zingraff-Hamed in August 2015).

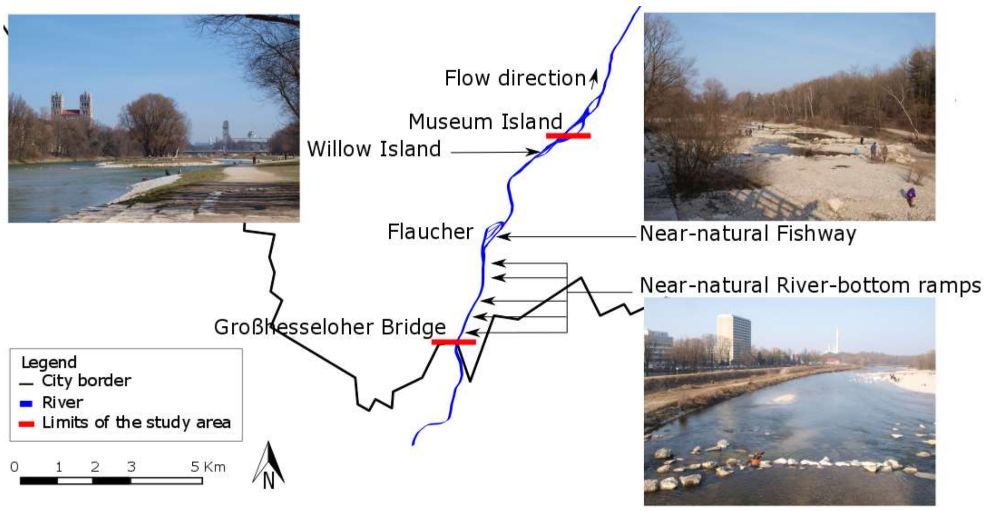

Figure 4. Localization and photograph of the cited site of importance at the restored Isar River section in Munich (Photograph took by Aude Zingraff-Hamed in March 2013).

2.2. Biology of *Chondrostoma nasus*

Chondrostoma nasus (L.), named the common nase, is a rheophilic migratory cyprinid fish that occurs in the drainage basins of the Black Sea, southern North Sea, and Baltic Sea. It inhabits moderate-to fast-flowing, medium-sized to large rivers with rock or gravel beds and grazes on benthic algae using a characteristic horny layer on the lower lip. Owing to their preference for benthic algae, nase often dwell in shallow, light-flooded habitats, where they can be easily seen. *C. nasus* is a potamodromous species that needs diverse and very closely connected habitats during its lifecycle. According to literature statements and expert descriptions, the nase population performs different types of movement during the year [64,65,67–74], which are also confirmed for the Isar River [65]. At the end of winter, adult nase often migrate more than 10 km upstream to reach shallow water to feed and recover after the migration and to wait until the environmental conditions are optimal for spawning. When the water temperature reaches 12 °C (between March and May), the adults perform a short migration to nearby well-oxygenated spawning areas in the main channel or tributaries. After spawning, they migrate to summer habitats downstream in the main channel. Before the first freeze-up of winter, the adults move to nearby wintering habitats. Around two weeks after spawning, eggs hatch and larvae drift to shallower habitats near the spawning area. Juveniles (1–3 years old) group in shallow water, e.g., slow-flowing anabranches, but gradually migrate to nearby summer habitats as adults (daily migration to seasonal migration). Accordingly, six habitats (Figure 5 and Table 1) have been identified by local fish biologists and cross-validated against the abovementioned literature [64,65,67–75].

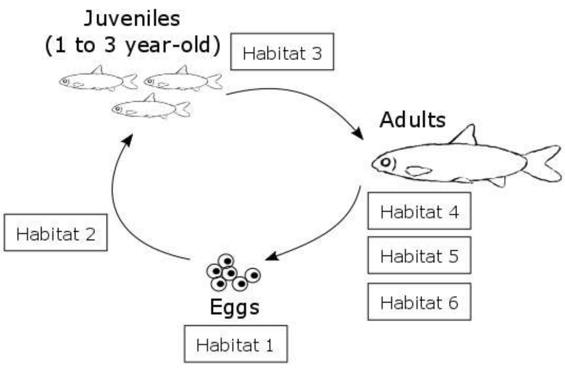

Figure 5. Lifecycle of *Chondrostoma nasus* L. and related habitats.

Table 1. List of habitats associated with lifecycle stages of *Chondrostoma nasus* (L.) described in terms of their physical characteristics.

Habitat Number	Lifecycle Stage	Season	Water Velocity (in m/s)	Water Depth (in cm)	Substratum
1	Adults spawning	Spring	High (1.0 to 1.5)	Moderate (20 to 40)	Gravel bars
2	Larvae	Spring	Low (0.5 to 0.7)	Low (5 to 10)	Fine-grained substratum
3	Juveniles	All	Very low (under 0.6)	Low (5 to 20)	Coarse substratum
4	Adults	Winter	High (1.0 to 1.5)	High (100 to 200)	Variable substratum
5	Adults (pre-reproduction)	Spring	Low to very low (less than 0.7)	Moderate (20 to 40)	Medium gravel to large stones
6	Adults	Summer and Autumn	Moderate to high (0.7 to 1.5)	Moderate (20 to 50)	Rock to gravel

C. nasus is a sensitive species that is locally threatened by morphological deterioration, e.g., damming and the destruction of spawning sites [64]. It is protected by the Berne Convention on the Conservation of European Wildlife and Natural Habitats [76]. According to the Red List of the International Union for Conservation of Nature and Natural Resources, *C. nasus* is classified as a species of "least concern" [75]. Historically, all lifecycle stages were found in the Isar River in Munich, although spawning areas were mostly located in the tributaries [65]. A population that indicates a good ecological status should reach 20 adults of *C. nasus* per 100 m river section [77]. In the period from 1995 to 2012, the species' abundance dropped from 40 to fewer than 5 individuals per 100 m in the river sections upstream and downstream from Munich [77], and tributaries of the Danube near Munich (Isar River, Inn River, Vils River, etc.) lost 41% of adult fish of reproductive age (>30 cm long, 4 to around 20 years old) [77]. In 2012, no *C. nasus* were found in the investigated urban section of the Isar River.

C. nasus are able to recolonize restored river stretches in a very short time span [65]. Studies on the Danube showed that reconnection of habitats using a nature-oriented scheme was successful, with 46% of the source species pool present in the study area after only two months [66]. Reconnection between the main river channel and spawning areas also enabled high recruitment of juveniles only two years after restoration [78].

3. Materials and Methods

3.1. Physical Characteristics of the River

3.1.1. The Substrate

The substrate properties were determined by field measurements in 2013 and were assumed to be constant over time. Because the water at mean low discharge (MNQ) was shallow and clear, we used a classic survey procedure by boat based on a 5-meter grid (Figure 6) to characterize the substrate (N = 1628). Nine substrate types were visually distinguished on the basis of the grain size of the dominant component:

1. Organic matter or detritus
2. Silt, clay, or loam
3. Sand (<2 mm)
4. Fine gravel (2–6 mm)
5. Medium gravel (6–20 mm)
6. Large gravel (2–6 cm)
7. Large stones (6–12 cm)
8. Boulders (>20 cm)
9. Rock or concrete.

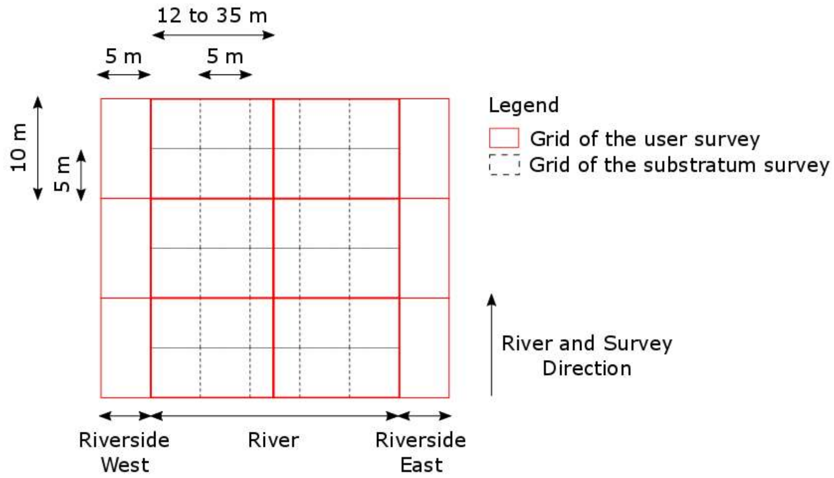

Figure 6. Grid design used for the substratum and user surveys.

3.1.2. The 2D Hydro-Morphological Model

To investigate the conflict between a suitable habitat for fish and intensive recreational uses, we established a 2D hydro-morphological model for 8 kilometers of the restored stretch of the Isar River, namely, from the Großhesseloher Bridge (48°4′29.59″ N, 11°32′25.83″ E) to Museum Island (48°7′41.42″ N, 11°34′46.88″ E). For generation of the grid and pre- and postprocessing of the simulated data, SMS software (Surface Modeling System, Aquaveo, Provo, Utah, USA) was employed, while for the hydraulic simulations the software Hydro_AS-2D version 3, was used, which solved the shallow-water equation using a finite-volume discretization. The digital elevation model of this area was based on cross-sectional data provided by the local water authority (Wasserwirtschaftsamt München, http://www.wwa-m.bayern.de/). In addition, local topographical measurements were conducted to consider topographical details. The topographical data were interpolated to an unstructured grid of 142,000 elements for the study region (Figure 7) and 6000 elements for the reference site. The average spatial resolution was in both reaches 8.0 m in flow direction and 3.0 m in lateral direction, which represented a recommended ratio between length and width of elements. The model was extensively calibrated and validated by comparing measured water levels (provided by the local water authority, Wasserwirtschaftsamt München, http://www.wwa-m.bayern.de/) and simulated water levels [79] for four discharges ranging from 65 m^3/s to 782 m^3/s by adapting the roughness values to verify adequate model performance. The roughness values were adapted towards best model performance for two discharges (calibration) and verified for the other two discharges (validation). The deviations between measured and simulated water levels ranged from +8.15 cm to −0.21 cm with a mean deviation of 1.68 cm, which proved to be an adequate model performance (R^2 = 0.98) for both low- and high-flow conditions. The simulated scenarios were:

1. Minimum discharge (NQ = 12 m^3/s)
2. Mean low discharge (MNQ = 16.5 m^3/s)
3. Annual mean discharge (MQ = 63.8 m^3/s)
4. Annual mean maximum discharge (HQ1 = 350 m^3/s)
5. Biennial mean maximum discharge (HQ2 = 405 m^3/s)
6. 5-year maximum discharge (HQ5 = 550 m^3/s)
7. 10-year maximum discharge (HQ10 = 650 m^3/s)
8. 50-year maximum discharge (HQ50 = 880 m^3/s)
9. 100-year maximum discharge (HQ100 = 1050 m^3/s).

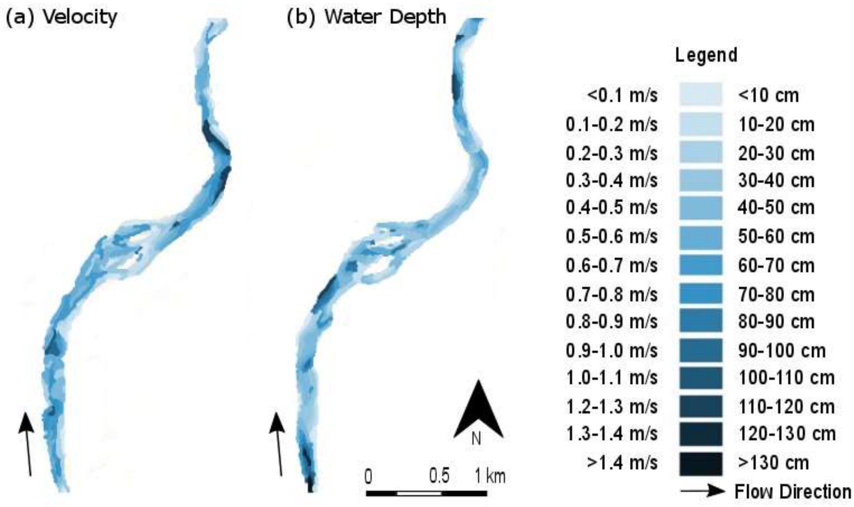

Figure 7. Mapping of the (**a**) Velocity and of the (**b**) Water Depth at mean annual discharge (displaying 3.5 kilometers of the 8 kilometers of the restored river section including the Flaucher).

While scenarios 2–5 were the most representative of the common situation, the other scenarios may inform about stressful situations. Scenario 1 simulated major dryness and enabled the estimation of dewatering risk as fish stranding. Scenarios 4–9 informed about the existence of refuge for the fishes during flood events, which depend of the diversity of the floodplain form. This also informed about the recreational potential of the area. Since the frequency of perturbations are important for resilience capacity of the species, we investigated different flood events from HQ1 to HQ100.

3.2. Recreational Pressure

Only expert knowledge can provide information on the response of species to recreational pressure [80]. This is commonly acquired by on-site data collection, such as user counting and surveys of user distribution [81–83]. Riverine recreational activities on the Isar River are water-based from May to October, e.g., boating and swimming, and land-based throughout the year, e.g., lying in the sun, walking, and cycling [84]. In accordance with common practice in studies of recreational intensity [34,36,81–83,85], user pressure was evaluated by counting users on a limited number of sampling days. A preliminary user survey during a sunny nonworking day in June at two sites inside the study river section showed that maximum user numbers may be found between noon and 2 p.m. in the south of the study area and between noon and 4 p.m. in the north of the study area (Figure 8). Therefore, users were counted along 8 kilometers of restored river stretch during 10 sunny days (3 during spring, 3 during summer, 3 during autumn, and 1 during winter) between noon and 3 p.m., beginning in the south of the study area. We counted all the recreational users we encountered while walking along the river. This was carried out by using a counter and by differentiating land-based and water-based activities in 10-m intervals (Figure 6), which were delimited using 10-m ropes on both sides of the river, either on the embankment (5-m broad sections) or in the water (between the embankment and the middle of the aquatic area, i.e., 12–35 m broad sections). In the water, users roamed through sections with lengths of 50–100 m by swimming and wading. User densities were classified into five ranks of recreational user density (Table 2; for the ranking procedure, see Section 3.3). User intensity maps were digitized using SMS 10 and acted as an additional parameter for the modeling procedure when testing the impact of users on the availability of fish habitats (see objectives (ii) and (iii) in Section 1).

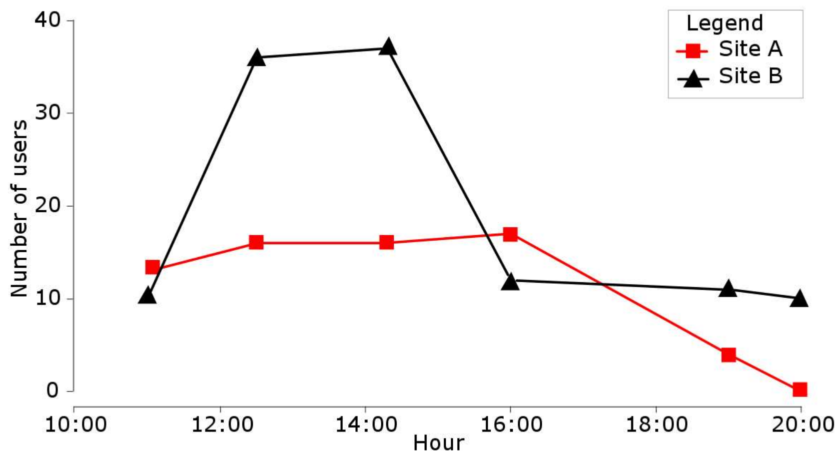

Figure 8. User numbers on two emerged gravel bars (100-m long and 20-m wide) during a sunny nonworking day in June at two sites: (A) in the north of the study area (48°7′37.85″ N, 11°34′40.15″ E) and (B) in the south of the study area (48°4′45.07″ N, 11°32′29.25″ E).

Table 2. List of variables used for the fuzzy sets.

Variable	Linguistic Category	Quantitative Fuzzy Meaning of the Physical Property
Water depth	very low	0 to 0.1 m (±5 cm)
	low	0.1 m (±5 cm) to 0.2 m (±5 cm)
	medium	0.2 m ±5 cm) to 0.5 m (±10 cm)
	high	0.5 m (±10 cm) to 1.15 m (±25 cm)
	very high	Above 1.25 m (±25 cm)
Velocity	very low	0 to 0.4 m/s (±0.1 m/s)
	low	0.5 m/s (±0.1 m/s) to 0.7 m/s (±0.1 m/s)
	medium	0.75 m/s (±0.1 m/s) to 0.9 m/s (±0.1 m/s)
	high	1 m/s (±0.15 m/s) to 1.5 m/s (±0.25 m/s)
	very high	Above 1.75 m/s (±0.25 m/s)
Substratum grain size	low	Organic material, detritus, silt, clay, loam, sand (<6 mm)
	medium	Gravel from 6 mm to 12 cm
	high	Large stones (12–20 cm)
	very high	Boulders (>20 cm), rock
User pressure (per 10-m long section)	very low	No users
	low	One user on the riverbank and no users in/on the water
	medium	Two or more users on the riverbank or one user in/on the water
	high	One user in/on the water and >1 users on the riverbank
	very high	More than two users in the water and more than two users on the riverbank
HSI	Very low	<0.1
	Low	[0.1 to 0.3]
	Medium	[0.3 to 0.6]
	High	[0.6 to 0.9]
	Very high	>0.9

3.3. Habitat Suitability Model

The suitability of habitats for *C. nasus* was modeled using CASiMiR. This software was designed to determine the suitability of habitats for target species using hydraulic and morphological characteristics. The CASiMiR procedure uses the three main parameters that determine fish habitat preferences [48,86]: water depth, flow velocity, and bed substrate type. Using them, CASiMiR calculates the habitat suitability using three indicators: weighted usable area (WUA), hydraulic habitat suitability index (HHS), and the Habitat Suitability Index (HSI). Both the WUA and the HHS represent functions that relate the habitat suitability to the flow regime. The HHS is obtained by dividing the WUA by the total wetted area, which leads to an index ranging from 0 to 1. The HHS thus eliminates the influence of the size of the wetted area and enables a direct comparison between scenarios [87];

for example, between scenarios for a single study area with different discharge levels. Highly suitable habitats were defined as those with an HSI >0.6. CASiMiR uses a multivariate fuzzy logic approach to link these abiotic attributes with the habitat requirements of fish. Therefore, the overlapping fuzzy magnitudes of the descriptive physical properties are formulated in terms of linguistic categories, i.e., "very high", "high", "medium", "low", and "very low" (Table 2). This approach has proven to be an excellent modeling technique for ecological purposes because the overlapping fuzzy sets allow researchers to deal with uncertain and imprecise information, which commonly occurs in ecological investigations [88]. Because little published information on quantified habitat preferences of *C. nasus* on the Isar River near Munich is available, the physical limits of the categories were partly based on expert knowledge. This concerned, in particular, the behavior of *C. nasus* when facing manmade stressors such as walkers, swimmers, and large groups of humans on the embankment. Therefore, individual interviews were conducted with seven experts, i.e., fish biologists belonging to the Chair of Aquatic Systems Biology of the Technical University of Munich (N = 2), the Bavarian Water Agency (N = 1), and the Bavarian State Research Center for Agriculture (N = 2), as well as with two fishermen from the NGO Isarfischer. They were asked to describe the *C. nasus* habitats on the Isar River near Munich considering all the possible combinations of the variables (Table 2) to establish fuzzy habitat suitability sets (Table 3 and Table S1), and to define the response of the species to recreational uses. Despite the fact that we interviewed the biologists in a nondirective manner, namely without list of possible answers, no major deviations between the interviewees were observed. The greatest difference between the interviewees regarded the limits of "low" velocity, namely, 0.5–0.7 or 0.4–0.6 m/s. We considered the deviating entries as the tolerance limits of the values. To validate the resulting habitat quality rules, a reference site with an established population of *C. nasus* was used. The reference site was located 5 kilometers downstream of the restored reach (Figure 1). According to the last survey performed by the Bavarian fish monitoring authorities, a robust population of *C. nasus* remains at this site [65,77]. The reference site was close to the restored section; it did not support recreational uses, and it has a high value for spawning activities. A 2D hydro-morphological model of a 2500-m long reference site, namely a 60,000 elements mesh, was created using the same procedure as for the 2D hydro-morphological model of the restored area (presented in Section 3.1.2). We performed the expert-based habitat modeling procedure on the reference site with the existing *C. nasus* population. The model outcomes showed suitable physical habitats for *C. nasus* (Figure 9). This result validated the habitat quality fuzzy rules and set of the model. The proportion of suitable wetted area supporting each habitat slightly varies between the reference and the restored sites. This variation can be explained by the length difference between the sites.

The particular aims of this study were to integrate the survey of recreational pressure as supplementary input data into the CASiMiR interface and to integrate the influence of recreational users on habitat suitability into the fuzzy sets and rules. Our interviews with fish biologists revealed the following: (a) *C. nasus* is for most of the year a very shy species that is easily scared by walkers at the riverside. Even moderate recreational pressure, namely, two or more users within the area nearest to the wetted area (10-m long river section and 5-m cross section), has a negative impact on the riverside habitat used by *C. nasus* (juveniles and adults during the summer); (b) *C. nasus* is rapidly scared away by fishermen walking in the river, and even single swimmers and inflatable boats have a high impact on habitat preference; (c) Remote users (far from the wetted area) have either no or a very low, indirect impact on *C. nasus*; (d) If well-suited habitats are no longer usable owing to disturbances, *C. nasus* may, within a narrow range of tolerance, use deeper habitats with higher flow velocities; however, this behavior may cause physiological stress; (e) The species is fearless during the annual reproduction migration and the pre-reproduction period.

Table 3. Example of a fuzzy rule set describing the habitat requirements of *Chondrostoma nasus* (L.) for adult fish in the Isar River during summer. (Full Table S1).

Velocity	Depth	Substrate	Recreational User Pressure	Habitat Suitability Index (HSI)	Example
VH	VH	VH	VH	VL	Rule 1: IF all input variables "Very high" THEN HSI "Very low"
VH	H	L	M	H	Rule 2: IF velocity "Very high" AND depth "High" AND substratum "Low" AND recreational pressure "Medium" THEN HSI "High"
H	H	L	L	VH	Rule 3: IF velocity "High" AND depth "High" AND substratum "Low" AND recreational pressure "Low" THEN HSI "Very high"
VL	M	VH	M	L	Rule 4: IF velocity "Very low" AND depth "Medium" AND substratum "Very high" AND recreational pressure "Medium" THEN HSI "Low"

VL = very low; L = low; M = medium; H = high; and VH = very high.

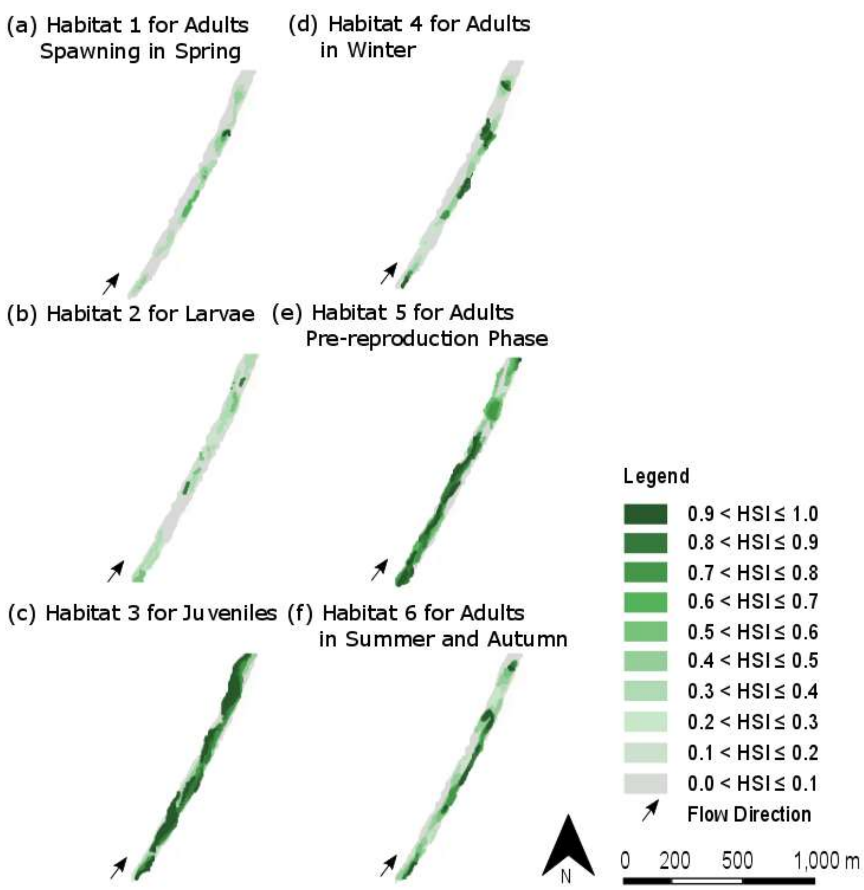

Figure 9. Habitat suitability map of the Reference site for (**a**) adults during summer, (**b**) adults during winter, (**c**) juveniles, (**d**) adults during the pre-reproduction period, (**e**) larvae, and (**f**) spawning adults at mean annual discharge.

3.4. Model Analysis

The model was run in two different ways: (a) exclusively using the tool for modeling physical habitat suitability applied to the 8 kilometers of studied river stretch (response to objective (i) in Section 1) and (b) adding "recreational pressure" as an additional component to identify potential conflicts between recreational uses and ecological quality (response to objectives (ii) and (iii) in Section 1).

