# Distribution and patterns of human stressors and their impacts on fish assemblages in the Austrian Drava and Mura River Basins

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## Abstract

This thesis addresses human stressors and their impacts on fish assemblages in the Austrian Drava and Mura River Basins. It supports the EU-project MARS (Managing Aquatic ecosystems and water Resources under multiple Stress) by analysing single and multiple stressors, environmental effects and stressor interactions.

Six mainly hydromorphological stressors from the national inventory assessment of the EU Water Framework Directive were recoded and aggregated to two new variables 'stressor category' and 'stressor quantity'. These served (1) to examine distribution and patterns of single and multiple stressors within the river basins and (2) to investigate related responses of a set of biotic, mainly fish based indicators. The 6 original stressors were linked to biotic indicators using Random Forest (RF) and Boosted Regression Tree (BRT) models. Two models were built, both analysing the response of biotic indicators to stressors, one including factor 'fish zone' to reflect longitudinal zonation (model 2).

Overall, investigated river basins are affected by 28 different stressor categories; partially up to 5 stressors per water body occur. Stressor-response analysis shows divergent results for stressor categories, a general trend of decreasing ecological integrity with increasing stressor quantity is observed. BRT models revealed goodness of fit up to 35% (model 1) and 78% (model 2). Indicators 'ecological status' and 'age-structure-metrics' showed the strongest response. Highest variable importance was observed for stressors morphological alteration, impoundment and residual flow; interactions were found between morphological alteration and connectivity disruption.

The knowledge gained in this thesis provides a basis for advanced investigations in related river basins and helps prioritizing further restoration- and management actions. Focusing on impacts of natural variability and introduction of primal stressors with adequate gradients is further recommended.



## Keywords

Riverine ecosystems, Fish assemblages, Multiple human stressors, Ecological status, Water Framework Directive

## Zusammenfassung

Diese Masterarbeit ist ein Beitrag zum EU-Projekt MARS. Sie behandelt anthropogene Einfach- und Mehrfachbelastungen an Fließgewässern und deren Auswirkungen auf Fischgemeinschaften in den Österreichischen Mur- und Drau-Einzugsgebieten. Weiteres liegt ein Augenmerk auf dem Einfluss von Umweltvariabilität sowie Wechselwirkungen zwischen den Belastungen. Basierend auf Daten, welche im Rahmen der Umsetzung der EU-Wasserrahmenrichtlinie national erhoben wurden, ergaben sich folgende Analysen: 1) Sechs Belastungsarten (hauptsächlich hydromorphologisch) mit unterschiedlichen Belastungsintensitäten wurden zu zwei neuen Variablen „Anzahl" und „Kombinationen" an Belastungen pro Wasserkörper aggregiert; 2) Mittels Boosted Regreesion Tree und Random Forest Modellen wurde der Zusammenhang zwischen mehreren biotischen, hauptsächlich fischbasierten Indikatoren und Belastungsvariablen untersucht. Es wurden zwei Modelle entwickelt, wobei Modell 2 die Variable „Fischregion" als Einflussfaktor für die longitudinale Zonierung mit einbezog.

Insgesamt sind die Wasserkörper beider Einzugsgebiete von 28 unterschiedlichen Einzel- und Mehrfachbelastungen betroffen; teilweise fallen bis zu 5 Belastungen am Wasserkörper an. Am stärksten reagierten die Indikatoren „Ökologischer Zustand" und jene basierend auf „Altersstruktur" mit einem Erklärungsgrad von bis zu 35% in Modell 1 und 78% in Modell 2. Während die Indikatoren gut auf morphologische Veränderungen und Stauhaltung reagierten, waren die Ergebnisse zu Restwasser, Kontinuumsunterbrechungen, Schwall und Chemischem Zustand divergent. Wechselwirkungen wurden zwischen morphologischen Veränderungen und Kontinuumsunterbrechungen festgestellt.

Die Analyse der Belastungen und deren Auswirkungen auf Fischgemeinschaften dienen als Beitrag zur Formulierung geeigneter Renaturierungsmaßnahmen und als Basis zukünftiger Untersuchungen. Hierfür wird die Einbeziehung von Umwelt- und alternativer Belastungsvariablen mit adäquaten Belastungsgradienten empfohlen.



## Schlagwörter

Fließgewässerökosystem, Fischgemeinschaften, Mehrfachbelastungen, Ökologischer Zustand, Wasserrahmenrichtlinie

# Index


1. Introduction ..... 7
*1.1. General Introduction* ..... 7
*1.2. Backgrounds* ..... 8
*1.3. The MARS project* ..... 10
*1.4. Stressor situation in Austria and in the Drava and Mura River Basins* ..... 13
*1.5. Research questions and hypotheses* ..... 14
2. Methods ..... 14
*2.1. Description of the study area* ..... 15
*2.2. Environmental data* ..... 15
*2.3. Stressor data* ..... 15
*2.4. Fish data* ..... 18
*2.5. Distribution and patterns of single and multiple stressors in water bodies* ..... 21
*2.6. Response of fish assemblages to multiple stressors* ..... 21
3. Results ..... 25
*3.1. Distribution and patterns of single