We modeled the habitats in 108 scenarios, which comprised combinations of six habitat types (type 1 for Adults spawning, type 2 for Larvae, type 3 for Juveniles, type 4 for Adults in winter, type 5 for Adults in pre-reproduction phase, and type 6 for Adults in summer and autumn), nine discharge levels (NQ, MNQ, MQ, HQ1, HQ2, HQ5, HQ10, HQ50, and HQ100), and two modalities (with and without user pressure). The outputs of the model for each of the 108 scenarios were threefold: (a) Habitat suitability maps, which were composed of the hydro-morphological grid, in which each 5-m element had a calculated habitat suitability index (HSI). The HSI is the most common index for describing biological responses to abiotic attributes and represents the suitability of a habitat for a target species and life stage. The HSI has scalar values between 0 and 1, where 1 at a given grid element represents the most suitable habitat and 0 represents the most unsuitable habitat. (b) A table listing the surface of the wetted area for each HSI value. (c) A table listing the weighted usable area (WUA) and hydraulic habitat suitability index (HHS) for each scenario.

First, to estimate the physical habitat suitability post-restoration for each of the six habitat types and for each discharge level, we first performed descriptive analyses of the WUA and HHS values. Second, to define potential conflict areas, the geographical distribution of suitable physical habitats and discharge level was indicated on physical habitat suitability maps, and the spatial distribution of users was described. Finally, to investigate the influence of recreational pressure on physical habitat suitability, we performed Mann–Whitney–Wilcoxon and Ansari–Bradley tests to compare the medians and variances of the HSI at 200 randomly chosen elements of the grid for the 108 scenarios. Analyses were performed on all scenarios. However, some Figures and Tables presented only the results at mean annual discharge. This choice had been made to increase the readability. Considering Figure 2, mean annual discharge was considered as the common situation. Results for the other scenarios are available in the supplementary material.

4. Results

4.1. Physical Habitat Suitability

Physical habitat modeling results in terms of WUA in function of discharge (Figure 10 and Table 4) showed that highly suitable habitats (HIS > 0.6) exist for adults during the winter, summer, and pre-reproduction periods and for juveniles. Few areas with suitable habitat quality for larvae and spawning adults occurred at the restored Isar River stretch (Table 4). The areas with suitable habitats were located at the site Flaucher and at near-natural river bottom ramps with honeycomb-shaped structures. On the scale of the whole modeled river section, the HHS varied between 0.01 and 0.55, according to all investigated lifecycle stages and discharge levels (Table 5). The highest rates were found at mean low discharge and mean discharge for juveniles (HHS = 0.4 and 0.3), pre-reproduction adults (HHS = 0.3 and 0.2), and adults during summer (HHS = 0.2 and 0.2). The highest HHS was reached for juveniles and pre-reproduction adults at minimum discharge—55% and 35%, respectively, of the wetted area was highly suitable. Suitable physical habitats for pre-reproduction adults and for juveniles largely decreased with an increase in discharge. Suitable habitats for larval development and spawning activities were rare at any discharge level (<10% of the wetted area).

4.2. Spatial Distribution of Suitable Habitats

At NQ, MNQ, and MQ, highly suitable physical habitats for adults in winter and summer (>80%) were mostly located in the southern two-thirds of the study area and predominantly along the western riverside. The Flaucher site had high physical habitat suitability for adult fish during summer (Figure 11f) and winter (Figure 11d), except in the seminatural fishway (more than 80% of which had an HSI of <0.1). River sections (100–200 m) upstream of weirs had low HSI values (mostly <0.1). The area surrounding Willow Island (800 m upstream and 1000 m downstream) also had low HSI values (>90% of the area had an HSI of <0.1) at NQ and MNQ, but HSI values increased in this area at higher discharges. During flood events, suitable habitats for adults were relocated to the western riverside, namely, in the flooded recreational meadows. For NQ, MNQ, and MQ, suitable physical habitats for juveniles and pre-reproduction adults were found in the whole restored section, even in backwaters upstream of weirs. The areas surrounding the Flaucher (Figure 11c,e) and Willow Island had a high density of habitat patches with an HSI >0.9. During flood events, no relocation of habitats for juveniles was found. Suitable physical habitats for larvae and spawning were very limited within the whole restored river section for all investigated discharge levels, even within the Flaucher (Figure 11a,b). Surprisingly, single spots with medium HSI values (0.4–0.7) for both habitats were located on the near-natural river bottom ramps.

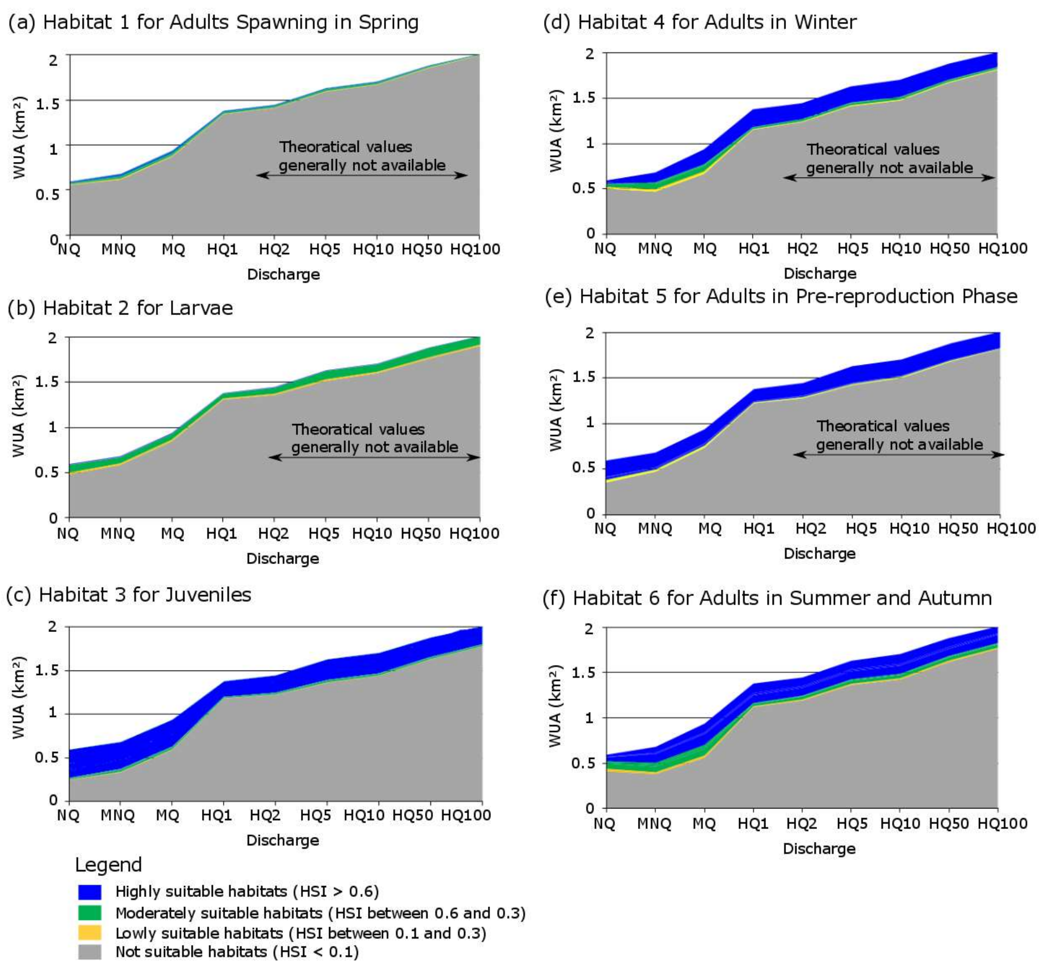

Figure 10. WUAs: (**a**) for spawning adults, (**b**) for larvae, (**c**) for juveniles, (**d**) for adults during winter, (**e**) for adults during the pre-reproduction period, and (**f**) for adults during summer and autumn. Flow acronyms defined in Section 3.1.2.

Table 4. Wetted area and relative percent of the wetted area with not suitable (HIS < 0.1), low suitability (HSI between 0.1 and 0.3), medium suitability (HSI between 0.3 and 0.6), and high suitability (HIS > 0.6) at mean annual discharge. Table S2 presents all the scenarios.

Lifecycle Stage	Indicators	Suitability			
		Not Suitable	Low	Medium	High
Adults Spawning	Wetted area (m^2)	559,100	6975	13,350	16,000
	% of the wetted area	94	1	2	3
Larvae	Wetted area (m^2)	481,400	20,550	86,350	7125
	% of the wetted area	81	3	14	1
Juveniles	Wetted area (m^2)	245,425	4125	20,300	325,575
	% of the wetted area	41	1	3	55
Adults in Winter	Wetted area (m^2)	506,350	16,725	36,425	35,925
	% of the wetted area	85	3	6	6
Adults (pre-reproduction)	Wetted area (m^2)	354,125	12,225	21,350	207,725
	% of the wetted area	59	2	4	35
Adults in Summer and Autumn	Wetted area (m^2)	412,375	28,150	83,875	71,025
	% of the wetted area	69	5	14	12

Table 5. Weighted Usable Area (WUA), Hydraulic Habitat Suitability index (HHS), and Mean Habitat Suitability Index (mean HSI) value for each habitat and scenarios MNQ (mean low discharge), MQ (mean annual discharge), and HQ (Annual mean maximum discharge), with and without users. Table S3 presents all the scenarios.

	Discharges	Scenarios					
		Without User			With User		
		NQ	MQ	HQ	NQ	MQ	HQ
Adults spawning	WUA (1000 m^2)	27	32	18	21	24	12
	HHS	0.03	0.03	0.01	0.03	0.03	0.01
	Mean HSI	0.0	0.0	0.0	0.0	0.1	0.0
Larvae	WUA (1000 m^2)	59	33	26	51	30	31
	HHS	0.07	0.04	0.02	0.06	0.03	0.02
	Mean HSI	0.0	0.1	0.0	0.1	0.1	0.0
Juveniles	WUA (1000 m^2)	330	269	145	291	232	167
	HHS	0.41	0.28	0.10	0.36	0.24	0.12
	Mean HSI	0.5	0.5	0.2	0.4	0.3	0.2
Adults in Winter	WUA (1000 m^2)	100	183	199	94	170	176
	HHS	0.12	0.19	0.14	0.12	0.18	0.13
	Mean HSI	0.3	0.4	0.3	0.1	0.2	0.2
Adults Pre-reproduction	WUA (1000 m^2)	248	178	145	243	176	183
	HHS	0.30	0.19	0.11	0.30	0.19	0.13
	Mean HSI	0.4	0.3	0.2	0.2	0.2	0.1
Adults in Summer and Autumn	WUA (1000 m^2)	167	238	195	156	217	173
	HHS	0.21	0.25	0.14	0.19	0.22	0.13
	Mean HSI	0.3	0.3	0.2	0.2	0.4	0.3

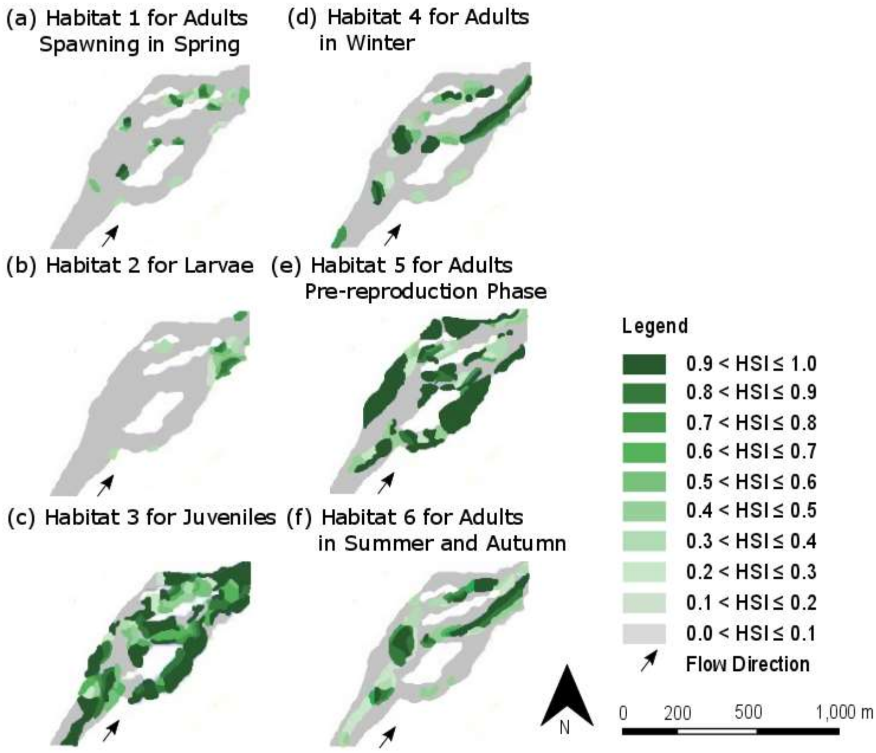

Figure 11. Habitat suitability map of the Flaucher site for (**a**) adults during summer, (**b**) adults during winter, (**c**) juveniles, (**d**) adults during the pre-reproduction period, (**e**) larvae, and (**f**) spawning adults at annual mean discharge.

4.3. Spatial and Temporal Distribution of Recreational Pressure

The number of users inside the study area increased at the end of April and decreased at the end of summer (Figure 12). The mean number of users during the study period was 599 (standard deviation (sd) = 211) per daily observation, among whom 23 (sd = 20) were swimmers. The maximum value, which was observed on a June day, was 774 users, including 60 swimmers. In summer, namely late July and August, the number of users dropped mainly due to major rain and flood events.

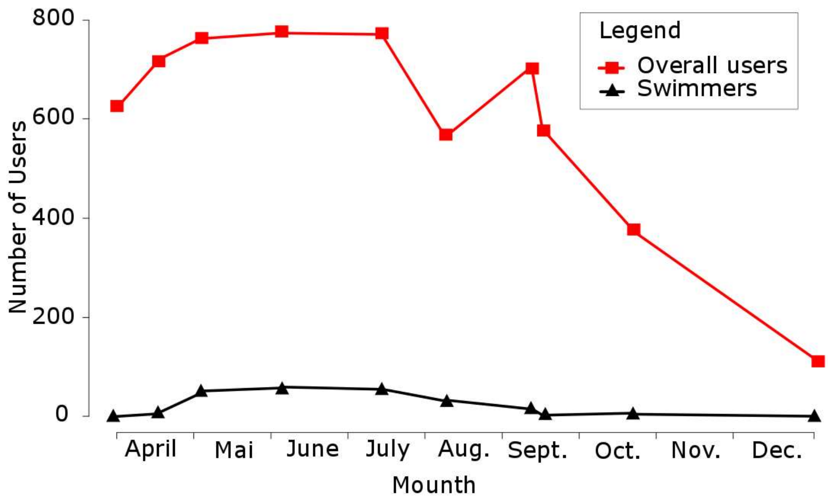

Figure 12. Plot of user numbers inside the whole study area on the 10 investigated days highlighting the number of swimmers.

User density varied inside the study area (Figure 13) (from 0 to 0.24 users per square meter). Most of the users were found on the eastern side (>90%). Recreational user pressure was high in five areas: (1) 600 m up- and downstream from Willow Island during the summer user density reached, on average, 0.12 users per square meter over the whole area. Single spots were found with 0.2 users per square meter, whereas the minimum value of 0.01 users per square meter was recorded in winter. Users mostly sat in small groups on the embankment close to the water and were present only on the eastern side of the river; (2) At the designed stairs, 0.18 (maximum) and 0.04 (minimum) users per square meter were found in summer and in winter, respectively; however, no swimmers were observed; (3) Around the Flaucher, user density in summer reached 0.24 users per square meter, and many users were found in the water (on average, N = 21); (4) On river-bottom ramps, user density locally increased to 0.12 users per square meter (maximum value); (5) From the Großhesseloher Bridge to 1000 m downstream, user density was lower (0.04 users per square meter on average), but a quarter of the users were swimmers. The western side of the river within the whole restored section was under low recreational user pressure.

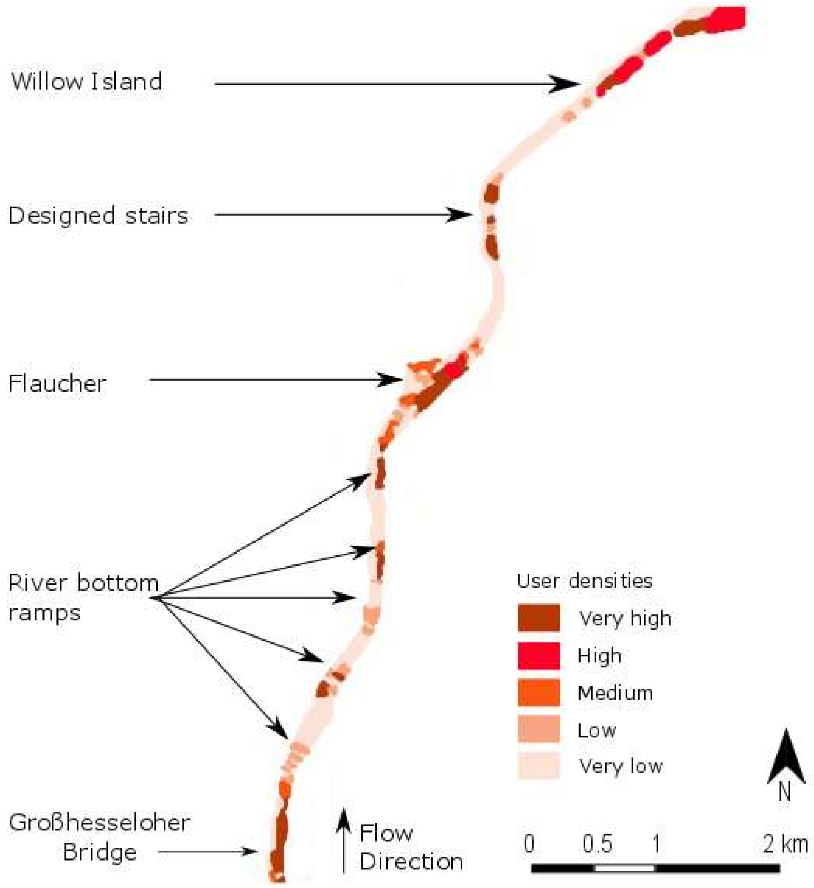

Figure 13. User density map of the Isar River in Munich indicating on the eastern side spots with high to very high user densities separated by long stretches with very low user densities, and on the western side, mostly very low user densities (categories are as defined in Table 2).

4.4. Influence of Recreational Users on Availability of Habitats for *C. nasus*

An overall comparison of the WUA values showed that, at MQ, 8% of highly suitable habitats for *C. nasus* may be lost owing to recreational pressure. Statistical analyses of the 200 randomly chosen points showed that the quantity of suitable habitats and the habitat quality of the restored river section for *C. nasus* decreased when recreational pressure was integrated into the evaluation procedure for juveniles, spawning adults, and larvae, but no significant differences were found for adults during summer, autumn, winter, and pre-reproduction periods (Figure 14). Potentially highly suitable habitats for juveniles, spawning activities, and larval development lost important parts of their surface areas due to recreational pressure (9%–15.5%, 20%–25%, and 71%–76%, respectively), whereas potentially highly suitable habitats for adults during summer, autumn, winter, and pre-reproduction periods lost only a small part of their surface areas due to recreational pressure (0%–9%, 0%–4%, and 0%–3%, respectively). The largest losses of potentially suitable habitats for juveniles owing to recreational pressure were found on the low-flow secondary arm flowing on the eastern side of Willow Island, on the eastern part of the Flaucher, and just downstream from the Großhesseloher Bridge (Figure 15). For example, the Flaucher site lost more than 60% of its highly suitable habitats for juveniles when recreational pressure was integrated into the model. All the relatively suitable habitats for spawning activities and larval development were located in areas with high user and swimmer densities.

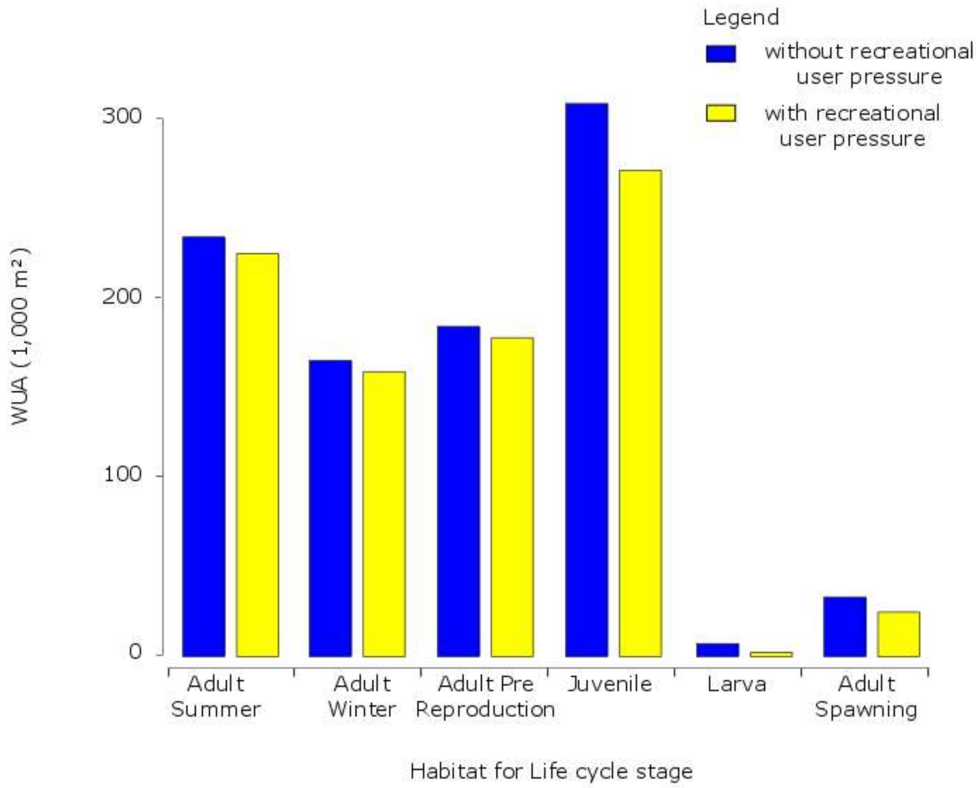

Figure 14. Weighted usable area (WUA) in square meters of the restored river stretch at annual mean discharge for the six habitats of *Chondrostoma nasus* L. with and without the inclusion of recreational pressure.

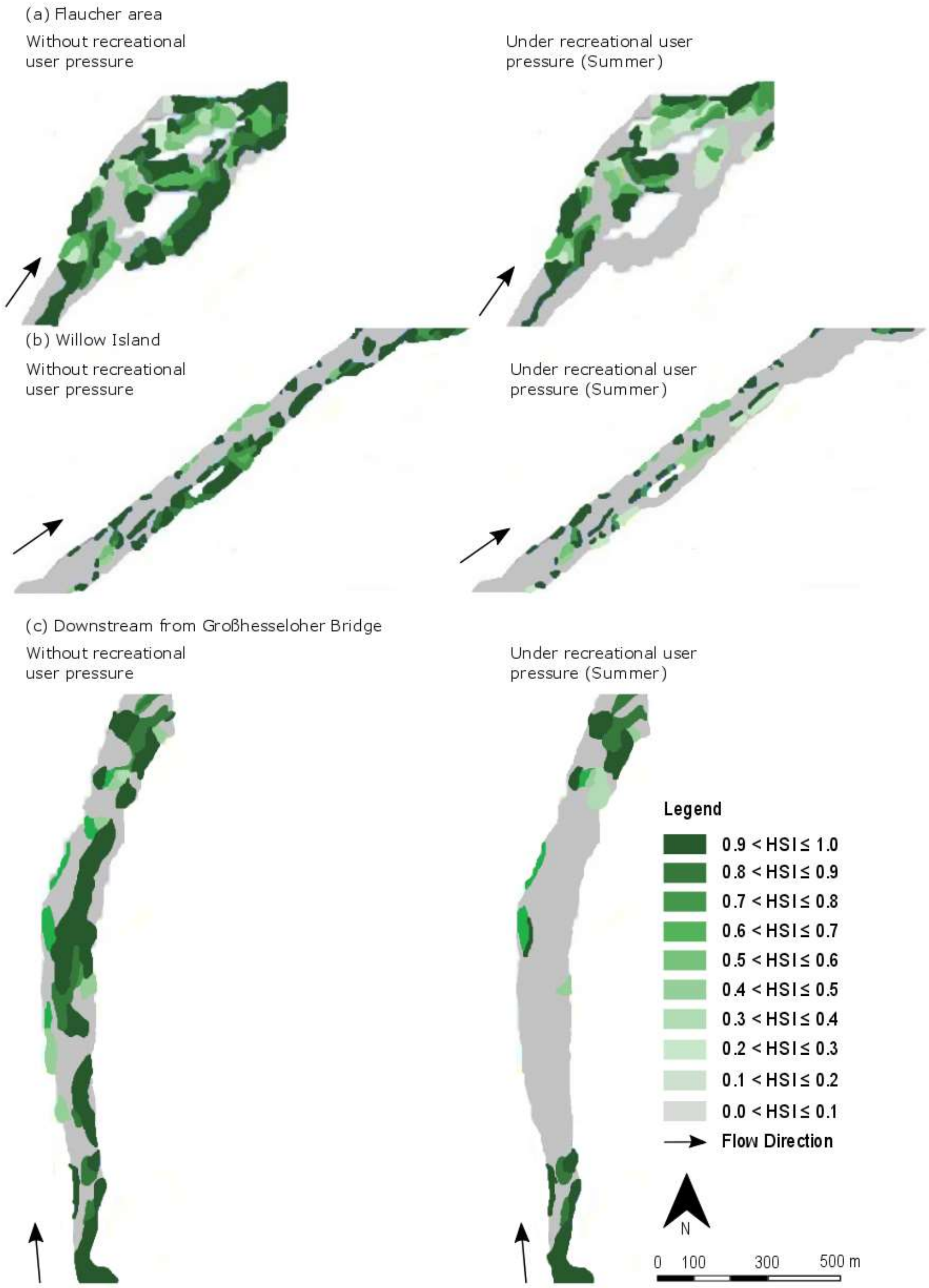

Figure 15. Habitat suitability map for juveniles of *Chondrostoma nasus* at mean annual discharge considering or ignoring recreational pressure in the case of (**a**) the Flaucher area, (**b**) Willow Island, and (**c**) the area near the Großhesseloher Bridge (HSI = Habitat Suitability Index).

5. Discussion

5.1. Physical Habitat Suitability

The modelling results show that the restored river section provides four out of six suitable physical habitats that *C. nasus* requires during the stages of its lifecycle, i.e., habitats for adult fish during summer, autumn, and winter, pre-reproduction periods as well as for juveniles. However, the results of the habitat suitability model also showed three major issues that may explain the nonrecovery of the species.

First, we found that the restored river section has very limited suitable habitats for spawning activities and larval development. However, the physical habitat model suggests that near-natural manmade elements, e.g., near natural river-bottom ramps with honeycomb-shaped structures, may have locally positive effects on physical habitat suitability for *C. nasus*, even if they did not succeed in recreating highly suitable habitats. River-bottom ramps result from the removal of linear low weirs and have honeycomb-shaped structures constructed with natural large rocks to disperse the hydraulic head over a short distance but with a gentle slope. These provide a high diversity of microhabitats with different velocities, depths, and substrata, e.g., for sensitive benthic invertebrates and fish in gravel bar rivers [89]. However, although slight improvements were found, the functionality of the created habitats remains to be proven for the nase. Cyprinidae species require recently deposited clean fine-gravel substratum for spawning and larval development, and further field research is needed to test if the sediments in the ramps are sufficiently clean to allow attachment of nase eggs. Another constraint for the re-establishment of the nase population in the Isar River is that tributaries that historically served as additional spawning sites are today dammed, canalized, and partly buried. Our findings suggest that the priority of the restoration/conservation strategy should be a long-term solution based on the improvement of both the migration potential (namely, the re-establishment of longitudinal and transverse connectivity between the main channel, secondary arms, and tributaries) and the restoration of physical habitats for spawning activities and larval development.

Second, the restored Isar River did not provide sufficient slow-flowing anabranches suitable for juvenile *C. nasus* during high-discharge events. According to the Isar River seasonal flow regime, major flood events may happen during reproduction or shortly afterward. Larvae and young fish are particularly sensitive to drift during flood events [65,70,72,73]. One anabranch has been recreated (Willow Island), but the goals of the restoration were set to maintain broad flat recreational grassland instead of meandering the riverbed and creating an undulating riverscape. As a consequence, the water velocity remains too high, and the sediment dynamics in the floodplain are too low to provide suitable habitats for recruitment. Even if the direct impact of the recreation is removed during the reproduction period and the early development stage of juveniles, the choice of the project goals, namely, to "provide flat grassland for recreational use", results in a low suitability of the habitats for these critical life stages. As a consequence, the population of *C. nasus* in the Isar River is ageing [65].

Natural recruitment is the most promising option for conservation [77], as previous attempts of restocking *C. nasus* have failed [74]. Our findings suggest that the restoration/conservation strategy should include the improvement of both the migration potential (namely, the re-establishment of longitudinal and transverse connectivity between the main channel, secondary arms, and tributaries) and the restoration of physical habitats for spawning activities and larval development by permitting more sediment dynamics. We predict that if recovery occurs, the southern section will have higher densities than the northern one due to its higher habitat suitability values.

5.2. Conflicts between Wildlife and Recreational User Pressure

Our results suggest that different conflicts occur according to lifecycle–specific habitat types of *C. nasus* and the periodic preferences of recreational users. We found that the highest user densities partly occurred in suitable habitats for juvenile *C. nasus*, i.e., low-flow zones and the submerged tops of gravel bars. However, the modelled habitats for juveniles were rather widely distributed over the restored river stretch, and the overall impact of users may remain limited. User densities were also high in the rare potential spawning areas, e.g., river-bottom ramps, causing a significant decrease in the WUA. However, the spawning period (beginning of May) may occur shortly before the user density ranges from high to very high (May to October), but overlapping of the areas used by *C. nasus* and recreationists remains likely. Our results suggest that users have a low impact (a) on adult fish during winter, because user density is significantly lower and *C. nasus* inhabits deeper water than during summer and autumn [64,65,69]; (b) on adult fish during summer and autumn, because users observed in our study were mostly located on the eastern side and suitable physical habitats were on the western side; and (c) on adults during the pre-reproduction period, because fish biologists described *C. nasus* as less sensitive to disturbance at this time. We suggest that conflicts may be avoided if user distribution can be wisely influenced by the design of restoration and by adequate guidance of users.

Tools for managers attempting to mitigate recreation–wildlife interactions are regulations, public education, and a user-management plan. First, we generally advise against the formulation of regulations forbidding the recreational use of larger riverine areas within the city because positive public support for sustainable management and restoration projects is strongly driven by perception, communication, possibilities to participate, and the usefulness of the restoration outcomes. However, in case of great importance, e.g., last occurrence of a population, restrictions may be the only solution. Acceptance of this restriction is efficient if the abstinence of using a protected site becomes a collective activity of respect towards an acknowledged heritage. Second, informing and educating the public can be addressed by an attitude-change strategy. Urban river beaches are prime sites for creating encounter places of man and nature, which help to re-establish emotional linkages, create motivation, and change decisional values in favor of maintaining or restoring ecosystem integrity [2]. A study on the Danube showed that only 40% of recreational users were aware that wildlife is disturbed by recreational activities, e.g., off-trail walking [90]. Educational work to increase the awareness and knowledge of the public seems to be a sustainable tool for avoiding conflicts between users and wildlife. However, a strategy for attitudinal change may be ineffective. A study showed that only 5% of recreationists change their behavior after educational work. Furthermore, a study in the United States showed that people are becoming less supportive toward fish and restoration efforts targeting fish species. Accordingly, we consider that this strategy may be very useful to provide sites for environmental education in cities and enable attitude change even beyond the visited site. However, highly sensitive species may not be able to sustain the disturbances at highly frequented sites. The targets for restoration projects need to be well defined, explained, and chosen by the public [15]. Third, managing flows of visitors applying a user-management plan may relocate users and separate sections of the river between recreationists and ecological refuges for wildlife [91]. Studies have shown that user preferences for waterscapes are driven by both visual values [23,92–95], e.g., parameters of fascination, vividness, and naturalness [93–95], and usability [96]. In our case study, it may be relevant to create suitable habitats for wildlife on the western side of the river, which is almost inaccessible to citizens because of the topography of the area. However, user preferences are complex because every individual may perceive landscapes in a different way and may be differently affected by environmental and societal stimuli.

Interest in the prediction of user density and distribution for implementing a motivational management strategy that regulates users has grown considerably in recent years. User distribution maps or models should be integrated into habitat suitability models to create a predictive tool to help choose the best restoration design, to define refuges for species, and to investigate future scenarios (climate change, industrialization, increases in user density, etc., see next paragraph). However, this area of scientific inquiry involves a broad range of disciplines and their respective fields of knowledge. More studies on recreational user preferences and recreational impacts on wildlife remain to be carried out to provide a strong baseline for the design of user-management plans based on an integrated framework for coexistence between recreationists and biodiversity.

5.3. Benefits of Integrating User Pressure into the Physical Habitat Model

The modeling of fish habitats using CASiMiR provided significant results for evaluating the quality of the physical habitats for *C. nasus* in the studied river section. A novelty was the inclusion of recreational user pressure as a new parameter in the habitat-modeling procedure, which showed clear differences from the results of modeling physical habitats only. The modeling procedure helped to identify conflict areas and the lifecycle stage (juveniles) that may be most affected by users. However, the method still has some limitations. Considering the precision of the assessment of recreational pressures, we have to state that occasional observations have revealed much higher figures of riverbank-users than the results from a standardized procedure presented here. In order to reduce bias from the high fluctuation of users (driven by working time and weather conditions), user surveys should be more frequent and long term. We suggest the use of drones or aerial photographs to reduce cost. Another critical point is the evaluation of species tolerance limits, namely, tolerated user intensities and frequencies. In this study, the habitat preferences and impacts of recreationists were estimated by expert statements of fish biologists because little scientific literature was available concerning these points. Despite the fact that expert evaluations of ecological quality may be as trustworthy as assessments made by experimental field investigations [97], future research designed specifically to evaluate the impact of recreationists on wildlife would be helpful.

Our study has demonstrated the existence of habitats with suitable flow velocities, depths, and substrata for all lifecycle stages of *C. nasus* historically observed in this Isar River section, and it suggests that the reduction of adequate spawning and juvenile habitats by physical destruction and by user pressure (on the juvenile habitats) is responsible for the absence of recruitment. However, it does not explain fully the absence of *C. nasus* in the restored Isar River section. Other habitat variables such as temperature, food sources, and predators as well as habitat availability on the scale of the catchment could be taken into account to complete the picture.

6. Conclusions

This study delivered a model of the suitability of habitats for the indicator species *Chondrostoma nasus* (L.) on the restored Isar River in Munich (Germany), including, as a novel feature, the impact of recreational users as a supplementary parameter in the habitat suitability model. The findings of the study are threefold. First, the research showed that the restoration of the studied river section succeeded in providing physically suitable habitats for all lifecycle stages of the species in general. It also showed that the establishment of habitats for spawning and larval development, the creation of refuges for sensitive lifecycle stages during flood events, and the re-establishment of a wide diversity of habitats has not been achieved within the northern part of the restored river section. Second, the model showed that recreational users may cause decreases in highly suitable habitats for sensitive lifecycle stages of *C. nasus* in identified zones of conflict, especially during summer, when recreational user density is high. We suggest to combine two approaches: (a) providing sections of riverine beaches as encounter sites of man and nature in the sense of the River Culture Concept [2] with (b) a user-management plan directing flows of visitors out of highly sensitive sites by making them less or not accessible.. Third, the developed method enabled an integrative evaluation of habitat quality for the target species. The modeling approach, which combines hydro-morphological–biological modelling with user pressure, has been shown to be a useful tool for increasing the efficiency of ecological restoration design, defining the best location for the re-introduction of sensitive species, and supporting user-management plans in urban contexts. Further research about the behavior of fish facing recreational pressures, variables such as temperature and the food-web composition, and habitat availability on the catchment scale is needed to identify the ultimate causes for the failure to re-establish *C. nasus*. We argue that there is an urgent need for a shift in the design of restoration projects and their evaluation toward holistic and interdisciplinary approaches that embrace the principles of socioecological systems.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/10/6/1747/s1. Table S1: Fuzzy sets and rules for the studied habitats, namely for adults (during the winter, the summer and autumn, during pre-reproduction, and spawning), larvae, and juveniles C. nasus at the Isar river (Germany) considering the input variables (i.e. velocity, water depth, Substratum, recreational pressure). Table S2: Wetted area and relative percent of the wetted area with not suitable (HSI<0.1), low suitability (HSI between 0.1 and 0.3), medium suitability (HSI between 0.3 and 0.6) and high suitability (HSI>0.6) at MQ. Table S2 presents all the scenarios. Table S3: Weighted Usable Area (WUA), Hydraulic Habitat Suitability index (HHS), and Mean Habitat Suitability Index (mean HSI) value for each habitat and all scenarios.

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Paper E

"Zingraff-Hamed, A., Noack, M., Greulich, S., Schwarzwälder, K., Pauleit, S., Wantzen K. M. (2018) Model-Based Evaluation of the Effects of River Discharge Modulations on Physical Fish Habitat Quality, Water (10) 374; doi:10.3390/w10040374"

The first author, Aude Zingraff-Hamed, conducted the study, namely: Identify the knowledge gaps and research questions; Develop the conceptual idea and analytical framework; Design questionnaires; Conduct field survey; and Perform analyses and calculations. The 2D hydromorphological model, which was used as input data for the habitat model procedure CASiMiR as presented in Paper D and E, was simulated by Dr. Markus Noack (University Stuttgart) and SKI GmbH + Co.KG. The hydromorphological field survey at the Isar was conducted by Aude Zingraff-Hamed in collaboration with Dr. Kordula Schwarzwälder (Technical University of Munich) and associated staff. All these research steps were discussed with the research supervisors: Prof. Stephan Pauleit, Prof. K. Matthias Wantzen, and Dr. Sabine Greulich. Contribution was written by Aude Zingraff-Hamed in collaboration with all the co-authors.

French Abstract/Résumé en langue française :

L’article E intitulé *Model-Based Evaluation of the Effects of River Discharge Modulations on Physical Fish Habitat Quality* a été soumis au journal *Water*. Il rapporte les résultats d’une étude sur la gestion équitable de la ressource en eau pour l’homme et la nature simulant différents scénarii. Cette étude a trois objectifs : a) Étudier l’effet de l’augmentation du débit minimal comme mesures de restauration. b) Présenter une méthode pour définir l’exigence en débit minimale pour les espèces sensibles cible de la restauration. Et c) définir le meilleur scénario pour les espèces étudiées dans le cas de l’Isar à Munich (Allemagne).

L’étude a été réalisée dans le cas de l’Isar à Munich qui a été hydromorphologiquement restaurée entre 1999 et 2011. Le lit a été remodelé, la diversité des habitats aquatique accrue et le débit minimal augmenté. Cette mesure a donné lieu à de nombreuses discutions entre le maître d’ouvrage, les associations de pêcheurs et l’exploitant des centrales hydro-électriques. Un accord a été trouvé augmentant le débit minimal de 5 à 12 m³/s alors que les associations écologiques demandaient 17m³/s. Cette étude modélise les habitats physique pour les différentes phases du cycle biologique de trois espèces de poissons cibles de la restauration et historiquement présentes à l’Isar à Munich : *Thymallus thymallus* L., *Hucho hucho* L., et *Chondrostoma nasus* L. La modélisation se base sur un modèle hydromorphologique à haute résolution informant pour chacune des 160 000 cellules de 1m x 1m sur les trois variables clefs décrivant les habitats du poisson : vélocité, profondeur de la colonne d’eau et type de substrat à la surface du lit. La morphologie fluviale post restauration a été établi utilisant le logiciel SMS 10 (Surface Modeling System, Aquaveo, USA) utilisant les données topographiques fournies par le bureau d’ingénierie en hydraulique ayant assisté la réalisation du projet de restauration. La vélocité a été calculée utilisant le logiciel Hydro_AS-2D version 3 et résolvant le modèle spectrale par les équations Sait-Venant et utilisant la méthode de discrétisation des volumes finis. Le modèle a été calibré pour quatre débits allant de 65 m³/s à 782 m³/s. Le substrat superficiel du lit a été documenté par relevé de terrain lors des basses eaux en 2013 en identifiant visuellement la taille du grain dominant. Le substrat de chaque cellule a été identifié utilisant les catégorie suivante: 1) Matière organique; 2) Limon ou argile; 3) Sable fin (<2 mm); 4) Sable moyen (2–6 mm); 5) Sable grossier (6–20 mm); 6) Gravier (2–6 cm); 7) Pierres (6–12 cm); 8) Rochers (>20 cm); et 9) Roche lisse ou béton. Quatre scenarii ont été étudiés : débit minimal de 5 m³/s, débit

minimal de 12 m³/s, débit minimal de 17 m³/s, et pas de diversion alimentant les centrales hydro-électriques. Le calcul des débits pour toute l'année hydrologique a été effectué es relevés réalisés chaque heure en 2016. Les données hydrologiques ont été fournies par l'agence de l'eau (*Wasserwirtschaftsamt*).

L'analyse du modèle montre la quantité et qualité des habitats varie avec les débits. Cependant, tous les habitats ne bénéficient pas des mêmes conditions. Alors que les habitats propices pour les poissons adultes augmentent généralement avec la quantité d'eau disponible dans le lit principale, les frayères bénéficient de débits plus faibles. Toutefois, chaque espèce ayant des préférences différentes aucun des quatre scenarii étudiés ne permet d'atteindre un maximal de qualité et de quantité pour les trois espèces en même temps. Ainsi, les objectifs de restauration doivent être considérés pour établir quel scénario devra être appliqué. Étonnement, le scénario sans diversion ne permet pas d'atteindre le maximum d'habitats propices suggérant que la morphologique établit par le projet de restauration ne permet pas une assez grande diversité des habitats. Dans un contexte urbain et considérant le system socio-écologique dans son ensemble, le succès d'une restauration durable demande la formulation d'objectifs réalistes apportant le maximal de profit pour l'homme et la biodiversité.

Mots clefs: débits minimum, modélisation des habitats du poisson, diversion d'eau, restauration des rivières, valeur des habitats.

water

MDPI

Article

Model-Based Evaluation of the Effects of River Discharge Modulations on Physical Fish Habitat Quality

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Abstract: The increase in minimum flows has rarely been considered to mitigate the ecological impact of hydroelectric power plants because it requires a site-specific design and expensive long-term monitoring procedure to identify the most beneficial scenario. This study presents a model-based method to estimate, within the model constraints, the most sustainable scenario of water resource sharing between nature and human needs. We studied physical habitat suitability of the Isar River in Munich (Germany) for three protected fish species: *Thymallus thymallus* L., *Hucho hucho* L., and *Chondostroma nasus* L. The analysis combined a high-resolution two-dimensional (2D) hydromorphological model with expert-based procedures using Computer Aided Simulation Model for Instream Flow Requirements (CASiMIR). We simulated a range of minimum discharges from 5 to 68.5 m^3/s and four scenarios: (A) maximum use of the resource for humans; (B) slight increase in the minimum water flow; (C) medium increase in the minimum water flow; and, (D) without diversion for hydroelectric production. Under the current hydromorphological conditions, model outputs showed that different life stages of the fish species showed preferences for different scenarios, and that none of the four scenarios provided permanently suitable habitat conditions for the three species. We suggest that discharge management should be combined with hydromorphological restoration actions to re-establish parts of the modified channel slope and/or parts of the previously lost floodplain habitat in order to implement a solution that favors all species at the same time. The modeling procedure that is presented may be helpful to identify the discharge scenario that is most efficient for maintaining target fish species under realistic usage conditions.

Keywords: fish habitat modeling; hydromorphological modeling; CASiMiR; sustainable water management; minimum water flow; environmental flows determination

1. Introduction

Demands for renewable energy production, e.g., hydroelectric power plants, increase, but their ecological impact remains considerable. In the face of increasing energy needs, a reduction of the fossil energy sources and climate changes, new policies, such as the Kyoto Protocol [1] and the EU Renewable Energy Directive [2], have been formulated, thus increasing the demand for renewable energy production. Hydropower is one of the two largest contributors to sustainable electricity generation worldwide and represented almost 80% of the electricity generated using renewable resources in 2012 [3]. It is the most affordable renewable energy source, and run-of-river hydroelectric power plants have the highest energy payback ratio (267 versus 39 for wind and nine for solar photovoltaic) [4]. However, they contribute greatly to the degradation of river ecosystems and biodiversity [5,6]: Retention structures are obstacles to the longitudinal connectivity of river habitats [7], reduce hydrodynamics, and foster exotic species invasion [8]; hydropeaking causes dewatering, fish stranding and modifies fish assemblage [9,10]; flow modifications have severe consequences for river ecosystems [8], and particularly for the fish population [11–15].

At the same time, awareness of ecological conservation and restoration is also increasing. The EU Water Framework Directive [16] aims at ensuring the quality and sustainable management of EU waters and demands the restoration of all European water bodies in order to achieve a good aquatic habitat quality, even in the case of heavily modified water bodies. Consequently, the EU Renewable Energy Directive (2009) conflicts with the EU Water Framework Directive (2000), and hydropower politics have to find the right balance between energy security, sustainability, climate change prevention and adaptation, biodiversity conservation, and water protection [4,17,18]. Much research has focused on the design of fish-friendly turbines [19], or fish passes [20], and on the formulation of guidelines to decrease the impact of hydropeaking on aquatic habitats [12–14,21,22]. Also, minimum flow requirements for aquatic habitats have been intensively studied during the last three decades and guidelines for sustainable water sharing between hydropower plants and aquatic habitats have been formulated [23].

The quantity, quality, and timing of water flows are the basic requirements for sustainable water sharing and are an issue for river restoration. Water managers must ensure that the water flows required to sustain freshwater ecosystems remain available [23–25]. Unfortunately, for economic reasons, findings on water security for biodiversity are relatively poorly integrated [26]. Surveys of restoration measures in Germany and in France showed that an increase in minimum flows remains a rare restoration measure, namely less than 6% of the rural projects [27] and less than 2% of the urban projects [28]. Most guidelines suggested minimum flow calculations that were based on river hydrology, namely a third of the annual mean low discharge [23] but this standardized approach does not consider the local specificities of aquatic habitats. Therefore, minimum flows should be assessed in relation to local conditions and aquatic habitat demand.

Habitat modeling is a scientific method to assess the (positive or negative) impact of hydromorphological changes on physical in-stream habitats. Fish are a common indicator of aquatic habitat richness because fish habitat preferences are well described, the number of native fish species is low and fish inform about the physical quality of the habitats [29–32]. For example, the European Water Framework Directive [16] defines fish as a key indicator species in determining the ecological status of surface water bodies. Even if the modeling procedures have model uncertainties and limitations, they solve major both temporal and spatial limitations of field observation approaches. Furthermore, advanced modeling procedures can quickly evaluate the success and cost-effectiveness of engineering measures [33,34], and are increasingly used in water resource management [29,34], e.g., to investigate habitat changes caused by hydropeaking [35,36], weir removal [37,38], and reservoirs [39]. The Computer Aided Simulation Model for Instream Flow Requirements (CASiMiR) is a habitat simulation tool for aquatic organisms with a focus on fish and macroinvertebrates. It uses a multivariate fuzzy-logical approach to link abiotic attributes with habitat requirements of aquatic species, resulting in a habitat suitability index (HSI). The use of fuzzy logic enable to deal with highly variable, linguistic, and even vague data [40]. It uses the three physical characteristics of rivers that allow for the determination of the quality of habitats for fish species: flow velocity, water depth, and substratum [41,42] Each parameter is classified by overlapping membership-functions that are described by vague linguistic variables (e.g., low, medium, high). The relationship between these physical parameters and the biotic response are determined by using IF-THEN rules (fuzzy-rules) [43]. Fuzzy rules are defined for all the possible combinations in close collaboration with biological experts. Hence, the experts themselves define the conditions under which habitat quality is described as 'high', 'medium', or 'low'. This procedure has the significant advantage that expert knowledge of aquatic biologists [44] can be easily transferred into a mathematical approach. The model output enables the predictions of habitat quality and quantity for different fish species and their life stages in the case of defined river sections [45,46].

The objectives of this study were (i) to investigate the effect of change of minimum water flow on physical aquatic habitats and (ii) to identify the best minimum water flow strategy in the context of water diversion to secure habitats for target fish species in a case study. The investigations were carried out in the hydromorphologically restored main channel of the Isar River in Munich (Germany) (Figure 1). Most of the Isar water (93% of the mean annual discharge) is diverted into a side channel to supply hydroelectric power plants. As part of a restoration project, intense negotiations were carried out with users, NGOs, and the energy producer to increase the minimal discharge flowing into the restored river section. Identification of the best water-sharing scenario should provide important insights for this and future restoration projects. We hypothesized that an increase in minimal water flow would have a positive effect on the physical habitat suitability for fish species and tested if the overall aquatic habitat quality is the best when water diversion is removed. We tested these hypotheses by modeling habitat suitability under different discharges for three fish species, which were a target of the restoration, i.e., *Thymallus thymallus* L., *Hucho hucho* L., and *Chondrostoma nasus* L.

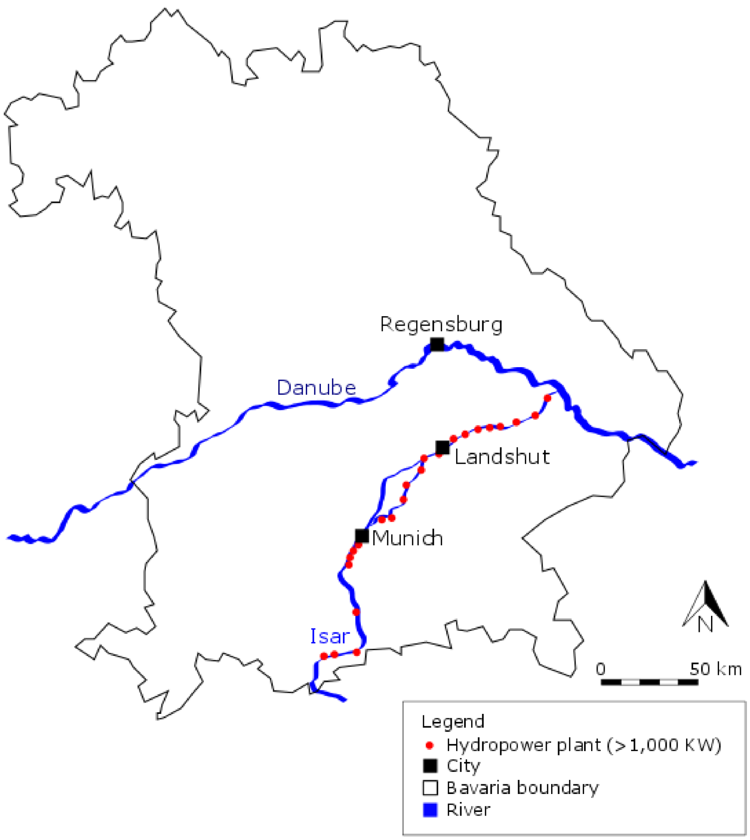

Figure 1. Map of Bavaria (Germany) with the location of the Isar River, Munich city and the hydroelectrical power plants at the Isar.

2. Material and Methods

2.1. Study Area

The pre-alpine Isar River drains the Northern Alps and joins the Danube River. The construction of 43 hydroelectric power plants at the Isar River and its canals began in the 1920s, causing major morphological changes, regulation of the flows, and longitudinal discontinuity. In 1959, the Sylvenstein Reservoir was built in the Alps 75 km upstream of Munich (Germany) as protection against major flood events, in order to avoid dryness and to ensure water supply for hydroelectric power plants and cooling water for nuclear and thermal power plants. Rain events and snowmelt inside the catchment area downstream of the reservoir influence the discharge of the Isar River in Munich. Winter is the driest season, with a mean discharge of 47.1 m^3/s recorded between 1959 and 2012 in Munich city center (http://www.hnd.bayern.de). In spring, discharge increases with temperature and snowmelt. During the summer, discharge is higher, but many variations occur. Flood events due to rain are frequent (mean maximum discharge in summer = 395 m^3/s) and cause very high discharges (650–1050 m^3/s). Summer dryness may also cause sporadic minimal discharges during summer, but are mostly avoided by the Sylvenstein Reservoir. Despite discharge regulations and water flow diversion, the Isar River bed benefits from frequent (at least biannual) major sediment transport during flood events. Furthermore, the water quality at the Isar River benefits from the absence of intensive agriculture and from the absence of industry and major cities upstream of the City of Munich (http://www.gkd.bayern.de/?sp=en).

The Isar River is intensively used for hydropower generation. In the Munich metropolitan area, 11 hydroelectric power plants produced 73.5 million kilowatt hours in 2013. At the southern city limit, a weir diverts the water of the Isar into a side canal (maximum discharge of 90 m^3/s), which supplies three run-of-river hydroelectric power plants: Isarwerk 1 with 15 million kWh in 2011, Isarwerk 2 with 15 million kWh in 2011, and Isarwerk 3 with 17 million kWh in 2011 (Figure 2). Within the river restoration project "New Life for the Isar" (1999–2011), the Bavarian Water Agency and Munich city government intended to improve the morphological status of eight kilometers of the Isar from the southern limit of the city territory to the city center. One of the restoration measures was the increase in minimum flow inside the near-natural original river bed (from 5 to 12 m^3/s) in order to improve riverscape aesthetic, recreational uses, and the quality of aquatic habitats.

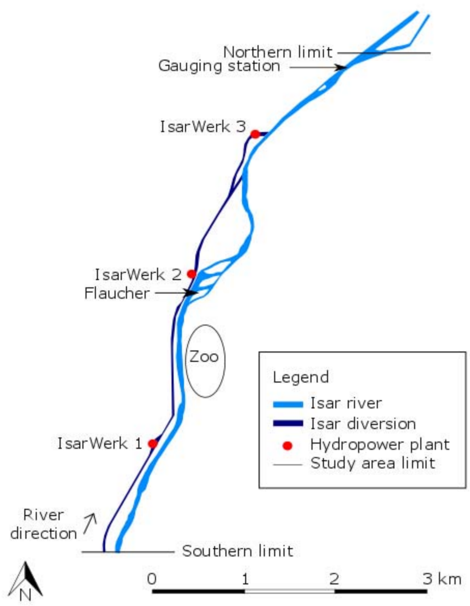

Figure 2. Map of the study area with the location of the hydroelectrical power plants at the Isar side canal.

2.2. Physical Characteristics

Substratum, flow velocity, and water depth are the most commonly used variables to describe physical habitats of fish species [41,42]. We established a two-dimensional (2D) hydromorphological model of the restored river reach, i.e., from the Großhesseloher Bridge (48°4′29.59″ N, 11°32′25.83″ E) to the Museum Island (48°7′41.42″ N, 11°34′46.88″ E) when considering these three river characteristics on a 5-m grid. First, the substratum characteristics were visually determined by 1628 field measurements performed by boat in summer 2013 during mean low discharge (MNQ = 16.5 m^3/s). Nine substratum types of the top layer of the river bottom were distinguished according to the grain size of the dominant component: (1) organic matter or detritus; (2) silt, clay, or loam; (3) sand (<2 mm); (4) fine gravel (2–6 mm); (5) medium gravel (6–20 mm); (6) large gravel (20–60 mm); (7) large stones (60–120 mm); (8) boulders (>200 mm); and, (9) rock or concrete. The resulting substratum map was digitalized using the software SMS 10 (Surface Modelling System, Aquaveo, Utah USA). We calculated that the medium gravel substratum (d50 = 26 mm) in the Munich region started to move at 290 m^3/s and that the fine-grained sediment (<10 mm) already drifted at 80 m^3/s. Consequently, substratum characteristics were assumed to be constant over time for discharges below these limits. Then, the hydromorphological model of the study area (160,000 elements)—the riverbed and the floodplain inside the dikes—was established using a two-dimensional hydrodynamic numerical model Hydro_AS-2D version 3 [47] to simulate the spatial distribution of the water depth and flow velocity for the investigated discharges in the riverbed. The model solved the shallow-water equations using finite volume discretization. In order to extensively calibrate and validate the model, water level measurements for four discharges ranging from 65 to 782 m^3/s were applied verifying adequate model performance.

In order to identify the most realistic scenarios to be tested with the CASiMIR modelling procedure, we first carried out open interviews and discussions with groups of recreational users, NGOs, and the energy producer concerning the potential minimal discharges flowing into the restored river section. Resulting from these consultations, we simulated the following four scenarios: Scenario A corresponds to the lowest residual water discharge flowing inside the riverbed, i.e., 5 m^3/s at the southern city border, according to the water use agreement prior to restoration and established in the early begin of the nineteenth century; Scenario B corresponds to an daily increase of 7 m^3/s (from 5 to 12 m^3/s), and was defined as maximal compromise by the energy producer; Scenario C corresponds to a daily increase of 12 m^3/s, namely from 5 to 17 m^3/s, as required by user NGOs as restoration measure; Scenario D corresponds to the mean annual discharge without diversion (68.5 m^3/s), as required by nature conservation NGOs. The discharges that are applied in the four scenarios correspond to values at the southern (upstream) limit of the modelled restored river segment. Flow variations were calculated applying a two-dimensional hydrodynamic numerical model using a 5 m grid. For all of the scenarios, steady-state boundary conditions were used. The complete discharge of the Isar, i.e., the main channel and the side canal used for hydropower generation, was measured at the gauging station (Figure 2) on an hourly basis by the WWA. The hydrological year 2016 was chosen as hydrological reference to compare the scenarios (Figure 3) because the data were the most recent, very accurate, and no unusual hydrological events, such as extreme floods or droughts (beyond the 500 year maximum/minimum values) happened. It is worth mentioning that for Scenarios A, B, and C, the discharge flowing into the riverbed was constant, except for flood events, which caused important flash floods (Figure 3). Isar flood events in March are due to snow melt and in summer are due to storm with major rain events in the Alps.

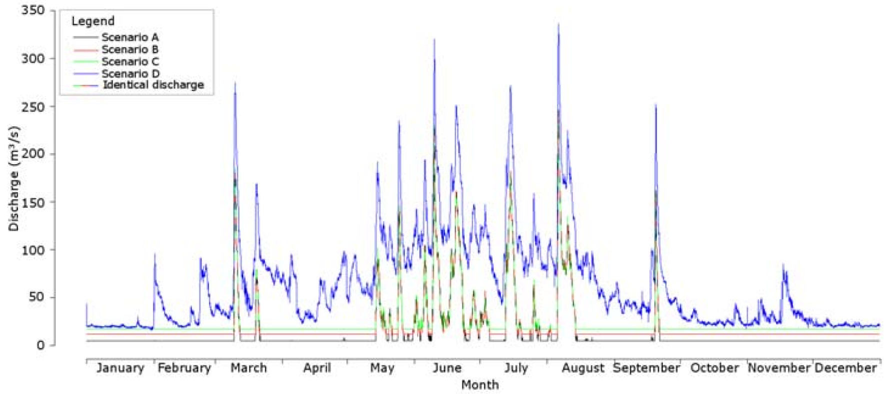

Figure 3. Hydrograph of the four scenarios based on data of the hydrological year 2016.

2.3. Fish Species Studied

The fish species for this study (*Thymallus thymallus* L., *Hucho hucho* L., and *Chondrostoma nasus* L.) were selected due to their status as a target of the restoration, as indicator species of the overall stream ecological quality, and according to historical information on typical Isar fish species [48].

Thymallus thymallus L. (European grayling) belongs to the family of Salmonidae and is the only species of the genus *Thymallus* that is native to Europe. It is a widespread species in submontane reaches of cold, fast-flowing, and well-oxygenated rivers with sand or stone substrate [49]. According to the IUCN Red List, the Grayling is classified as "Least Concern" by the European Union but the species suffers locally from river pollution, dam constructions, and river regulations [50]. A very low density of European grayling has been found at the Isar in Munich and its tributaries [51]. Fewer than five fish per 100-m river section have been fished inside the investigated river section, whereas a healthy population should achieve more than 150 individuals per section [52]. Three habitat types that are related to different life cycle stages have been identified [49–51,53–65] and were labeled TTA (Habitat for Adults), TTS (Habitat for Spawning), and TTJ (Habitat for Juveniles) (Table 1).

Hucho hucho L., commonly named European huchen or Danube salmon, is the world's biggest salmonid and it is threatened with extinction. It is a salmonid endemic to the Danube drainage basin in Central Europe, inhabiting fast-flowing and well-oxygenated streams with gravel bars [66,67]. The species is listed in Annex II of the European Flora Fauna Habitat Directive [68], as an endangered species in Appendix III of the Convention on the Conservation of European Wildlife and Natural Habitats [69], and it is classified as "Endangered" on the Red List. The current main threats to the species are flow regulations from dams and water pollution [66,70,71]. The European huchen occurs at a very low density in the Isar in Munich and its tributaries, with fewer than five fishes per 100 m of river [51,52]. Three habitat types that are related to different life cycle stages have been identified [66,67,70–76] and were labeled HHA (Habitat for Adults), HHR (Habitat for Adults during the pre-reproduction period), and HHJS (Habitat for spawning and Juveniles) in this study (Table 1).

Chondrostoma nasus L., commonly named Common nase, is an endemic cyprinid in the drainage basins of the Southern Baltic, the Southern North Sea and the Black Sea, e.g., the Danube basin, inhabiting moderately to fast-flowing large to medium-sized rivers with a rock or gravel bottom. According to the Red List Category, the common nase is classified as "Least Concern". It is protected by the Convention on the Conservation of European Wildlife and Natural Habitats [69] and it is locally threatened by damming, destruction of spawning sites, and pollution [49]. The common nase historically occurred in the investigated urban section of the Isar, but currently, no *C. nasus* can be found [52]. Six habitats have been identified [49,77–81] and were labeled CNS (Habitat for spawning), CNL (Habitat for larval development), CNJ (Habitat for Juveniles), CNR (Habitat for Adults during the pre-reproduction period), CNAS (Habitat for Adults during the summer), and CNAW (Habitat for Adults during the winter) in this study (Table 1).

Table 1. List of habitats associated with life-cycle stages of *Thymallus thymallus* L., *Hucho hucho* L., and *Chondrostoma nasus* L. described in terms of their physical characteristics.

Fish Species	Habitat Type	Life Cycle Stage	Season	Water Velocity	Water Depth	Substratum
Thymallus thymallus	TTA	Adults	All	Moderate to high (0.7–1.1 m/s)	High (100–140 cm)	Medium to fine-grained substratum
	TTS	Adults spawning	Spring (January–April)	Very low (0.2–0.4 m/s)	Low to very high (10 cm–230 cm)	Fine-grained substratum
	TTJ	Juveniles	All	Moderate to high (0.7–1.1 m/s)	Moderate (50–80 cm)	Fine-grained to medium substratum
Hucho hucho	HHA	Adults	All	Moderate to very high (>0.7 m/s)	High (>100 cm)	Fine-grained to medium substratum
	HHR	Adults (pre-reproduction)	Spring (February–April)	High to very high (>1.0 m/s)	Moderate to high (30–150 cm)	Medium gravel to large stones
	HHSJ	Adults spawning and Juveniles	Spring (February–May) All	High to very high (>1.0 m/s)	Moderate (20–60 cm)	Medium gravel
Chondrostoma nasus	CNS	Spawning	Spring (March–May)	High (1.0–1.5 m/s)	Moderate (20–40 cm)	Medium to fine-grained substratum
	CNL	Larvae	Spring	Low (0.5–0.7 m/s)	Low (5–10 cm)	Fine-grained substratum
	CNJ	Juveniles	All	Low (under 0.6 m/s)	Low (5–20 cm)	Coarse substratum
	CNAW	Adults	Winter	High (1.0–1.5 m/s)	High (1–2 m)	Variable substratum
	CNR	Adults (pre-reproduction)	Spring (February–May)	Low to very low (less than 0.7 m/s)	Moderate (20–40 cm)	Medium gravel to large stones
	CNAS	Adults	Summer	Moderate to high (0.7 to 1.5 m/s)	Moderate (20–50 cm)	Rock to gravel

2.4. Habitat Model

The CASiMiR software (Ecohydraulic Engineering GmbH, Stuttgart, Germany) computes habitat suitability for selected indicator species using a multivariate fuzzy logic approach to link the abiotic attributes with the habitat requirements of fish, e.g., the temporal and spatial variability of water depth, flow velocities, and bed substrate types [43,44]. The calculation uses fuzzy quantities of the descriptive physical properties, as formulated by fish biologists in the form of linguistic categories, i.e., “very high”, “high”, “medium”, “low”, and “very low” (Table 2). The fuzzy logic approach is an excellent modeling technique to overcome the problems of dealing with uncertain and unprecise information, which commonly occur in ecological investigations [82].

Table 2. List of the variables used as input for the habitat suitability model.

Linguistic Modalities	Velocity	Water Depth	Substratum
Very low	0–0.4 m/s (±0.1 m/s)	0–0.1 m (±5 cm)	Organic matter
Low	0.5–0.7 m/s (±0.1 m/s)	0.1–0.2 m (±5 cm)	Sand < 6 mm
Medium	0.75–0.9 m/s (±0.1 m/s)	0.2 (±5 cm) to 0.5 (±10 cm)	Gravel from 6 to 120 mm
High	1 m/s (±0.15 m/s) to 1.5 m/s (±0.25 m/s)	0.5 (±10 cm) to 1.15 m (±25 cm)	Large stones 12–20 cm
Very high	Start at 1.75 m/s (±0.25 m/s)	Start at 1.25 (±25 cm)	Boulders > 20 cm, Rock

The influence of the interactions between the three physical variables on habitat suitability have been elaborated based on the literature and in collaboration with a fish biology expert from the Bavarian State Research Center for Agriculture (Bayerische Landesanstalt für Landwirtschaft) during a personal interview (Table 3) [81].

Table 3. Example of a fuzzy rule set describing the habitat requirements of the European grayling for adult fishes in the Isar River (Germany).

Velocity	Depth	Substrate	HSI	Example
M	H	VH	VL	Rule 1: IF velocity ‘Medium’ AND depth ‘High’ AND substratum ‘Very high’ THEN HSI ‘Very low’
M	H	H	H	Rule 2: IF velocity ‘Medium’ AND depth ‘High’ AND substratum ‘High’ THEN HSI ‘High’
M	H	M	VH	Rule 3: IF velocity ‘Medium’ AND depth ‘High’ AND substratum ‘Medium’ THEN HSI ‘Very high’
M	M	H	M	Rule 4: IF velocity ‘Medium’ AND depth ‘Medium’ AND substratum ‘High’ THEN HSI ‘Medium’
M	M	M	H	Rule 5: IF velocity ‘Medium’ AND depth ‘Medium’ AND substratum ‘Medium’ THEN HSI ‘High’

2.5. Data Analysis

The model was run for the three fish species to investigate the influence of increased minimum and annual mean discharges on the physical habitat suitability. First, we investigated the suitability of the physical habitats when considering a discharge spectrum from the minimal discharge applied (5 m^3/s) to the natural mean annual discharge (68.5 m^3/s). Then, we investigated which scenario produced the best habitat quality. For comparison we used: The Habitat Suitability Index (HSI), the Weighted Usable Area (WUA) of each HSI value, and the Hydraulic Habitat Suitability index (HHS). The HSI is computed by CASiMiR for each element of the hydromorphological mesh. The HSI is the most common index describing the biological response to abiotic attributes and represents the suitability of a habitat for a target species [43]. The HSI has scalar values between 0 and 1, with the latter representing the most suitable habitat. The mean, median, and standard deviation of the HSI values for the whole river stretch were compared using both Ansari-Bradley test and Wilcoxon-Mann-Whitney-Test, and were plotted for each scenario and habitat types per species. The WUA corresponds to the wetted area weighted by its suitability for a target fish species and habitat type, and is related to a spectrum of different flow rates for the whole stretch [44]. The HHS removes the effect of changing the surface of the wetted area between discharge on the WUA values [83]. While the HHS provides information about the overall quality of the river for one habitat type, the WUA for each HSI provides information about the quantity of suitable habitats, for example, the surface of the highly suitable habitat (SI > 0.6) for one habitat type. For all of the comparisons, we used both the Kruskal–Wallis rank sum test, and a pairwise comparison using t-tests with pooled standard deviation.

3. Results

The quality and quantity of the suitable habitat surface varied with discharge. These relationships varied according to habitat type. The proportion of suitable habitats for Adults (HHA, CNAW, CNAS, and TTA) generally increased with discharge (Figure 4a), but for *T. thymallus* (TTA) they decreased at discharges above 17 m^3/s. The quality of the habitats that were used during the pre-reproduction period decreased with discharge for *C. nasus* (CNR), but increased with discharge for *H. hucho* (HHR) (Figure 4b). Spawning habitats (HHJS, TTS, and CNS) benefited from a slight increase in discharge, but habitat suitability decreased for *T. thymallus* (TTS) and remained stable for *H. hucho* (HHJS) at medium to high discharges (Figure 4c). Increasing discharge led to decreasing habitat suitability for Juveniles (CNJ and TTJ), but Juvenile *H. hucho* (HHJS) benefited from a discharge increase below 16.5 m^3/s (Figure 4d). Since the trends were different between the fishes, further analyses are presented separately for each species. The following figures represent the results for the entire study area, with the exception of the last, which exemplarily shows maps of the distribution of habitat suitability for the Flaucher area.

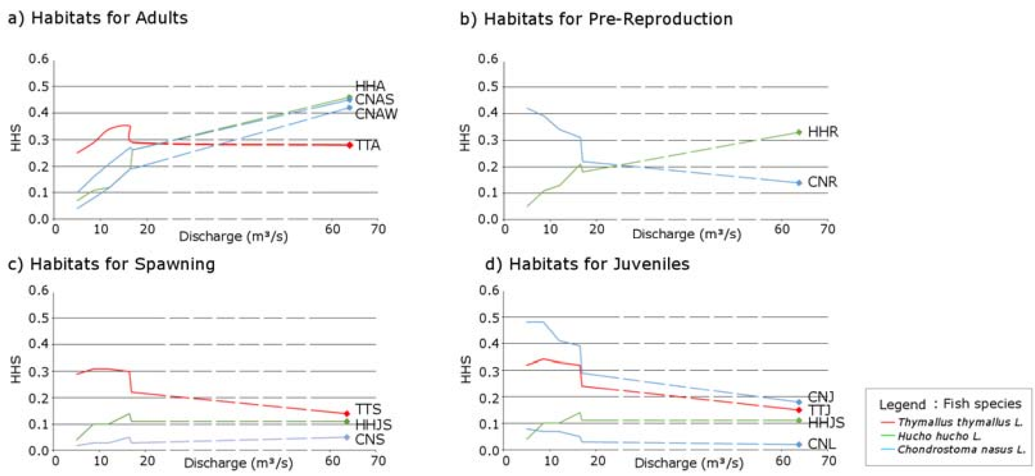

Figure 4. Hydraulic habitat suitability (HHS) for the twelve habitat types considering discharge variations from 5 to 68.5 m^3/s: (**a**) Habitat for Adults *C. nasus* in winter (CNAW), *C. nasus* in summer (CNAS), *T. thymallus* (TTA), and *H. hucho* (HHA); (**b**) Habitat types for Adults pre-reproduction *H. hucho* (HHR) and *C. nasus* (CNR); (**c**) Habitat type for Adults spawning *T. thymallus* (TTS), *H. hucho* (HHJS), and *C. nasus* (CNS); (**d**) Habitat types for Juveniles *C. nasus* (CNJ), *T. thymallus* (TTJ), and *H. hucho* (HHJS), and for larval development of *C. nasus* (CNL).

3.1. *Thymallus thymallus L.*

The highest HHS for *T. thymallus* was found at 16.5 m^3/s and the highest proportion of highly suitable habitats (HIS > 6) for scenario B was: TTA = 26.1% (Figure 5a), TTJ = 25.5% (Figure 5b), and TTS = 22.8% (Figure 5c). The difference between scenarios B and C was not statistically significant. The HSI values differed between scenarios A, B (or C) and D for all of the studied habitats ($p < 0.01$, Kruskal–Wallis and pairwise test). Scenario A had significantly lower HSI values than scenarios B and C. An increase from 5 to 12 m^3/s in minimal water flow (A to B), increased the mean HSI values for all studied habitats, i.e., TTA (Figure 6a), TTJ (Figure 6b), and TTS, (Figure 6c). A major increase in water quantity, as simulated by scenario D, decreased the HSI values of all the investigated habitat types ($p < 0.01$, Kruskal–Wallis and pairwise test). The best scenario for Adults was C, but for recruitment, it was B (Table 4). While highly suitable habitats for Adults were near to the zoo (Figure 2), highly suitable habitats for recruitment were located at the Flaucher (Figure 7a–c).

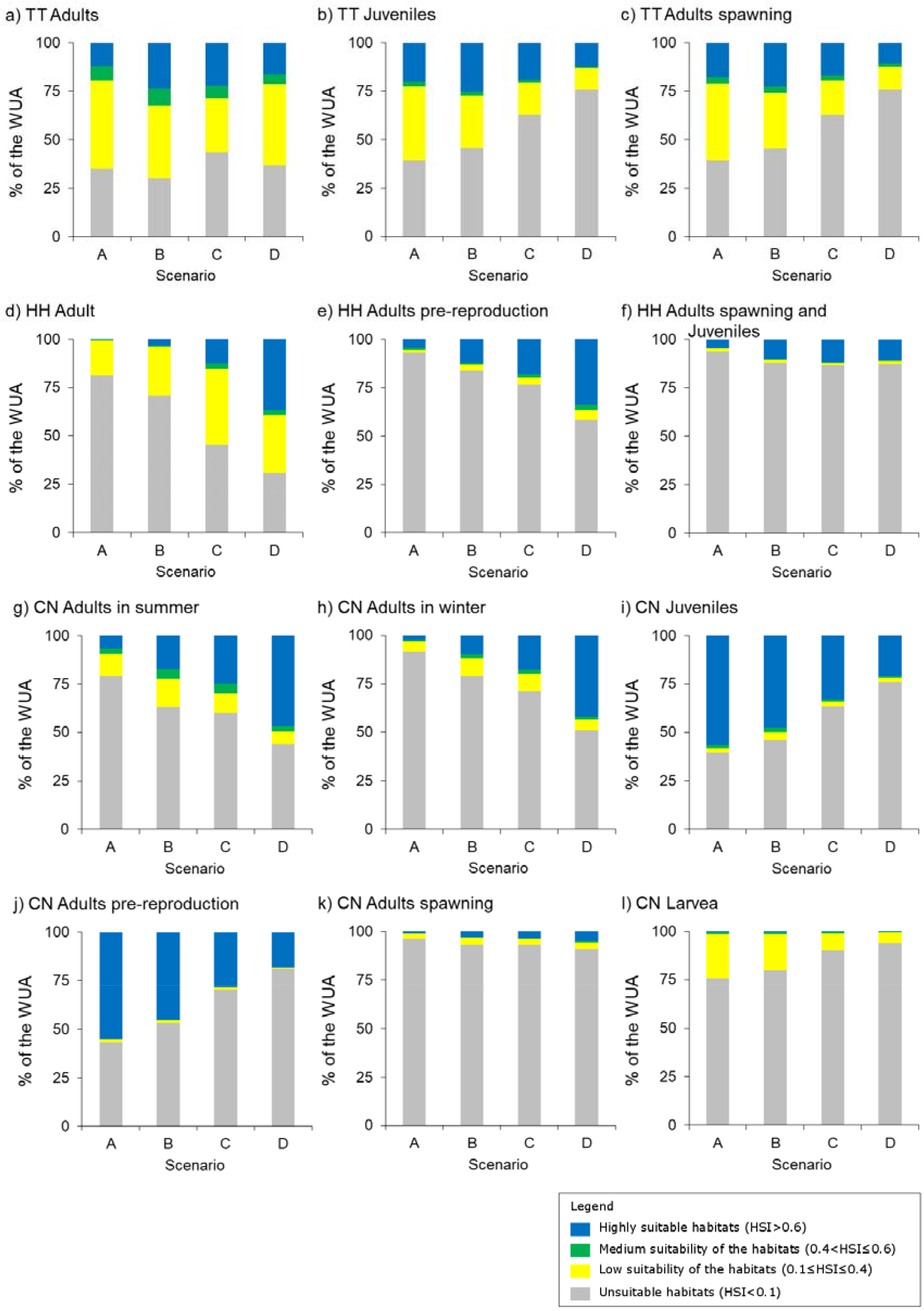

Figure 5. Percent of the Weighted Usable Area (WUA) that is characterized from highly suitable to unsuitable habitats for each scenario considering each habitat type of *Thymallus thymallus* L. (**a**–**c**), *Hucho hucho* L. (**d**–**f**), and *Chondostroma nasus* L. (**g**–**l**).

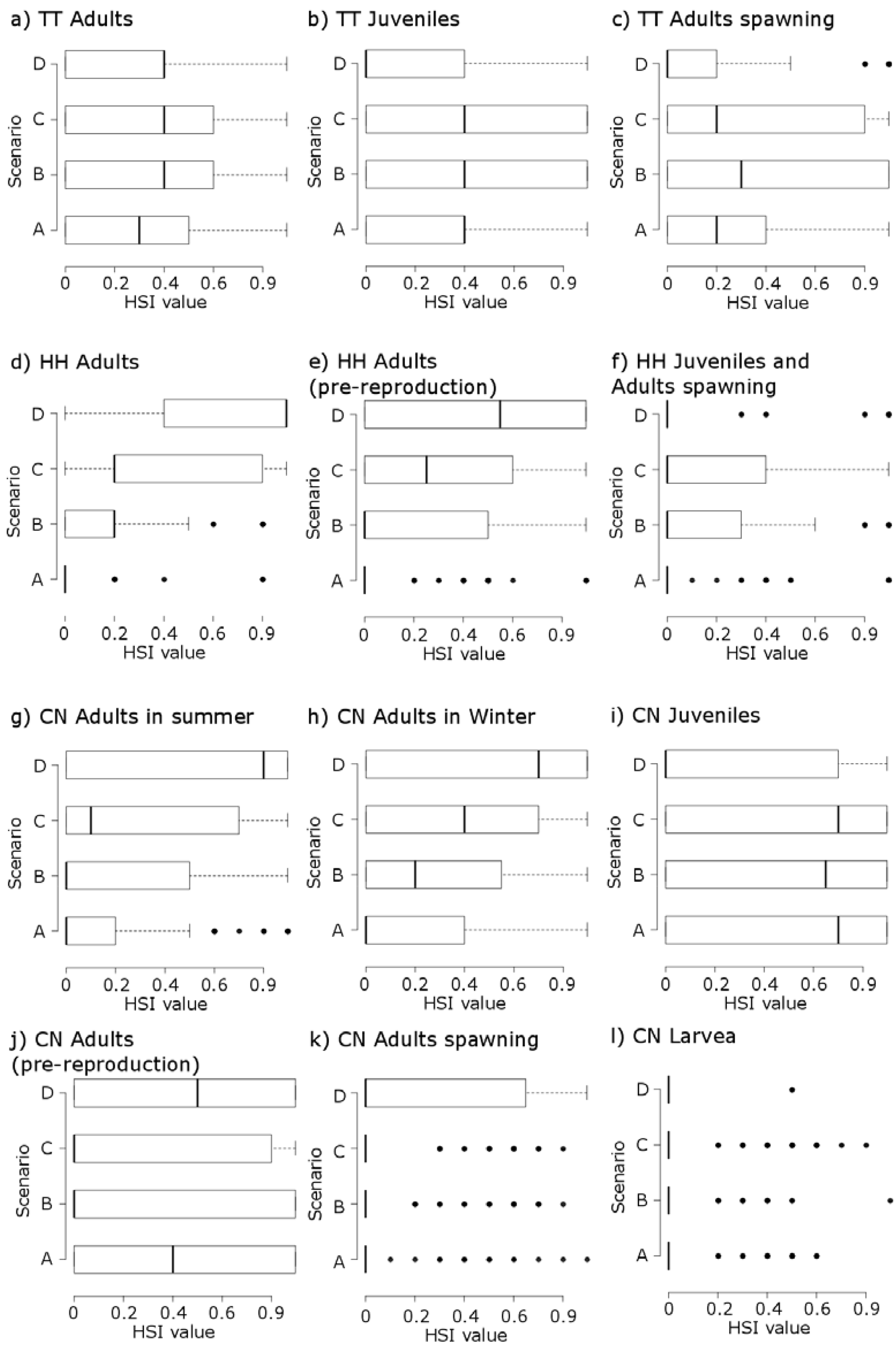

Figure 6. Box plots of the Habitat Suitability Index (HSI) value for the different scenarios considering each habitat type of *Thymallus thymallus* L. (**a**–**c**), *Hucho hucho* L. (**d**–**f**), and *Chondostroma nasus* L. (**g**–**l**). For abbreviations of habitat types see Table 1 (mean is the black line, black dots are outliers).

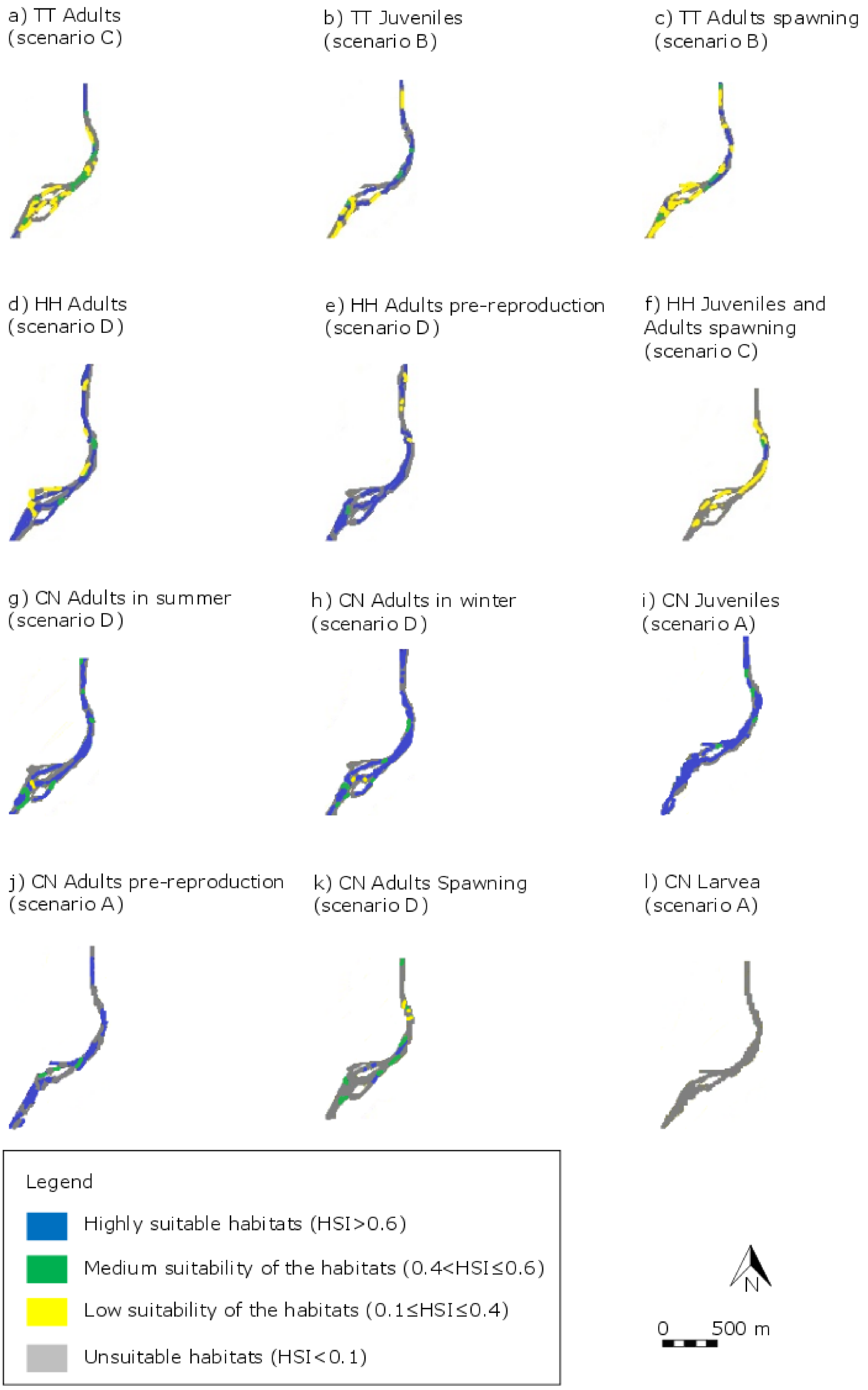

Figure 7. Extract of Habitat suitability maps of the Flaucher site. Model outputs displayed the spatial distribution of the usable area for the best scenario found while considering each habitat type of *Thymallus thymallus* L. (**a**–**c**), *Hucho hucho* L. (**d**–**f**), and *Chondostroma nasus* L. (**g**–**l**) at annual mean discharge.

Table 4. Weighted Usable Area (WUA), Hydraulic Habitat Suitability index (HHS), and Mean Habitat Suitability Index (mean HSI) value for each habitat and scenario. The best scenario for each habitat is highlighted.

Fish species	Life cycle stage (Habitat types)	Indicators	Scenario A	Scenario B	Scenario C	Scenario D
Thymallus thymallus	Adults (TTA)	WUA (1,000 m^2)	183	274	276	233
		HHS	0.25	0.34	0.29	0.28
		Mean HSI	Low	Low	Medium	Low
	Spawning (TTS)	WUA (1,000 m^2)	212	255	210	121
		HHS	0.29	0.31	0.22	0.14
		Mean HSI	Low	Low	Medium	Very low
	Juveniles (TTJ)	WUA (1,000 m^2)	229	270	222	128
		HHS	0.32	0.33	0.24	0.15
		Mean HSI	Low	Low	Low	Very low
Hucho hucho	Adults (HHA)	WUA (1,000 m^2)	48	94	243	384
		HHS	0.07	0.12	0.26	0.46
		Mean HSI	Very low	Low	Low	High
	Adults pre-reproduction (HHR)	WUA (1,000 m^2)	35	102	171	277
		HHS	0.05	0.13	0.18	0.33
		Mean HSI	Very low	Very low	Very low	Medium
	Spawning and Juveniles (HHJS)	WUA (1,000 m^2)	31	79	104	88
		HHS	0.04	0.10	0.11	0.11
		Mean HSI	Very low	Very low	Low	Very low
Chondrostoma nasus	Adults during the summer (CNAS)	WUA (1,000 m^2)	72	167	241	377
		HHS	0.10	0.21	0.26	0.45
		Mean HSI	Low	Low	Low	Medium
	Adults during the winter (CNAW)	WUA (1,000 m^2)	30	100	182	355
		HHS	0.04	0.12	0.19	0.42
		Mean HSI	Low	Low	Medium	Medium
	Adults pre-reproduction (CNR)	WUA (1,000 m^2)	300	277	207	118
		HHS	0.42	0.34	0.22	0.14
		Mean HSI	Medium	Low	Low	Medium
	Juvenils (CNJ)	WUA (1,000 m^2)	341	330	268	153
		HHS	0.48	0.41	0.29	0.18
		Mean HSI	Medium	Medium	Medium	Low
	Spawning (CNS)	WUA (1,000 m^2)	11	27	32	39
		HHS	0.02	0.03	0.03	0.05
		Mean HSI	Very low	Very low	Very low	Low
	Larvae (CNL)	WUA (1,000 m^2)	60	57	31	18
		HHS	0.08	0.07	0.03	0.02
		Mean HSI	Very low	Very low	Very low	Very low

3.2. *Hucho hucho* L.

The HHS of all the habitats of *H. hucho* increased with discharge: HHA (Figure 4a), HHR (Figure 4b), and HHJS (Figure 4c). The proportion of highly suitable habitats for Adults (HHA and HHR) increased with discharge reaching 36.7% (Figure 5d) and 34% (Figure 5e) at a discharge of 63.8 m^3/s. Interestingly, the proportion of highly suitable areas for spawning (HHJS) (Figure 5f) also increased with discharge, but peaked at 16.5 m^3/s. The HHS remained stable between scenarios C and D, but the proportion of highly suitable areas was higher for scenario B than C and higher for scenario C than D: 15.2%, 11.7%, and 10.9% of the area, respectively (Figure 5f). The mean HSI differed among the scenarios for all of the studied habitats ($p < 0.01$, Kruskal–Wallis and pairwise test). From scenario A to D, the mean HSI of the habitats for Adults (HHA) increased from very low to high (Figure 6d) and the mean HSI for habitats for the pre-reproduction period increased from very low to medium (Figure 6e). It is noteworthy that the trend was different for the habitats for spawning and juvenile growth (HHJS). While from scenario A to C the mean HSI values increased from very low to low, they decreased from scenario C to D (Figure 6f). The best scenario for Adults was D, but for recruitment, it was C (Table 4). While highly suitable habitats for Adults were distributed all around studied area, highly suitable habitats for recruitment were located at the South of the zoo and not at the Flaucher (Figure 7d–f).

3.3. *Chondrostoma nasus* L.

The HHS for Adults *C. nasus* increased with discharge (Figure 4a), remained very low for spawning (Figure 4b), and decreased with the discharge for recruitment (Figure 4c,d). The largest proportions of highly suitable habitats (HIS > 6) for Adults during the summer (CNAS) and the winter (CNAW) for scenario D were: 46.7% (Figure 5g) and 42.8% (Figure 5h) of the wetted area, respectively. Contrarily, the largest proportion of highly suitable habitats for Juveniles (CNJ) and for Adults during the pre-reproduction period (type CNR) for scenario A were: 56.5% (Figure 5i) and 54.97% (Figure 5j) of the area, respectively. Highly suitable habitats for spawning and larval development (CNS and CNL) remained rare: 5.22% (Figure 5k) and 5% (Figure 5l) of the wetted area, respectively. While the mean HSI of habitats for Adults during the summer (Figure 6g) and the winter (Figure 6h) increased with discharge, it decreased with discharge for Juveniles (Figure 6i). The mean HSI value for Adults in the pre-reproduction period decreased with discharge, increased for scenario D, and achieved the medium HSI value again (Figure 6j). Interestingly, mean HSI of habitats for spawning remained very low, but for scenario D, the variation in HSI value was important and locally reached a very high value (Figure 6k). However, for larval development habitats remained unsuitable. The best scenario for Adult survival and reproduction was D, but for recruitment, it was A (Table 4). While highly suitable habitats for Adults and Juveniles were located at the two third south of the river section, included the Flaucher (Figure 7g–l), highly suitable habitats for spawning activities and larval development were almost inexistent.

4. Discussion

4.1. Identification of the Best Scenario

We investigated the effects of an increase in minimal water flow on the quality of the physical habitats for three target fish species in the Isar in Munich (Germany). The presented modeling approach was set up to analyze whether there was a single discharge scenario suitable for all of the fish species, but there was no "one size fits all" solution. None of the four scenarios provided permanently suitable habitat conditions for the three species, rather, different life stages of the fish species showed preferences for different scenarios. However, general trends could be identified. While the slight increase in minimal water flow increased the quality and quantity of almost all of the investigated habitats, a medium or large increase in discharge reduced some of them.

Since all of the investigated species historically occurred in the Isar in Munich, we expected scenario D (no diversion, MQ of 63.8 m^3/s) to be ecologically the best. It was identified as the best for adult *Hucho hucho*, but it provided too high flow for *Thymallus thymallus*, which benefited more from discharges that were simulated by scenarios B and C (MQ between 12 and 17 m^3/s). Variations in water depth mostly differentiated *Hucho hucho* habitats [66,71], and the best scenario for juvenile habitats for *Hucho hucho* was C. Habitats of *Chondostroma nasus* have very different combinations of flow velocities and water depths [79]. While Scenario D was the best for adults, the habitats for juveniles were better and more numerous in scenario A.

Given the current morphological setting of the remaining river, it was not possible to improve all habitats of all three target species by only changing the discharge. Consequently, change of discharge schemes from the hydropower dam could be run to favor one or two species per year (and the schemes could be varied from year to year in order to favor different species over time).

We therefore suggest that restoration procedures should combine the morphological and hydrologic measures. During the two last centuries, the wetted area in the river corridor has been reduced by more than 75% [84–86]. Furthermore, the slope of the river bed has changed dramatically due to an accelerated incision [85]. Morphological restoration, namely the removal of the channelization, meandering and slope reduction, increases the diversity of physical habitats [87,88], and the investigated river reach was hydro-morphologically restored. However, morphological restoration in urban areas, namely of heavily modified water bodies [16], remains difficult because of physical limitations [89]. These findings suggest that despite successfully implemented restoration measures, the slope of the Isar remains too steep to support suitable habitats for all three fish species. Additional measures, specifically the re-establishment of fringing floodplain area, should allow for further braiding and meandering of the river to support a higher diversity of aquatic habitats.

We also like to suggest that nature-like and seasonal discharge modulation should improve the quality and quantity of the habitats when they are most needed. Dynamic minimum water control has already been defined as crucial to assure or improve habitat quality, despite the regulated river system [90]. Further investigations should examine the aspect of timing and the match and mismatch between the actual hydromorphological situation and the specific habitat requirements of the life stage of the studied species. This can determine the "windows of opportunity" or "windows of susceptibility" for individual species, and result in a "serial biodiversity" of assemblages of species that have similar ecological requirements [91–93].

The European Commission [94] has developed a common implementation strategy (CIS) to implement the concept of ecological flows, i.e., the "amount of water required for the aquatic ecosystem to continue to thrive and provide the services we rely upon", i.e., an improvement of the flow regime to warrant the targets of the European Water Framework Directive. This approach is based upon the natural flow paradigm [95], the Flood Pulse Concept [92],and the environmental flow concept [23,96].

In the case of alpine and pre-alpine rivers, such as the Isar, the flow regime is specifically relevant for the distribution of sediments, the generation of habitats (and refuge) during flood events, and protection from drought and overheating of the water during low-flow periods. Practical discussions among river managers, however, mostly focus on the latter point (minimum flows during summer), whereas our study shows the complexity of the problem and the need to tackle the flow regime, the available habitat space, and the river gradient at the same time. The manipulation of the flow regime via the discharge management of the hydropower dams upstream towards a more natural flow regime can only be seen as a first and (as stand-alone activity) transitory measure to be taken in order to reduce the environmental impact until measures to increase and improve available habitats will be implemented.

In the case of the Isar in Munich for, since no additional water source is available, there are conflicts between ecological requirements of the investigated fish species and the economic needs in the case of the Isar at Munich. The studied fish species need the full discharges to reorganize sediment structures and to create habitats for spawning and juvenile development during winter and spring, while human needs for electrical energy prevail the entire year. Economic feasibility studies to assess the costs of a more nature-like discharge from the hydropower dams are needed. The decision scheme, however, should also include the ecosystem services that are provided by a healthy river. The modeling procedure presented here, combined with an economic feasibility study may help to define the best restoration scenario and to design a dynamic minimum water strategy. The model also provides a cost-efficient method to support the design of future mitigation and restoration projects.

4.2. Habitat Distribution Changes

The modeling procedure showed that spatial distribution of the habitats differs between the species. Accordingly, the method provides important insights to define management preferences in terms of managing for a single habitat in chosen river sections. Spawning habitats for *Chondostroma nasus* L. were rare or absent in the restored stretch of the Isar. This finding is consistent with historical data indicating that *Chondostroma nasus* L. preferred to spawn in Isar tributaries rather than in the main river channel [79]. Today, the connectivity between the main channel of the Isar and its tributaries is hampered by barriers and degradation [97]. Restoration of the Isar may intend to create instream spawning sites but adult fish are bound to their historical spawning area [77–79,98] and reproduction in new and man-made environments showed only limited success [99]. Therefore, the biological potential of such reconstructed reproduction areas remains unclear [100]. Thus, in the case of the nase, an appropriate restoration goal could be the reestablishment of suitable habitats for adults and juveniles rather than for reproduction activities, which should be established by restoration measures of the tributaries and an improved connectivity between mainstream and tributaries.

Interestingly, in the scenarios with water diversion (scenarios A, B, and C), hydropeaking occurred frequently. It is a major ecological issue and it has been identified as one of the most significant pressures in alpine streams causing quick alterations in habitat quantity and quality [13]. Fish species are the group of aquatic organisms that are best able to adapt to long-term changes in hydropeaking by changing their habitat preferences, provided that heterogeneous river morphology is given [11,13]. Noack and Schneider [101] examined habitat suitability during hydropeaking events and found a significant shift in suitable habitats of juvenile European graylings from the main channel towards gravel bars at river banks. The high flow velocities and water depth in the main channel were above those preferential to the juvenile graylings, while the gravel bar provided a favorable combination of water depths and flow velocities. Further research should also investigate the shifting location of habitats as well as the change in quality and quantity of habitats during minimum flow conditions.

Finally, the impact of climate changes may cause modifications of fish habitat distribution. Another study already proved general distribution shifts of fish species that were caused by temperature increases [102]. Furthermore, climate change causes impacts on the hydrology in the Alps [103–106]. Two of the climatic scenarios (RCP4.5 and RCP8.5) that were adopted by the Intergovernmental Panel on Climate Change (www.ipcc.ch) for its fifth Assessment Report in 2014 [107] predicted a decrease in summer precipitation by 25% before 2100, which corresponds to a decrease in discharge of more than 10% [105,106]. For the case of the Isar and other alpine rivers, a further reduction of the already scarce floodplain habitats, and a temporary loss of fish refuges in deep zones can be anticipated. Consequently, the modeling procedure, as presented here, may help to understand climate change effects and help to design adaptation measures.

4.3. Method Discussion

For our model, substratum characteristics have been assumed to be constant for the different discharge scenarios because fine-grained sediment (<10 mm) in the Isar River in Munich began to drift at 80 m^3/s and the modeling scenarios that were used here were all below this limit. Consequently, only flow velocities and water depth varied between the simulations. Accordingly, the potential effects of sediment dynamics on substratum quality were not considered as a triggering variable by the model. However, this variable may be of interest for the spawning habitats. The quality and quantity of those remained very low for all of the flow velocities and depth variations that were investigated, and no significant variations were found between the scenarios, suggesting that substratum may be the triggering variable for these habitats. The sediment is very important for spawning, since all of the investigated species lay their eggs into or onto the freshly deposited substratum, or even dig redds for oviposition (as with *Hucho hucho*) [50,56,66,76,78,79]. The absence of fine sediments, excessive biofilms, and other organic matter is crucial to the survival of the eggs and early juvenile stages. Future models should consider the sediment dynamics leading to variation in substratum quality of this habitat type [108,109].

Our study may help to define the best restoration scenario in the case of the Isar in Munich for the investigated fish species. It presents a method and a tool to design the best restoration practice. The physical habitat modeling allowed for us to investigate what may happen to habitat quantities and qualities when changing the three driving hydromorphological variables (water depth, flow velocity, substratum). The habitat suitability model in this study remains at a theoretical level since the predictions have not been verified by field measurements. However, field verifications, e.g., electrofishing, have shown limits in validating model predictions [57]. In fact, false positive or negative predictions may not imply a model error. Fish occurrence might also depend on other variables than those that are included in the habitat suitability model. Furthermore, suitable habitats may occur but may not be used by fish due to additional environmental stressors. Finally, capacities of such physical habitat modeling remain yet limited. Much current research is focused on solving model limitations, for example, integrating different requirements for different seasons, or including sediment transport and morphological dynamic changes [110]. However, further research on habitat modeling still needs to be done to increase model robustness.

5. Conclusions

This study has assessed the potential effects of increased minimum discharge on the habitat quality of three fish species, i.e., *Thymallus thymallus* L., *Hucho hucho* L., and *Chondostroma nasus* L. in the Isar in Munich using the modeling procedure CASiMiR. Although a positive effect of a moderate increase in discharge favored all fish species, the four scenarios had different effects on the species and their life stages. Considering that a large part of floodplain water bodies has been lost, and the slope of the channel has been changed considerably in the past, the restoration of the flow regime can only be seen as a part of the solution. The study also showed the potential and the caveats of the modeling approach. Several parameters, such as sediment characteristics, the timing of the discharge variation, extreme events, and historical trends should be considered in greater detail to better understand the quality, quantity, and distribution of suitable habitats. Other site-specific aspects, including the limited accessibility to spawning sites in tributaries, limitations of the river restoration potential due to urbanization and hydroelectric power plants, or the unsuitability of habitats due to recreational pressure [81] are beyond the scope of physical habitat modeling but need to be considered for successful restoration. If they were included, the use of the modeling procedure could help to design restoration trajectories that combine technical and political solutions in order to maximize ecosystem integrity with an adequate and non-destructive use of the natural resources [111–113].

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Scientific report

Abstract:

The scientific report was published for and by the city government of Munich the 3rd November 2014 to describe the protocol used to reintroduce the 10th May 2014 Myricaria germanica L. into the restored Isar section crossing the city of Munich. The report also documented the preliminary results produced after the first summer.

During the summer 2009, 200 seeds of Myricaria germanica L. were harvested at the Pupplinger Aue and were planted on a seedbed sourcing from the Isar river bank (sand-gravel). The seeding procedure was identic for all seeds and was performed by Dr. Habersbrunner (BUND). The seedlings should be reintroduced at the Middle Isar, but the project did not get enough funding to be implemented. The seedlings were left without any care and only 27 plants survived. They were donated to the Technical University of Munich for this doctoral study. The seedlings were reintroduced at the Isar in Munich to evaluate the success of the restoration project and to estimate the recreation pressure on the recovery of this sensitive species.

Five sites were identified as potentially suitable to accomplish the reintroduction procedure. The survey of the suitable habitats was performed in March 2014 in collaboration with Prof. Gregory Egger (WWF Auen-Institut Rastatt, KIT). Two sites have been selected to receive the seedlings in two groups, 14 and 13 plants respectively. Reintroduction protocol followed Egger et al. (2010). To mimic natural settlement, the seedlings were transplanted along the annual high water marks. The temperature, the lightness, and the soil moisture were recorded during the summer but no significant difference between both sites was found. Survivor rate at the site in the South, namely the site with medium recreational user density, was after 143 days of 65%, while the survivor rate at the site in the North, namely with high recreational user density was at the same day of 25%. In both sites, death rate caused by flood event reach 20 to 25%. The other losses were caused by recreational users. Since the plants did not flower yet, and consequently no secondary establishment could be recorded, it is too early to affirm the success or the failure of the reintroduction.

French Abstract/Résumé en langue française :

French Abstract/Résumé en langue française :

Le rapport scientifique a été publié le 3 novembre 2014 par et pour la Ville de Munich. Il décrit le protocole de réintroduction de Myricaria germanica L réalisé le 10 mai 2014 et décrit les premiers résultats après la première année de développement végétatif.

Durant l'été 2009, 200 graines de Myricaria germanica L. provenant de la Pupplinger Aue ont été semées dans du substrat provenant de l'Isar (sable-gravier grossier). Les semis ont été réalisés dans des conditions identiques par Dr. Habersbrunner (BUND) afin d'approvisionner un projet de réintroduction du Tamarin d'Allemagne à l'Isar en aval de Munich. Par manque de financement, le projet n'a jamais vu le jour et les plantes ont été abandonnées. Les 27 plantes survivantes ont été offertes à l'Université Technique de Munich pour cette étude doctorale. Les plantes ont été réintroduites à l'Isar à Munich afin d'évaluer le succès de la restauration et d'estimer l'impact du loisir de proximité sur le potentiel ré-établissement de cette espèce sensible.

Cinq sites sur le tronçon restauré de l'Isar à Munich ont été identifiés comme propices à la réintroduction de M. germanica par des observations de terrain réalisées en collaboration avec Prof. Gregory Egger (WWF Auen-Institut Rastatt, KIT). Deux de ces sites étaient assez grands pour accueillir la totalité des exemplaires partagés en deux groupes de 14 et 13 plantes. Afin d'imiter les peuplements naturels, les plantes ont été transplantées sur la ligne des hautes eaux annuelles. La température, la luminosité et l'humidité du sol ont été mesurées sur les deux sites tout l'été et aucune différence significative de ces conditions abiotiques n'a pu être établie. Le site au sud avait une densité moyenne des usages pour le loisir de proximité et les plantes réintroduites sur ce site eurent un taux de survie de 65%, alors que le taux de survie au site nord ayant une forte densité des usages récréatif n'était que de 25%. Sur les deux sites, de 20 à 25% des pertes enregistrées ont été causées par les crues. Le reste des pertes a été causé par les usages récréatifs. Les plantes n'ayant pas encore fleuri et n'ayant donc pas produit de

peuplement secondaire, le succès ou l'échec de la procédure de réintroduction ne peut être attesté.

Urban River Restoration 273

The first author, Aude Zingraff-Hamed, conducted the study, namely: Identify the knowledge gaps and research questions; Develop the conceptual idea and analytical framework; Design questionnaires; Conduct field survey; and Perform analyses and calculations. All these research steps were discussed with the research supervisors: Prof. Stephan Pauleit, Prof. K. Matthias Wantzen, and Dr. Sabine Greulich. The contribution was written by Aude Zingraff-Hamed in collaboration with all the co-authors. The identification of the reintroduction sites was realized in cooperation with Prof. Gregory Egger (WWF-Auen Institut KIT).

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03.11.2014

Zwischenbericht

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Zusammenfassung

Am 10. Mai 2014 wurde ein Wiederansiedlungsversuch der Deutschen Tamariske an der renaturierten Isar im Stadtgebiet München mit positiven Ergebnissen durchgeführt. Ein längerfristiger Erfolg kann jedoch noch nicht bestätigt werden. Die vorläufigen Ergebnisse deuten darauf hin, dass die positive ökologische Wirkung der Renaturierung der Isar vor allem durch die Dichte der Naherholung begrenzt wird. Im Rahmen des Forschungsprojekts werden weitere Überwachungen ohne Pflegemaßnahmen durchgeführt. Wesentlich wäre jedenfalls, dass auf den Flächen der Wiederansiedlung keine Pflegemaßnahmen oder sonstige anthropogene Eingriffe in den Standort erfolgen. Falls es aus Gründen des Hochwasserschutzes dennoch zwingend erforderlich ist im Nahbereich der Tamariskenstandorte Maßnahmen durchzuführen, bitten wir um eine Kontaktaufnahme mit dem Forscherteam.

Kontext des Experimentes

Deutsche Tamariske - Lebensraum, Verbreitung und Gefährdung

Myricaria germanica (L) desv. auch als Deutsche Tamariske bekannt, ist eine empfindliche alpine bis voralpine Pflanzenart. Sie ist eine Charakterart des FFH-Lebensraumtyps 3230 „Alpine Flüsse mit Ufergehölzen von Myricaria germanica". Ihr Vorkommen in Europa beschränkt sich auf den Alpenraum in Frankreich, Italien, Deutschland, Slowenien und Österreich (Kudrnovsky, 2005, 2011, 2013). Historisch war M. germanica südliche der Donau in Deutschland an der Iller, Lech, Isar, Inn und Salzach weit verbreitet (Bill, Spahn, Reich, & Plachter, 1997). Auch im Stadtgebiet München waren in den 1950er Jahren im Bereich des deutschen Museums noch Deutsche Tamarisken zu finden (Rädlinger, 2012). Aktuell ist die Art in Bayern vom Aussterben bedroht und steht auf der Roten Liste für Bayern und Deutschland. Ihr Habitat ging durch hydromorphologische Änderungen stark zurück und ist in Deutschland nur mehr als Reliktbestand zu finden (Bill et al., 1997; Weis, 2007). An der Isar haben der Bau des Sylversteinspeichers 1959 und massive wasserbauliche Maßnahmen zum Hochwasserschutz, die seit Anfang des 19. Jahrhunderts durchgeführt wurden (Staffler, 1999), zu einem drastischen Rückgang der Art geführt. Die bedeutendsten Restbestände der Deutschen Tamariske (Abb. 1) befinden sich aktuell noch an der Oberen Isar (Bill, 2001; Kudrnovsky, 2005; Weis, 2007).

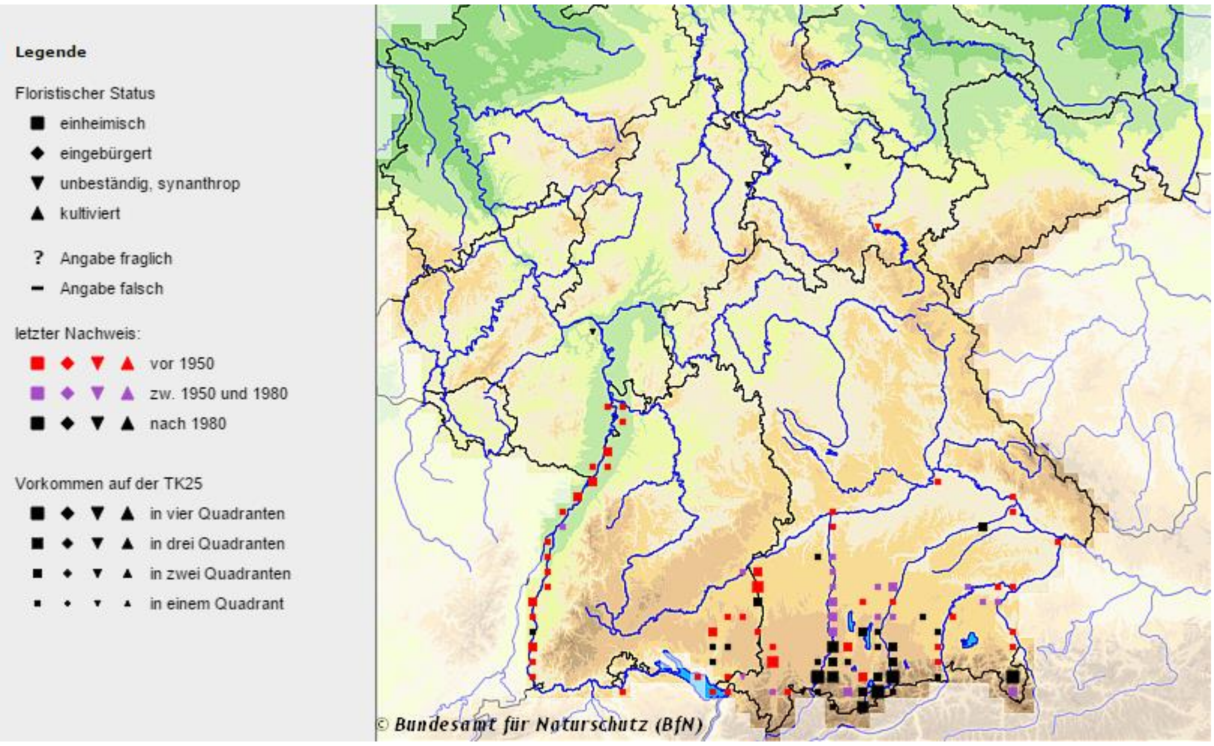

Abb. 1: Verbreitung der Myricaria germanica (L) desv in Süd-Deutschland (http://www.floraweb.de/webkarten/ von 30.10.2014)

Fragestellung und Ziele

Das Projekt „Neues Leben für die Isar" (2001-2011), das auf acht Kilometer Fluss im südlichen Stadtgebiet München umgesetzt wurde, zielte auf eine Verbesserung des Hochwasserschutzes, der Lebensqualität für Menschen durch mehr Naherholungspotential und des ökologischen Zustands des Flusses. Durch bedeutende Maßnahmen, wie die Verbreitung des Flussbettes, die Entfernung der verbauten Ufer, die Erhöhung der Restwassermenge und die Förderung natürlichen Sedimenttransports wurden Umlagerungsstrecken wiederhergestellt. Da die Deutsche Tamariske ein wichtiger Bioindikator für naturnahe sand- und schotterreiche Flussalluvionen alpiner und voralpiner Flüsse ist (Kudrnovsky & Stöhr, 2013), die durch Hochwasser entscheidend geprägt werden (Kudrnovsky, 2005), könnte deren vorkommen und natürliche Vermehrung den Erfolg der Renaturierung greifbar machen. Haben die Renaturierungsmaßnahmen es ermöglicht, den natürlichen Lebensraum der *Myricaria germanica (L) desv* wieder zur Verfügung zu stellen?

Durch einer Modellierung der Habitate, die sich auf die aktuellen physikalischen Parameter der renaturierten Isar stützt, kann die Wahrscheinlichkeit einer kurzen, mittleren- oder langfristigen Etablierung der Deutschen Tamariske überprüft werden. Das Vorkommen empfindlicher Arten wird vom komplexen Zusammenspiel biologischer und physikalischer Aspekte bestimmt. Zum Beispiel und im Gegensatz zu den verschiedenen Salix-Arten ist das natürliche Verbreitungspotential der *M. germanica* nicht groß genug, um neue bzw. weit entfernte Lebensräume schnell wieder zu besiedeln (Bill, 2000). *M. germanica* vermehrt sich innerhalb natürlicher Vorkommensbereiche an der Isar alle 5 bis 10 Jahre (Bill, 2000; Bill et al., 1997) auf frischen Ablagerungen von feinem Sediment in unmittelbarem Nahbereich einer Mutterpflanze (Lener, Egger, & Karrer, 2013). Da die Quell-Population eine möglichen spontanen Besiedlung sehr weit im Süden ist und weil die Renaturierung erst vor wenigen Jahren durchgeführt wurde, ist es sehr unwahrscheinlich, das *M. germanica* sich in den nächsten Jahren an der Isar in München wieder ansiedelt. Deswegen wurde im Frühjahr/Sommer 2014 ein Wiederansiedlungsversuch durchgeführt und die Art an potentiell geeigneten Standorten wieder eingebracht. Mit einer erfolgreichen Wiederansiedlung der Tamariske an der Oberen Isar im Stadtbereich von München wird ein Beitrag zur Erhaltung der bayerischen Bestände angestrebt. Auf Basis der Modellierung mittels Casimir Vegetation (Egger et al., 2013) soll darüber hinaus gezeigt werden, welche Faktoren entscheidend für eine Wiederansiedlung der Art sind. Zusätzlich wird anhand von Szenarien aufgezeigt, welche Rahmenbedingungen notwendig sind bzw. welche anthropogenen Einflussfaktoren (wie z- B. die Nutzung des Gebietes) verändert werden müssen, um eine erfolgreiche Etablierung zu sichern.

Dieses Dokument hat zum Ziel (i) einen vorläufigen Überblick über Methoden, Standorte und Entwicklung der angesiedelten Populationen seit Mai 2014 zu geben und (ii) Informationen zum Schutze der wiederangesiedelten Tamarisken während zukünftiger morphologischer Pflegemaßnahmen, die im

Hochwasserbett der Isar von der Landeshauptstadt München bzw. Tiefbaureferat durchgeführt werden könnten, zu geben.

Wiederansiedlungsverfahren

Pflanzenmaterial

27 Sämlinge wurden für die Wiederansiedlung der Deutschen Tamariske an der Isar im Münchener Stadtgebiet von Dr. Habersbrunner (BUND – Vorsitzender, Ortgruppe München West) aufgezogen. Die Samen wurden im September 2009 an der Pupplinger Aue gesammelt und in mit sandigen und kiesigen Substrat gefüllten Blumentöpfen verteilt. Das Pflanzmaterial wurde ohne weitere Pflege 5 Jahre lang in Töpfen im Außenbereich gelagert. Das Pflanzenmaterial war in einem heterogenen und zum Teil schlechten Zustand. Die Pflanzen waren im Durchschnitt 30cm hoch und bestanden aus 1 bis 2 Trieben mit im Durchschnitt ca. 30 aktiven Knospen je Trieb (Abb. 2).

Abb. 2: Aufnahme der Mutterpflanze Nr. 11 am 10.05.2014 (A.ZH)

Standorte

Um geeignete Standorte für eine erfolgreiche Etablierung zu identifizieren, wurden folgende Parameter berücksichtigt:

- Hochwasserlinien: Erfolgreiche Wiederansiedlungen finden zumeist über die HQ1-Linie statt (Egger, Angermann, & Gruber, 2010; Kammerer, 2003; Nikowitz, 2010; Schletterer & Scheiber, 2008; Staffler, 1999). Typ und Alter der Sukzession wurden als Indikator herangezogen.
- Bestehende Vegetation: Die Tamariske gehört zu den charakteristischen Pflanzen der Pflanzengesellschaft Salici-Myricarietum MOOR 58. Deren Lebensraum ist als FFH Lebensraumtyp „3230 Alpine Flüsse mit Ufergehölzen von Myricaria germanica" geschützt (Kudrnovsky, 2005, 2011, 2013). Bestehende typische Begleitvegetationen der Deutschen Tamariske (Ellenberg, 1996; Jürging & Schauer, 1998; Kammerer, 2003; Oberdorfer, 1992) wurden als Indikator herangezogen.
- Substrat: Die primäre Etablierung ist in Fein- bis Grobsubstrat erfolgreich (Egger et al., 2010). Die sekundäre Etablierung ist aber bevorzugt auf feinem Substrat erfolgreich. Bestehendes Substrat wurde kartiert.
- Entfernung vom Grundwasser: Die beste Grundwasserentfernung wurde durch Standortbeobachtungen auf circa 1 Meter geschätzt, weil diese Standorte aufgrund ihrer tiefen Lage häufigeren und höheren morphodynamischen Störungen ausgesetzt sind (Egger et al., 2010; Ellenberg, 1996).
- Störungsregime: Die Beobachtung von Egger et al. (2010) hat gezeigt dass die Vitalität der deutschen Tamariske bei mittleren Störungsregimen höher ist als bei starken oder geringen. Um die Störungsregime zu identifiziert, wird die Umlagerungshäufigkeit bzw. Störungsfrequenz der Vegetation als Indikator herangezogen.
- Lichtverhältnisse: Die Entwicklung der deutschen Tamariske ist sehr lichtabhängig (Benkler & Bregy, 2010; Bill et al., 1997; Lener, 2011). Der Deckungsgrad und die Vegetationshöhe wurden als Indikator herangezogen.

Fünf geeignete Standorte für eine erfolgreiche Wiederansiedlung der deutschen Tamariske wurden am 22. März auf Basis einer Standortkartierung Gregory Egger (WWF Auen-Institut Rastatt, KIT) und von Aude Hamed (TUM) an der Isar bei München festgestellt.
Zwei Standorte wurden wegen unterschiedlicher Nutzungsdichte und ausreichender Größe ausgewählt (Abb. 3).

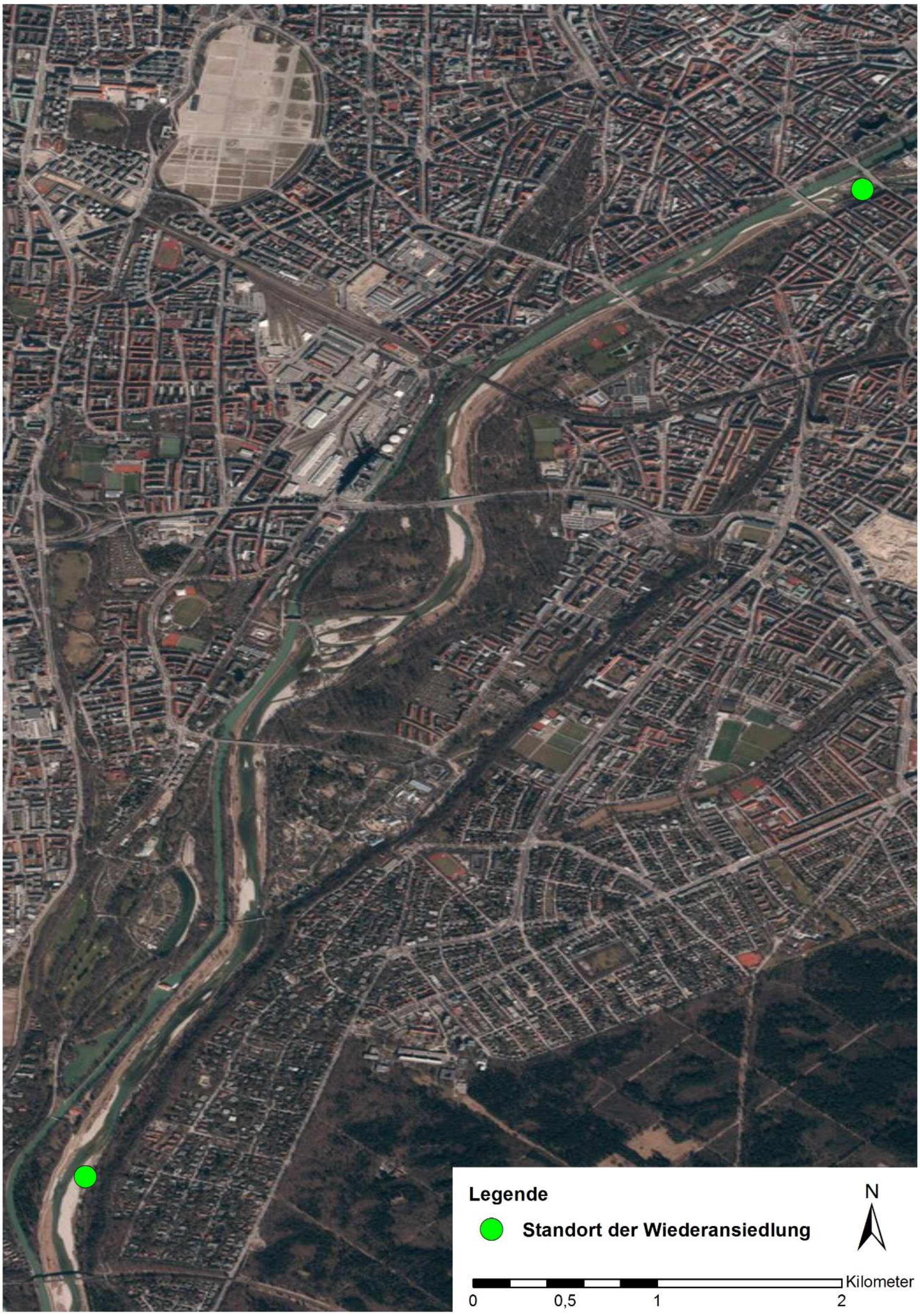

Abb 3. Karte der Lage der Wiederansiedlung von Myricaria germanica (L) desv. im Stadtgebiet München (A.ZH).

Standort „Isar Sud“

Abb. 4: Standort „Isar Sud“ - N 48° 7'39.49", E 11°34'44.82" am 30.03.2014 (A.ZH)

Nach dem 2013er Hochwasser hat sich eine Rinne gebildet, die außer bei Hochwasser trocken ist. Sie besteht aus feinsandigem und schluffigem Substrat. Da die Rinne circa 30 Zentimeter über dem Grundwasser liegt, ist der Bodenwasserhaushalt des Standortes trotz sandigem Sediment als „frisch“ einzustufen. Circa 20 m² große Sandauflandungen wurden für eine primäre und sekundäre Etablierung der Deutschen Tamariske in 2014 als geeignet eingestuft (Abb. 4)

Standort „Kleine Isar“

Nach der Bebauung des dritten Bauabschnitts haben sich in der kleinen Isar zwei seitliche Rinnen gebildet. An der unteren Rinne ist eine Insel entstanden, die aus feinem Sediment besteht. Ein großer Anteil der Vegetation wurde während des 2013-Hochwassers weggespült, und bildete seit dem einen sonnigen und offenen Standort. Die bestehende und übrige Vegetation besteht aus 1 bis 2-Jahre alten Weiden und Gräsern. Sie hat einen Gesamtdeckungsgrad von 25 bis 30 Prozent. Das Grundwasser liegt in ca. 50 cm Tiefe. Da der Boden aus feinsandigem und schluffigem Substrat besteht, ist der Wasserhaushalt des Standortes als „frisch“ einzustufen. Circa 25 m² große Sandanlandungen wurden sind für eine primäre und sekundäre Etablierung der Deutsche Tamariske in 2014 als geeignet eingestuft.(Abb. 5)

Abb. 5: Standort „kleine Isar“ - N.48° 4'47.70", E 11°32'31.52"E am 30.03.2014 (A.ZH)

Pflanzung

Die Ausbringung der Tamariskenpflanzen erfolgte am 11. Mai 2014. Die 27 Sämlinge *Myricaria germanica (L.) Desv.* (Deutsche Tamariske) wurden mit möglichst viel Substrat entlang der Isar an den beschriebenen Standorten eingebracht (Abb. 6). Die Auswahl der konkreten Pflanzungen innerhalb der potentiell geeigneten Standorte wurde erfolgte nach dem Zufallsprinzip.

Abb. 6: Photographie der Tamariske Nr. 21 nach der Pflanzung am 11.05.2014 (A.ZH)

Pflegemaßnahmen

Die Pflanzen wurden lediglich gegossen, ansonsten wurden keine weiteren Pflegemaßnahmen (wie Ausschneiden, Entkrauten, usw.) vorgenommen.

Nach dem Einbringen wurden die Sämlinge täglich beobachtet, um die erste Symptome eines Trockenstresses zu erkennen. Bei fehlendem Regen wurden im ersten Monat die Sämlinge alle 2 bis 3 Tage und danach alle 4 bis 5 Tage mit Wasser der Isar gegossen, um sie vor dem Austrocknen zu schützen. Jedes Mal wurde ein halber Liter pro Pflanze eingebracht. Nach zwei Monaten wurden zwei weitere Monate wöchentliche Beobachtungen durchgeführt, jedoch keine Pflegemaßnahmen mehr vorgenommen.

Monitoring

Im Mai und Juni 2014 wurden die Pflanzen alle drei Tage gezählt und der jeweilige Zustand dokumentiert. Jede Woche wurden die Länge der Triebe der einzelnen Pflanzen mit einem Messband und der Durchmesser der Triebe mit einen digitalen Messschieber gemessen. Im Juli, August und September wurde die Vermessung zwei Mal im Monate durchgeführt. Die Umweltbedingungen wurden via der online lokalen Vorhersage dokumentiert. Die Temperaturen wurden alle 15 Minuten via HOBO Data Loggers am Boden erfasst. Der Boden wurde mit einer visuellen Bewertungsmethode beschrieben. Die Bodenfeuchtigkeit wurde mit gleichem Abstand wie die Pflanzüberwachung beschrieben. Die Wasserhöhe wurde jeden Tag um 11Uhr mittels online Hochwassernachrichtenmeldung erfasst. Der Nutzungsdruck wurde acht Mal im Laufe des Sommers bei sonnigen Tagen durch Zählen der Besucher und Besucherinnen in den Wiederansiedlungsgebieten und im Wirkungsraum der Besucher bzw. auf bis zu 50m Entfernung von dem Bepflanzungsgebiet dokumentiert. Wegen der häufigen Regen und Gewitter im Juli und August wurden nur 5 Kartierungstage, zwei Sonntage, ein Samstag, ein Donnerstag und ein Montag im Mai und im Juni als relevant eingestuft.

Vorläufige Ergebnisse

Die Überlebungsquote ist stark vom Standort abhängig. Sie liegt 143 Tage nach der Pflanzung bei mehr als 65% an der Isar Süd bei ca. 25% an der kleinen Isar. Diese Überlebungsquote ist weit über anderen Wiederansiedlungen der deutschen Tamariske mit ähnlichem Pflanzmaterial (Egger, Angermann, & Gruber, 2010). Die Standorte unterschieden sich hauptsächlich durch verschiedene Nutzungsdichten. An der kleinen Isar wurden zwischen 10 und 18 Uhr im Durchschnitte 12 Besucher je 20 Minute pro Wiederansiedlungsgebiet und 61 im Einflussgebiet beobachtet. Die maximalen Werte wurden am 19. Juni zwischen 16 Uhr 30 und 16 Uhr 50 beobachtet: 30 Besucher im Bereich des Wiederansiedlungsgebietes und 137 im Bereich des Einflussgebietes. Die Kartierungen am gleichen Tagen an der Isar Süd zeigten eine niedrigere Nutzungsdichte mit 10 Besuchern alle 20 Minuten auf dem Wiederansiedlungsgebiet und 8 im Einflussgebiet. Die maximalen Werte wurden am 15. Juni zwischen 15 Uhr10 und 15 Uhr30 beobachtet: 37 Besucher im Wiederansiedlungsgebiet und 18 im Einflussgebiet. An beiden Standorten wurden die gleichen Schäden beobachtet (Abb. 7). Es trat kein Verlust infolge der Standortbedingungen oder Anpassungsstörungen ein. Zwischen 20-25% der Verluste wurden wegen natürlicher Erosions- oder Ablagerungsprozess während des sommerlichen Hochwassers beobachtet. Beobachtungen der Schäden und der Standorte deuten darauf, dass die Naherholung den größten Verlust verursacht. 25% der Pflanzen an der Isar Süd und 60% an der kleinen Isar wurden von Menschen beschädigt. Die Pflanzen wurden in 80% der Fälle ausgerissen und in der unmittelbaren Nähe des Pflanzungsortes wieder weggeworfen. Die Standortbeobachtungen zeigten, dass diese Schäden ohne böse Absicht von Kindern verursacht wurden. Da die Deutsche Tamariske feinsandige Sedimentablagerung am Uferbereich benötigt, ist ihre Nische zugleich auch als „natürlicher Sandkasten“ geeignet. Eine Wiederansiedlung im frühen Frühling oder eine natürliche Vermehrung sollte dank besserer Verwurzelung diese Schäden verringern. Trotz alle Erwartungen haben die andere Nutzungsforme wie Liegen, Grillen, Baden und Hunde in Begleitung wenig Einfluss auf den Etablierungserfolg.

Abb 7. Karte der Lage der wiederansiedlte Myricaria germanica (L) desv. im Stadtgebiet München (A.ZH).

Schlussfolgerung

Die Wiederansiedlung der Deutschen Tamariske an der renaturierten Isar in München zeigt positive Ergebnisse. Die Pflanzen haben sich angewurzelt und haben die ersten Hochwasser überstanden. Der längerfristige Erfolg der Wiederansiedlung kann jedoch noch nicht bestätigt werden, weil die Pflanzen noch nicht blühten und von daher keine sekundäre Etablierung stattgefunden hat und sie bislang auch keinen Winter überlebt haben bzw. nur ein Hochwasser bislang aufgetreten ist. Auch könnten der kalte und nasse Sommer sowie das sommerliche Hochwasser eine Erklärung für die fehlende Blütezeit sowie der geringen Nutzungsschäden sein. Es sind jedenfalls weiter Beobachtungen notwendig, um die Entwicklung der wiederangesiedelten Population zu dokumentieren. Die vorläufigen Ergebnisse deuten jedoch darauf hin, dass die positive ökologische Wirkung der Renaturierung der Isar vor allem durch die Dichte der Naherholung begrenzt wird.

Schutz und Beobachtung der Population

Im Rahmen des Forschungsprojekts werden weitere Überwachungen aber keine Pflegemaßnahmen durchgeführt. Wesentlich wäre jedenfalls, dass auf den Flächen der Wiederansiedlung keine Pflegemaßnahmen oder sonstige anthropogene Eingriffe in den Standort erfolgen. Falls es aus Gründen des Hochwasserschutzes als zwingend erforderlich ist im Nahbereich der Tamariskenstandorte doch Maßnahmen durchzuführen, bitten wir um eine Kontaktaufnahme mit dem Forscherteam, um ein angepasstes Verfahren zu entwickeln, welches das Aufkommen der Pflanzen und deren unmittelbare Umgebung nicht gefährdet.

Danksagung

Ich bedanke mich bei der Baureferat der Stadt München insbesondere bei Frau. Daniela Schaufuß für die Stellung der Grundstücke.

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Ohne die Hingabe aller für eine „gesunde und schöne“ Isar wäre nichts möglich gewesen.

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Supplementary material

Form A1: Interview form to survey projects

Table A1: List of the urban and rural river restoration in France

Table A2: List of the surveyed urban areas and related river restoration projects in France and Germany

Table A3 Fuzzy rules and sets for *Chondostroma nasus* L. considering recreational pressure as supplementary variable

Table A4 Fuzzy rules and sets for *Hucho hucho* L., *Thymallus thymallus* L., and *Chondostroma nasus* L.

Form A1: Interview form to survey projects

City: …….

1) Project

Did river(s) inside the city territory have been restored since 1980?

- ☐ Yes
- ☐ No

What is the project title? ……………………………………………………………………………………

Could you please shortly describe the project mentioning context elements and main goals?

…….

…….

…….

2) Status

How was the morphological status of the river/stream before the project?

- ☐ Channelized river course
- ☐ Straightened channel
- ☐ Impervious riverbank
- ☐ Artificial river bed
- ☐ Longitudinal connectivity damaged
- ☐ Existence of national road or Highway at the river side
- ☐ Buried river

Is the river navigable?

- ☐ yes
- ☐ no

3) project motivation

What is the project motivation (single answer)?

- ☐ Implementation of the WFD
- ☐ Ecological (ante signature of the WFD), e.g. Reestablishment of the migration potential for fish, Nature conservation (Natura 2000), Restoration of (sensitive) habitats
- ☐ Improvement of the flood protection strategy
- ☐ Improvement of the quality of life for citizens
- ☐ Other ………………………………………………………………………………..

4) project cost and funds

How expensive was the project (€):
……….

Which institution or program financed the project?

☐ European Union
If yes, which program? ……………………………………..
If yes, which percent of financing? ……………………

☐ State and Water Agency
If yes, which percent of financing? ……………………

☐ City government
If yes, which percent of financing? ……………………

☐ NGO
If yes, which percent of financing? ……………………

5) Restoration measures

Which measures have been implemented to :

a) improve the flood protection potential

- ☐ Dyke removal
- ☐ Dyke renewal or construction
- ☐ Creation of shallow water area
- ☐ Creation of flood depression area
- ☐ Increase retention potential of the floodplain

b) to improve the water quality

- ☐ Construction of water treatment plant
- ☐ Planting of green buffer area
- ☐ Treatment of rainwater
- ☐ Removal of rainwater outlet

c) to restore riparian habitats

- ☐ Creation of ponds
- ☐ Flooded area
- ☐ Creation of wetland
- ☐ Improvement of the vegetation mosaic
- ☐ Change of the management concept
- ☐ Riparian forest conversion
- ☐ Planting of vegetation succession
- ☐ Planting of riparian forest
- ☐ Extensive uses of the riparian area
- ☐ Species reintroduction

d) to restore aquatic habitats

- ☐ Deadwood management
- ☐ Improve the erosion or the sedimentation potential through morphological changes
- ☐ Riverbank flattening
- ☐ Creation of shallow water area inside the water course
- ☐ Creation of temporary water
- ☐ Improvement of the flow heterogeneity
- ☐ Improvement of the flood depression potential
- ☐ Creation of spawning area

e) to reestablish near-natural patterns of the river hydromorphology

- ☐ Substrate excavation
- ☐ River bed expansion
- ☐ Water course extension
- ☐ Removal of artificial bank constructions
- ☐ River bank flattening
- ☐ Meandering
- ☐ Connection of sidearm or tributaries
- ☐ Reopening of tributaries
- ☐ River bed raising
- ☐ Creation of island

f) to renew the city planning

- ☐ Improvement of the accessibility
- ☐ Creation of new connection, e.g. bridge
- ☐ Road removal
- ☐ Creation of residential area
- ☐ Creation of business park
- ☐ Creation of pier
- ☐ Creation of shopping area
- ☐ Creation of recreational area
- ☐ City reconstruction

g) to enhance the recreational potential at the river

- ☐ Improve accessibility
- ☐ Creation of paths
- ☐ Creation of platform
- ☐ Planting of recreational grassland
- ☐ Enable contact with nature
- ☐ Creation of fitness trail
- ☐ Creation of playground
- ☐ Design park
- ☐ Rehabilitation of towpath

- ☐ Creation of swimming facilities
- ☐ Nature protection and conservation pedagogic opportunities
- ☐ Creation of watersport facilities
- ☐ Creation of recreational pier

h) to reestablish the longitudinal connectivity

- ☐ Weir removal
- ☐ Creation of fish pass
- ☐ Slide removal
- ☐ Creation of bed ramp
- ☐ Bed glide removal
- ☐ Creation of bypass channel

i) to reduce pressures caused by hydropower plant

- ☐ Increase residual water
- ☐ Decrease residual water
- ☐ Construction of hydropower plant
- ☐ Removal of hydropower plant

Table A1: List of the urban and rural river restoration in France

ID	Project label	City	Project type	Site Type	Motivation
1	Effacement d'un plan d'eau de loisirs sur la Zinsel du Sud	Steinbourg	2	Rural	Habitat
2	Acquisition foncière sur les rives de l'Ouche	Fauverney	2	Rural	Habitat
3	Arasement du seuil du moulin du Viard sur l'Orne	Grimbosq	1	Rural	Fish
4	Remise en eau des méandres du Colostre	Riez	2	Rural	Habitat
5	La restauration du Merlue et de son marais	Écrille	3	Rural	WFD
6	Restauration du matelas alluvial de la Clouère par recharge granulométrique	Availles-Limouzine	1	Rural	WFD
7	Reméandrage de la Petite Veyle en amont du moulin du Geai	Biziat	3	Rural	WFD
8	Remise en eau d'un ancien lit du Dadon et restauration de l'habitat aquatique	Rumilly	3	Urban	WFD
9	Effacement partiel du seuil Cros sur la Dunière	Dunière	1	Rural	Fish
10	Remise à ciel ouvert du Redon à Margencel	Margencel	1	Rural	Fish
11	Effacement du seuil de Stalapos sur l'Alagnon	Murat	1	Rural	Fish
12	Effacement du barrage de Maisons-Rouges sur la Vienne	Ports et Nouâtre	1	Rural	Fish
13	Effacement du barrage de Fatou sur la Beaume	Solignac sur Loire	1	Rural	Fish
14	Effacement du seuil de Cussy sur le ruisseau de la Maria	Villapourçon	1	Rural	Fish
15	Dérivation et recréation du lit mineur de la Veyle au droit de la gravière de Saint-Denis-lès-Bourg	Saint-Denis-Bourg	3	Urban	WFD
16	Démantèlement de l'ouvrage du Pont Fourneau sur la Selle	Cateau-Cambresis	1	Rural	Fish
17	Effacement de vingt petits ouvrages et diversification du lit mineur du Couasnon	Auverse	3	Rural	WFD
18	Remise en eau de l'ancien lit du Fouillebroc à Touffreville	Touffreville	3	Rural	WFD
19	Effacement d'un chapelet de cinq étangs sur le ruisseau du Val des Choues	Villiers Duc	3	Rural	WFD
20	Suppression d'une digue d'étang en barrage sur un affluent du Petersbach	Butten	1	Rural	Fish
21	Effacement du seuil de la Seine Granitière sur la Seine amont	Châtillon sur Seine	1	Rural	Fish
22	Reméandrage du Hardtbach à Wissembourg	Wissembourg	3	Rural	WFD
23	Réduction de l'impact de trois étangs sur cours d'eau dans le bassin du Cousin	Champeau-Morvan	3	Rural	WFD
24	Arasement du vannage du moulin de Reveillon et réaménagement du lit mineur de la Blaise et réaménagement Lit Mineur Blaise	Dreux	3	Urban	WFD
25	Effacement du seuil du moulin du Bourg sur le Vicoin	Nuillé-sur-Vicoin	1	Rural	Fish
26	Contournement d'un plan d'eau de loisirs sur le Gratteloup au niveau de la commune de La Ville-aux-Clercs	Ville-aux-Clercs	1	Rural	Fish
27	Effacement du seuil du Moulin d'Hatrize sur l'Orne	Hatrize	1	Rural	Fish
28	Le reméandrage du Nant de Sion	Arenthon	3	Rural	WFD
29	Démantèlement de neuf ouvrages sur le cours de l'Aa	Merck-Saint-Liévin	3	Rural	Fish
30	Effacement du seuil du Moulin de Ver sur la Sienne	Ver	1	Rural	Fish
31	Effacement du seuil de Carayon sur le Thoré	Mazamet	1	Urban	Fish
32	Restauration des habitats de l'écrevisse à	Saulny	1	Rural	Habitat

	pieds blancs par la recharge sédimentaire du ruisseau de Saulny				
33	Restauration de la dynamique naturelle de l'Adour amont	Bagnères-de-Bigorre	2	Rural	Habitat
34	Reconstitution du matelas alluvial sur l'Ardèche	Aubenas	3	Urban	WFD
35	Remise à ciel ouvert du ruisseau du Trégou à Luc-la-Primaube	Luc-La-Primaube	3	Rural	WFD
36	Reconnexion d'un bras secondaire du Rhin : le Schafteu	Rhinau	3	Rural	WFD
37	Retour du Steinbaechlein dans son talweg d'origine	Morschwiller-le-Bas	3	Rural	WFD
38	Effacement du barrage de Kernansquillec sur le Leguer	Plounévez-Moëdec	2	Rural	Fish
39	Reméandrage du Marolles à Genillé	Genille	3	Rural	WFD
40	Remise à ciel ouvert du ru d'Orval à Cannectancourt	Cannectancourt	3	Rural	WFD
41	Suppression des protections de berges sur l'Orge aval	Morsang-sur-Orge	2	Urban	Habitat
42	Rehaussement du fond du lit du Trec et valorisation paysagère du site	Marmande	3	Urban	WFD
43	Création d'un chenal d'étiage sinueux en milieu urbain sur le ruisseau de Montvaux	Châtel-Saint-Germain	3	Rural	WFD
44	Travaux ponctuels de diversification du lit mineur et de valorisation paysagère sur le bassin versant de l'Hers-Mort	Montesquieu-Lauragais	3	Rural	WFD
45	Effacement partiel de cinq seuils sur le ruisseau du Bagas	Vielmur sur Agout	1	Rural	Fish
46	Effacement du barrage de l'ancien moulin Maurice sur le Ventron	Cornimont	1	Rural	Fish
47	Effacement du seuil du Martinet sur la Bave	Frayssinhes	1	Rural	Fish
48	Effacement partiel de 14 seuils sur le Mutterbach et l'Hosterbach à Holving et Hoste	Holving	1	Rural	Fish
49	Effacement d'un seuil à la Roche d'Alès sur la Dême	Marray	1	Rural	Fish
50	Effacement partiel d'un seuil sur l'Artuby à la Martre	Martre (La)	1	Rural	Fish
51	Arasement du seuil des Treize Saules sur la Quilienne	Pas-en-Artois	1	Rural	Fish
52	Effacement du seuil de Chelles Basse sur le Miodet	Saint-Dier d'Auvergne	1	Rural	Fish
53	Arasement du seuil de Sainte-Marie sur la Roanne	Dampniat	1	Rural	WFD
54	Arasement du seuil du pont Paillard sur un bras secondaire de l'Aume	Fouqueure	1	Rural	WFD
55	Retour de la Doquette dans son talweg d'origine	Hambye	1	Rural	WFD
56	Arasement d'un seuil industriel sur le Rhins	Regny	1	Rural	Fish
57	Effacement du barrage-clapet sur la Touques à Lisieux	Lisieux	1	Urban	Fish
58	Effacement partiel du seuil de Vas sur le Céans	Orpierre	1	Rural	Fish
59	Effacement du plan d'eau de Coupeau sur le Vicoin et réaménagement du lit mineur	Saint-Berthevin	1	Rural	Fish
60	Arasement d'un seuil sur la Corrèze au sein de l'agglomération de Tulle	Tulle	1	Urban	Fish
61	Reconstitution des écoulements de surface de deux affluents temporaires de la Clauge amont	Fraisans	3	Rural	WFD
62	Création d'un chenal d'étiage sinueux sur le Merloz	Nantua	3	Rural	WFD
63	Démantèlement et ouverture de quatre vannages sur la Vence	Francheville (La)	1	Rural	Fish
64	Aménagement d'un chenal d'étiage sinueux sur le Lange	Groissiat	3	Rural	WFD

65	Démantèlement du barrage de Laparayrié sur l'Agout	Montredon-Labessonnie	1	Rural	Fish
66	Rétablissement de la continuité écologique sur la Canche à Hesdin	Hesdin	1	Urban	Fish
67	Restauration de l'Hermance dans la traversée du bourg de Veigy-Foncenex	Veigy-Foncenex	3	Rural	WFD
68	Réouverture du Furan	Saint-Etienne	5	Urban	QualityLife
69	Parc Garonne	Toulouse	5	Urban	QualityLife
70	Requalification du Fier	Annecy	5	Urban	QualityLife
71	Revalorisation des canaux et berges	Calais	5	Urban	QualityLife
72	Coulée verte	Nice	5	Urban	QualityLife
73	Requalification de la rive Sud	Orléans	5	Urban	QualityLife
74	Plan Garonne	Bordeaux	5	Urban	QualityLife
75	Berges du Rhone	Lyon	5	Urban	QualityLife
76	Parc naturel urbain du Gave de Pau	Pau	5	Urban	QualityLife
77	Programme de lutte contre les inondations	Le Mans	4	Urban	Flood
78	Restauration de la Penfeld	Brest	3	Urban	WFD
79	Confluence Leysse Hyeres	Chambéry	4	Urban	Flood
80	Réouverture du Verderet	Grenoble	3	Urban	WFD
81	Aménagement de la rivière Meurthe	Nancy	4	Urban	Flood
82	Lez Vert	Montpellier	5	Urban	QualityLife
83	Restauration du Muhlbach de Koenigshoffen	Strasbourg	3	Urban	WFD
84	Réouverture d'un tronçon de la Bièvre en milieu urbain	Fresnes	3	Urban	WFD
85	Restauration de continuité écologique au Lac Tir	Dijon	1	Urban	WFD
86	Ré-aménagement de l'Huveaune	Marseille	3	Urban	WFD
87	Aménagement des bords du Doubs	Besancon	5	Urban	QualityLife
88	Contrat rivière	Annemasse	NA	Urban	Habitat
89	Prairies Saint-Martin	Rennes	5	Urban	QualityLife
90	Réaménagement de la Tet	Perpignan	3	Urban	WFD
91	Le reméandrage de la Drésine et du ruisseau de Remoray	Labergement Sainte Marie	2	Rural	Habitat
92	Restauration de l'annexe hydraulique de Bellegarde et recharge sédimentaire de la rivière d'Ain	Priay	3	Rural	WFD
93	Réouverture de la Bièvre	Paris	3	Urban	WFD
94	Retour de la Fontenelle dans son lit d'origine à Saint-Wandrille-Rançon	Saint-Wandrille-Rançon	3	Rural	WFD
95	Effacement du seuil des Brosses sur le Soanan	Legny	1	Rural	Fish
96	Effacement d'un chapelet de huit étangs sur la Bildmuehle	Lemberg	3	Rural	WFD
97	Reméandrage du Vistre et création d'un chenal d'étiage sur le Buffalon	Nîmes	3	Urban	WFD
98	Création de chenaux de crues et restauration des échanges entre lit majeur et lit mineur sur la Vezouz	Lunéville	4	Urban	Flood
99	Le reméandrage du ruisseau des Vurpillières	Labergement Sainte Marie	2	Rural	Habitat
100	Reméandrage du Mardereau à Sorigny	Sorigny	3	Rural	WFD
102	Aménagement des canaux	Valence	5	Urban	Fish
101	Parc périurbain Orne Odon	Caen	1	Urban	QualityLife
103	Trame verte	Reims	5	Urban	QualityLife
104	Aménagement des berges du Clain	Poitier	5	Urban	QualityLife

105	Restauration de la sinuosité sur la Trie à Tœufles	Toeufles	3	Rural	WFD
106	Renaturation de la Seille	Metz	5	Urban	QualityLife
107	Rives Nouvelles	Angers	5	Urban	QualityLife
108	Contrat rivière	Limoges	3	Urban	WFD
109	Restauration de la Tiretaine	Clemont-Ferrand	5	Urban	Habitat
110	Renaturation des berges de Moselle	Thionville	3	Rural	NA
111	Définition concertée d'un espace de mobilité pour l'Adour	Catchment area	NA	NA	Fish
112	Des actions pour le rétablissement de la continuité sur la Canche et ses affluents classés	Catchment area	NA	NA	Fish
113	Reméandrage du Drugeon et gestion intégrée de son bassin versant	Catchment area	NA	NA	Habitat
114	Restauration des annexes hydrauliques de la Loire et de ses affluents	Catchment area	NA	NA	WFD
115	Abaissement et démantèlement de trois clapets sur l'Orge aval	Catchment area	NA	NA	Fish
117	Gestion adaptative des ouvrages hydrauliques de la Sèvre Nantaise et du Thouet	Catchment area	NA	NA	WFD
118	Rétablissement de la continuité écologique sur le bassin de la Touques	Catchment area	NA	NA	Fish

Table A2: List of the surveyed urban areas (Published Supplementary material available online in Zingraff-Hamed et al., 2017b).

City name	Country	Project title (original language)
Cities with project		
Recklinghausen	Germany	Wiederherstellung der Durchgaengigkeit des Baerenbachs
Annemasse	France	Contrat rivière
Limoges	France	Contrat rivière
Angers	France	Rives Nouvelles
Augsburg	Germany	Wertach Vital
Bottrop	Germany	Emscher Zukunft
Chambéry	France	Confluence Leysse et Hyeres
Frankfurt am Main	Germany	Main 2015
Hamm	Germany	Lippeaue
Lyon	France	Berges du Rhône
Montpellier	France	Lez Vert
Munich	Germany	Neues Leben fuer die Isar
Neuss	Germany	Pilotprojekt Gnadenthal
Nice	France	Coulee verte
Reims	France	Trame verte
Rennes	France	Prairies Saint-Martin
Saarbruecken	Germany	Stadtmitte am Fluss
Siegen	Germany	Siegen zu neuen Ufern
Caen	France	Parc periurbain Orne Odon
Duisburg	Germany	Rhein Park in Duisburg
Ingolstadt	Germany	Stadt Park Donau
Offenbach am Main	Germany	Mainuferpark
Pau	France	Parc naturel urbain du Gave de Pau
Toulouse	France	Parc Garonne
Bordeaux	France	Plan Garonne
Le Mans	France	Programme de lutte contre les inondations
Besançon	France	Amenagement des bords du Doubs
Cottbus	Germany	Umgestaltung der Spree
Fürth	Germany	Neugestaltung der Gewaesser Talraum in Pegnitz
Halle	Germany	Umgestaltung der Saale
Hannover	Germany	Umgestaltung der Ihme
Kiel	Germany	Naturnahe Umgestaltung des Gewaessersystems Hasseldieksau und Struckdieksau
Krefeld	Germany	Deichsanierung an der Rhein
Leverkusen	Germany	Naturnahe Umgestaltung der Dhuenn
Marseille	France	Réamenagement de l'Huveaune
Nancy	France	Aménagement de la rivière Meurthe
Perpignan	France	Réamenagement de la Têt
Poitiers	France	Aménagement des berges du Clain
Valence	France	Aménagement des canaux
Annecy	France	Requalification du Fier
Calais	France	Revalorisation des canaux et berges
Orléans	France	Requalification de la rive Sud

Metz	France	Renaturation de la Seille
Thionville	France	Renaturation des berges de Moselle
Darmstadt	Germany	Offenlegung des Darmbachs
Grenoble	France	Reouverture du Verderet
Leipzig	Germany	Offenlegung der Pleisse und des Elstermuehlgrabens
Paris	France	Réouverture de la Bièvre
Saint-Etienne	France	Réouverture du Furan
Aachen	Germany	Renaturierung der Wurm
Berlin	Germany	Renaturierung der Panke
Bochum	Germany	Renaturierung der Emscher
Bremen	Germany	Renaturierung Weserufer
Brest	France	Restauration de la Penfeld
Clermont-Ferrand	France	Restauration de la Tiretaine
Dijon	France	Restauration de continuité écologique au Lac du Tir
Goettingen	Germany	Renaturierung der Leine
Herne	Germany	Renaturierung der Emscher
Hildesheim	Germany	Renaturierung Grabens
Karlsruhe	Germany	Renaturierung der Alb
Kassel	Germany	Renaturierung Ahna
Köln	Germany	Renaturierung des Flehbachs
Ludwigshafen am Rhein	Germany	Renaturierung des Altrheingrabens Isenach Moerschbachs
Moenchengladbach	Germany	Renaturierung des Bungtbachs
Moers	Germany	renaturierung der Moersbach
Muenster	Germany	Renaturierung der munstersche Aa
Nurenberg	Germany	Renaturierung der Pegnitz
Paderborn	Germany	Renaturierung der Pader
Pforzheim	Germany	Renaturierung der Enz Wurm Nagold
Potsdam	Germany	Renaturierung Nuthe
Rostock	Germany	Renaturierung des Carbaek
Strasbourg	France	Restauration du Muhlbach de Koenigshoffen
Stuttgart	Germany	Renaturierung der Nektar
Wolfsburg	Germany	Renaturierung Allerniederung der Kästorf bei Warmenau
Wuppertal	Germany	Renaturierung der Wupper
Cities without project		
Angoulême	France	
Bayonne	France	
Béthune	France	
La Rochelle	France	
Lorient	France	
Montbéliard	France	
Nîmes	France	
Rouen	France	
Toulon	France	
Valenciennes	France	
Magdeburg	Germany	
Cities without answer		

Amiens	France
Avignon	France
Creil	France
Dunkerque	France
Le Havre	France
Lille	France
Mulhouse	France
Nantes	France
Saint-Nazaire	France
Tours	France
Troyes	France
Bergisch Gladbach	Germany
Bielefeld	Germany
Bonn	Germany
Braunschweig	Germany
Chemnitz	Germany
Dortmund	Germany
Dresden	Germany
Düsseldorf	Germany
Erfurt	Germany
Erlangen	Germany
Essen	Germany
Freiburg im Breisgau	Germany
Gelsenkirchen	Germany
Hagen	Germany
Hamburg	Germany
Heidelberg	Germany
Heilbronn	Germany
Jena	Germany
Koblenz	Germany
Lübeck	Germany
Mainz	Germany
Mannheim	Germany
Mülheim an der Ruhr	Germany
Oberhausen	Germany
Oldenburg	Germany
Osnabrück	Germany
Regensburg	Germany
Remscheid	Germany
Reutlingen	Germany
Salzgitter	Germany
Solingen	Germany
Trier	Germany
Ulm	Germany
Wiesbaden	Germany
Würzburg	Germany

Table A3 Fuzzy sets and rules for adults (during the winter, the summer, on breeding ground, and spawning), larva, and juvenile habitats of common Nase in the Isar river (Germany) considering the input variables (i.e. velocity, water depth, Substratum, recreational pressure). VL – Very low; L – Low; M – Medium; H – High; VH – Very high.

Input variables				HSI					
Velocity	Water depth	Substratum	Recrea-tional pressure	Adults (winter)	Adults (summer)	Spawning area	Breeding ground	Larval developmen t	Juvenile
VH	VH	VH	VH	VL	VL	VL	VL	VL	VL
VH	VH	H	VH	VL	VL	VL	VL	VL	VL
VH	VH	M	VH	VL	VL	VL	VL	VL	VL
VH	VH	L	VH	VL	VL	VL	VL	VL	VL
VH	H	VH	VH	VL	VL	VL	VL	VL	VL
VH	H	H	VH	VL	VL	VL	VL	VL	VL
VH	H	M	VH	VL	VL	VL	VL	VL	VL
VH	H	L	VH	VL	VL	VL	VL	VL	VL
VH	M	VH	VH	VL	VL	VL	VL	VL	VL
VH	M	H	VH	VL	VL	L	VL	VL	VL
VH	M	M	VH	VL	VL	L	VL	VL	VL
VH	M	L	VH	VL	VL	L	VL	VL	VL
VH	L	VH	VH	VL	VL	VL	VL	VL	VL
VH	L	H	VH	VL	VL	L	VL	VL	VL
VH	L	M	VH	VL	VL	L	VL	VL	VL
VH	L	L	VH	VL	VL	L	VL	VL	VL
VH	VL	VH	VH	VL	VL	VL	VL	VL	VL
VH	VL	H	VH	VL	VL	VL	VL	VL	VL
VH	VL	M	VH	VL	VL	VL	VL	VL	VL
VH	VL	L	VH	VL	VL	VL	VL	VL	VL
H	VH	VH	VH	VL	VL	VL	VL	VL	VL
H	VH	H	VH	VL	VL	VL	VL	VL	VL
H	VH	M	VH	VL	VL	VL	VL	VL	VL
H	VH	L	VH	VL	VL	VL	VL	VL	VL
H	H	VH	VH	VL	VL	VL	VL	VL	VL
H	H	H	VH	VL	VL	VL	VL	VL	VL
H	H	M	VH	VL	VL	VL	VL	VL	VL
H	H	L	VH	VL	VL	VL	VL	VL	VL
H	M	VH	VH	VL	VL	VL	VL	VL	VL
H	M	H	VH	VL	VL	H	VL	VL	VL
H	M	M	VH	VL	VL	H	VL	VL	VL
H	M	L	VH	VL	VL	M	VL	VL	VL
H	L	VH	VH	VL	VL	VL	VL	VL	VL
H	L	H	VH	VL	VL	VH	VL	VL	VL
H	L	M	VH	VL	VL	VH	VL	VL	VL
H	L	L	VH	VL	VL	M	VL	VL	VL
H	VL	VH	VH	VL	VL	VL	VL	VL	VL
H	VL	H	VH	VL	VL	VL	VL	VL	VL

H	VL	M	VH	VL	VL	VL	VL	VL	VL
H	VL	L	VH	VL	VL	VL	VL	VL	VL
M	VH	VH	VH	VL	VL	VL	VL	VL	VL
M	VH	H	VH	VL	VL	VL	VL	VL	VL
M	VH	M	VH	VL	VL	VL	VL	VL	VL
M	VH	L	VH	VL	VL	VL	VL	VL	VL
M	H	VH	VH	VL	VL	VL	VL	VL	VL
M	H	H	VH	VL	VL	VL	VL	VL	VL
M	H	M	VH	VL	VL	VL	VL	VL	VL
M	H	L	VH	VL	VL	VL	VL	VL	VL
M	M	VH	VH	VL	VL	VL	VL	VL	VL
M	M	H	VH	VL	VL	L	VL	VL	VL
M	M	M	VH	VL	VL	L	VL	VL	VL
M	M	L	VH	VL	VL	L	VL	L	VL
M	L	VH	VH	VL	VL	VL	VL	VL	VL
M	L	H	VH	VL	VL	M	VL	VL	VL
M	L	M	VH	VL	VL	M	VL	L	VL
M	L	L	VH	VL	VL	L	VL	M	VL
M	VL	VH	VH	VL	VL	VL	VL	VL	VL
M	VL	H	VH	VL	VL	VL	VL	VL	VL
M	VL	M	VH	VL	VL	VL	VL	VL	VL
M	VL	L	VH	VL	VL	VL	VL	L	VL
L	VH	VH	VH	VL	VL	VL	VL	VL	VL
L	VH	H	VH	VL	VL	VL	VL	VL	VL
L	VH	M	VH	VL	VL	VL	VL	VL	VL
L	VH	L	VH	VL	VL	VL	VL	VL	VL
L	H	VH	VH	VL	VL	VL	VL	VL	VL
L	H	H	VH	VL	VL	VL	VL	VL	VL
L	H	M	VH	VL	VL	VL	VL	VL	VL
L	H	L	VH	VL	VL	VL	VL	VL	VL
L	M	VH	VH	VL	VL	VL	VL	L	VL
L	M	H	VH	VL	VL	VL	VL	L	VL
L	M	M	VH	VL	VL	VL	VL	L	VL
L	M	L	VH	VL	VL	VL	VL	M	VL
L	L	VH	VH	VL	VL	VL	VL	VL	VL
L	L	H	VH	VL	VL	VL	VL	VL	VL
L	L	M	VH	VL	VL	VL	VL	H	VL
L	L	L	VH	VL	VL	VL	VL	VH	VL
L	VL	VH	VH	VL	VL	VL	VL	VL	VL
L	VL	H	VH	VL	VL	VL	VL	VL	VL
L	VL	M	VH	VL	VL	VL	VL	M	VL
L	VL	L	VH	VL	VL	VL	VL	H	VL
VL	VH	VH	VH	VL	VL	VL	VL	VL	VL
VL	VH	H	VH	VL	VL	VL	VL	VL	VL
VL	VH	M	VH	VL	VL	VL	VL	VL	VL
VL	VH	L	VH	VL	VL	VL	VL	VL	VL
VL	H	VH	VH	VL	VL	VL	VL	VL	VL

VL	H	H	VH	VL	VL	VL	VL	VL	VL
VL	H	M	VH	VL	VL	VL	VL	VL	VL
VL	H	L	VH	VL	VL	VL	VL	VL	VL
VL	M	VH	VH	VL	VL	VL	VL	VL	VL
VL	M	H	VH	VL	VL	VL	VL	VL	VL
VL	M	M	VH	VL	VL	VL	VL	VL	VL
VL	M	L	VH	VL	VL	VL	VL	VL	VL
VL	L	VH	VH	VL	VL	VL	VL	VL	VL
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VL	VL	VH	VH	VL	VL	VL	VL	VL	VL
VL	VL	H	VH	VL	VL	VL	VL	VL	VL
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VL	VL	L	VH	VL	VL	VL	VL	VL	VL
VH	VH	VH	H	VL	VL	VL	VL	VL	VL
VH	VH	H	H	VL	VL	VL	VL	VL	VL
VH	VH	M	H	VL	VL	VL	VL	VL	VL
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VH	H	VH	H	M	M	VL	VL	VL	VL
VH	H	H	H	M	M	VL	VL	VL	VL
VH	H	M	H	M	M	VL	VL	VL	VL
VH	H	L	H	M	M	VL	VL	VL	VL
VH	M	VH	H	L	L	VL	VL	VL	VL
VH	M	H	H	L	L	L	VL	VL	VL
VH	M	M	H	L	L	L	VL	VL	VL
VH	M	L	H	L	L	L	VL	VL	VL
VH	L	VH	H	VL	VL	VL	VL	VL	VL
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VH	L	M	H	VL	VL	L	VL	VL	VL
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VH	VL	VH	H	VL	VL	VL	VL	VL	VL
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H	VH	H	H	VL	VL	VL	VL	VL	VL
H	VH	M	H	VL	VL	VL	VL	VL	VL
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H	H	VH	H	M	M	VL	VL	VL	VL
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H	M	M	H	L	L	H	VL	VL	VL
H	M	L	H	L	L	M	VL	VL	VL

H	L	VH	H	VL	VL	VL	VL	VL	VL
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H	L	L	H	VL	VL	M	VL	VL	VL
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VL	VH	M	H	VL	VL	VL	VL	VL	VL
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VH	L	VH	L	VL	VL	VL	VL	VL	L
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VL	M	VH	L	L	L	VL	VL	L	H
VL	M	H	L	L	L	VL	H	L	VH
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M	VL	L	VL	VL	VL	VL	VL	L	VL
L	VH	VH	VL	VL	VL	VL	VL	VL	VL

L	VH	H	VL	VL	VL	VL	VL	VL	VL
L	VH	M	VL	VL	VL	VL	VL	VL	VL
L	VH	L	VL	VL	VL	VL	VL	VL	VL
L	H	VH	VL	L	M	VL	VL	VL	VL
L	H	H	VL	L	M	VL	VL	VL	VL
L	H	M	VL	L	M	VL	VL	VL	VL
L	H	L	VL	L	M	VL	VL	VL	VL
L	M	VH	VL	L	M	VL	VL	L	H
L	M	H	VL	L	M	VL	L	L	VH
L	M	M	VL	L	M	VL	L	L	VH
L	M	L	VL	L	M	VL	L	M	H
L	L	VH	VL	VL	VL	VL	VL	VL	H
L	L	H	VL	VL	VL	VL	M	VL	VH
L	L	M	VL	VL	VL	VL	M	H	VH
L	L	L	VL	VL	VL	VL	M	VH	H
L	VL	VH	VL	VL	VL	VL	VL	VL	VL
L	VL	H	VL	VL	VL	VL	VL	VL	VL
L	VL	M	VL	VL	VL	VL	VL	M	VL
L	VL	L	VL	VL	VL	VL	VL	H	VL
VL	VH	VH	VL	VL	VL	VL	VL	VL	VL
VL	VH	H	VL	VL	VL	VL	VL	VL	VL
VL	VH	M	VL	VL	VL	VL	VL	VL	VL
VL	VH	L	VL	VL	VL	VL	VL	VL	VL
VL	H	VH	VL	L	L	VL	VL	VL	VL
VL	H	H	VL	L	L	VL	VL	VL	VL
VL	H	M	VL	L	L	VL	VL	VL	VL
VL	H	L	VL	L	L	VL	VL	VL	VL
VL	M	VH	VL	L	L	VL	VL	L	H
VL	M	H	VL	L	L	VL	VH	L	VH
VL	M	M	VL	L	L	VL	VH	L	VH
VL	M	L	VL	L	L	VL	VH	M	H
VL	L	VH	VL	VL	VL	VL	VL	VL	H
VL	L	H	VL	VL	VL	VL	VH	VL	VH
VL	L	M	VL	VL	VL	VL	VH	L	VH
VL	L	L	VL	VL	VL	VL	VH	L	H
VL	VL	VH	VL	VL	VL	VL	VL	VL	VL
VL	VL	H	VL	VL	VL	VL	VL	VL	VL
VL	VL	M	VL	VL	VL	VL	VL	L	VL
VL	VL	L	VL	VL	VL	VL	VL	L	VL

Table A4 Fuzzy sets and rules *Chondostroma nasus* L, *Thymallus thymallus* L., and *Hucho hucho* L. in the Isar river (Germany) considering the input variables (i.e. Velocity, Water depth, Substratum). VL – Very low; L – Low; M – Medium; H – High; VH – Very high.

Input variables			Habitat types											
Velocity	Water depth	Substratum	TTA	TTS	TTJ	HHR	HHJS	HHA	CNWS	CNAS	CNS	CNR	CNL	CNJ
VH	VH	VH	VL	VL	VL	VL	VL	VH	VL	VL	VL	VL	VL	VL
VH	VH	H	VL	VL	VL	VL	VL	VH	VL	VL	VL	VL	VL	VL
VH	VH	M	VL	VL	VL	VL	VL	H	VL	VL	VL	VL	VL	VL
VH	VH	L	VL	VL	VL	VL	VL	H	VL	VL	VL	VL	VL	VL
VH	H	VH	VL	VL	VL	L	VL	VH	VH	H	VL	VL	VL	VL
VH	H	H	VL	VL	VL	L	VL	VH	VH	H	VL	VL	VL	VL
VH	H	M	L	VL	VL	L	VL	H	VH	H	VL	VL	VL	VL
VH	H	L	L	VL	VL	L	VL	H	VH	H	VL	VL	VL	VL
VH	M	VH	VL	VL	VL	M	VL	M	VH	VH	VL	VL	VL	L
VH	M	H	VL	VL	VL	M	L	M	VH	VH	VL	L	VL	L
VH	M	M	VL	VL	VL	M	M	M	VH	VH	VL	L	VL	L
VH	M	L	VL	VL	VL	L	VL	L	VH	VH	VL	L	VL	L
VH	L	VH	VL	VL	VL	M	VL	VL	VL	VL	VL	VL	VL	L
VH	L	H	VL	VL	VL	M	VL	VL	VL	VL	VL	L	VL	L
VH	L	M	VL	VL	VL	M	VL	VL	VL	VL	VL	L	VL	L
VH	L	L	VL	VL	VL	VL	VL	VL	VL	VL	VL	L	VL	L
VH	VL	VH	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL
VH	VL	H	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL
VH	VL	M	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL
VH	VL	L	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL
H	VH	VH	VL	VL	VL	L	VL	VH	VL	VL	VL	VL	VL	VL
H	VH	H	VL	VL	VL	L	VL	VH	VL	VL	VL	VL	VL	VL
H	VH	M	VL	VL	VL	L	VL	VH	VL	VL	VL	VL	VL	VL
H	VH	L	VL	VL	VL	VL	VL	M	VL	VL	VL	VL	VL	VL
H	H	VH	VL	VL	VL	VH	VL	VH	VH	VH	VL	VL	VL	VL
H	H	H	L	VL	VL	VH	VL	VH	VH	VH	VL	VL	VL	VL
H	H	M	M	VL	VL	VH	VL	VH	VH	VH	VL	VL	VL	VL
H	H	L	M	VL	VL	H	VL	M	VH	VH	VL	VL	VL	VL
H	M	VH	VL	VL	VL	VH	L	M	VH	VH	VL	VL	VL	L
H	M	H	L	VL	VL	VH	H	M	VH	VH	VL	H	VL	L
H	M	M	M	VL	VL	VH	VH	M	VH	VH	VL	H	VL	L
H	M	L	M	VL	VL	H	L	L	VH	VH	VL	M	VL	L
H	L	VH	VL	VL	VL	M	VL	VL	VL	VL	VL	VL	VL	L
H	L	H	L	VL	VL	M	M	VL	VL	VL	VL	VH	VL	L
H	L	M	L	VL	VL	M	M	VL	VL	VL	VL	VH	VL	L
H	L	L	L	VL	VL	L	VL	VL	VL	VL	VL	M	VL	L
H	VL	VH	VL	VL	VL	L	VL	VL	VL	VL	VL	VL	VL	L

H	VL	H	VL	VL	VL	L	VL	VL	VL	VL	VL	VL	VL	L
H	VL	M	VL	VL	VL	L	VL	VL	VL	VL	VL	VL	VL	L
H	VL	L	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	L
M	VH	VH	VL	VL	VL	L	VL	VH	VL	VL	VL	VL	VL	VL
M	VH	H	VL	VL	VL	L	VL	VH	VL	VL	VL	VL	VL	VL
M	VH	M	VL	VL	VL	L	VL	VH	VL	VL	VL	VL	VL	VL
M	VH	L	VL	VL	VL	L	VL	M	VL	VL	VL	VL	VL	VL
M	H	VH	VL	VL	VL	VH	VL	VH	H	H	VL	VL	VL	VL
M	H	H	H	VL	VL	VH	VL	VH	H	H	VL	VL	VL	VL
M	H	M	VH	VL	VL	VH	VL	VH	H	H	VL	VL	VL	VL
M	H	L	VH	VL	VL	L	VL	M	H	H	VL	VL	VL	VL
M	M	VH	VL	VL	VL	VH	VL	M	M	H	VL	VL	VL	M
M	M	H	M	VL	H	VH	M	M	M	H	VL	L	VL	H
M	M	M	H	VH	VH	VH	VH	M	M	H	VL	L	VL	H
M	M	L	H	VH	VH	L	VL	L	M	H	VL	L	L	M
M	L	VH	VL	VL	VL	M	VL	VL	VL	VL	VL	VL	VL	H
M	L	H	L	L	H	M	L	VL	VL	VL	M	M	VL	H
M	L	M	M	H	H	M	M	VL	VL	VL	M	M	L	H
M	L	L	M	H	H	L	VL	VL	VL	VL	M	L	M	H
M	VL	VH	VL	VL	VL	L	VL	VL	VL	VL	VL	VL	VL	VL
M	VL	H	VL	VL	VL	L	VL	VL	VL	VL	VL	VL	VL	VL
M	VL	M	VL	VL	VL	L	VL	VL	VL	VL	VL	VL	VL	VL
M	VL	L	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	L	VL
L	VH	VH	VL	VL	VL	VL	VL	M	VL	VL	VL	VL	VL	VL
L	VH	H	VL	VL	VL	VL	VL	M	VL	VL	VL	VL	VL	VL
L	VH	M	VL	VL	VL	VL	VL	L	VL	VL	VL	VL	VL	VL
L	VH	L	VL	VL	VL	VL	VL	L	VL	VL	VL	VL	VL	VL
L	H	VH	VL	VL	VL	L	VL	M	L	M	VL	VL	VL	VL
L	H	H	H	VL	VL	L	VL	M	L	M	VL	VL	VL	VL
L	H	M	VH	VL	VL	L	VL	L	L	M	VL	VL	VL	VL
L	H	L	VH	VL	VL	VL	VL	L	L	M	VL	VL	VL	VL
L	M	VH	VL	VL	VL	L	VL	L	L	M	VL	VL	L	H
L	M	H	M	L	H	L	VL	L	L	M	H	VL	L	VH
L	M	M	H	VH	VH	L	VL	L	L	M	H	VL	L	VH
L	M	L	H	VH	VH	VL	VL	VL	L	M	H	VL	M	H
L	L	VH	VL	L	L	VL	VL	VL	VL	VL	VL	VL	VL	H
L	L	H	L	L	H	VL	VL	VL	VL	VL	VH	VL	VL	VH
L	L	M	M	H	H	VL	VL	VL	VL	VL	VH	VL	H	VH
L	L	L	M	H	H	VL	VL	VL	VL	VL	VH	VL	VH	H
L	VL	VH	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL
L	VL	H	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL
L	VL	M	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	M	VL
L	VL	L	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	H	VL
VL	VH	VH	VL	VL	VL	VL	VL	M	VL	VL	VL	VL	VL	VL
VL	VH	H	VL	VL	VL	VL	VL	M	VL	VL	VL	VL	VL	VL
VL	VH	M	VL	VL	VL	VL	VL	M	VL	VL	VL	VL	VL	VL
VL	VH	L	VL	VL	VL	VL	VL	L	VL	VL	VL	VL	VL	VL

VL	H	VH	VL	VL	VL	L	VL	M	L	L	VL	VL	VL	VL
VL	H	H	L	VL	VL	L	VL	M	L	L	VL	VL	VL	VL
VL	H	M	M	VL	VL	L	VL	M	L	L	VL	VL	VL	VL
VL	H	L	M	VL	VL	VL	VL	L	L	L	VL	VL	VL	VL
VL	M	VH	VL	VL	VL	L	VL	VL	L	L	VL	VL	L	H
VL	M	H	L	L	M	L	VL	VL	L	L	H	VL	L	VH
VL	M	M	M	M	M	L	VL	VL	L	L	H	VL	L	VH
VL	M	L	M	M	M	VL	VL	VL	L	L	H	VL	M	H
VL	L	VH	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	H
VL	L	H	L	L	L	VL	VL	VL	VL	VL	VH	VL	VL	VH
VL	L	M	L	M	M	VL	VL	VL	VL	VL	VH	VL	L	VH
VL	L	L	L	M	M	VL	VL	VL	VL	VL	VH	VL	L	H
VL	VL	VH	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL
VL	VL	H	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL
VL	VL	M	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	L	VL
VL	VL	L	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	L	VL

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Education

Since 2012	PhD student in Ecology and Strategies for Landscape Management at the University of Tours (France) and at the Technical University of Munich (Germany) Thesis title : *Urban River Restoration – a socio-ecological approach*
2010 – 2011	Master of Science in Ecology, delivered by the University of Angers (France) Master Thesis title : *Comment articuler les enjeux écologiques et paysagers dans le projet urbain de réaménagement des zones fluviales urbaines ? Etude des cas Munich et Angers*
2005 – 2011	Dipl.-Ing. in Landscape Planning & Landscape Architecture, delivered by the Hochschule Weihenstephan-Triesdorf (Germany)
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1998 – 2002	Brevet delivered by Collége Jean Bauchez, Ban Saint Martin (France)
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Professional History

10.2012 - now	Doctoral Researcher at the Technical University of Munich, chair for Strategic Landscape Planning and Management (Prof. Pauleit)
10.2012 - 04.2016	Scientific staff at the University François Rabelais de Tours (France)
11.2011 - 12.2012	Lanscape designer at Richter Landschaftsarchitekten, Munich (Germany)
02.2011 - 06.2011	Trainee at the TUM, Freising (Germany)
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05.2008 - 08.2008	Trainee at CAUE 49 (Conseil d'Architecture, d'Urbanisme et d'Environnement), Maine et Loire (France)
05.2007 - 08.2007	Trainee at Arboreta/Aux plaisirs du Jardins, Paris (France)
07.2006 - 08.2006	Worker at Springyellow farm, Charlottetown, Prince Edward Island (Canada)

Teaching experience

03.2015	Lecturer: Module – Urban aquatic ecosystems (5 ECTS) Europe: River restoration in the city for the Master in Urban Planning, Université Francois Rabelais de Tours (France)
10.2011	Lecturer: Module – Public Participation and Landscape Planning (5 ECTS) for the Master in Regional Planning, AgoCampus Ouest (France)

Student Supervision

2014	Master thesis "Aerial Assessment of the Hydromorphology of Flowing River Bodies" written by Kathrin Undeutsch submitted to the Technical University of Munich (Germany)
2014	Student project "Landscape Quality Perception of an Urban Restored River" written by Eva Jirka submitted to the Technical University of Munich (Germany)
2013	Master thesis "Perception du paysage fluvial en milieu urbain" written by Alysée Palpied submitted to the AgoCampus Ouest (France)

Language skills French (mother tongue); English (good in speaking & writing), German (good in speaking & writing), Spanish (good in speaking & writing), Arabic (basic)

Informatics skills

CAD-GIS : Vektorworks, Autocad, ArcView, MapSource
Hydromorphological Model : SMS
Habitat Model : CASiMiR
Statistique : Splus, Statgraph, R
Genetic analysis : Bioedit, Genetix
Textual analysis : EraMuTeQ
Design : Photoshop, InDesign, Publisher, Photofiltre, Photoscape
Office : Excel, Word, PowerPoint, Paint, Office One, Combine PDF, EndNote, OneNote, Workbench, Project Professional
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Publications

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Zingraff-Hamed A., Popp A. (2011) Stadtmitte am Fluss : unvollständige Nachhaltigkeit, Landschaft und Garten, December 2011, pp 46-47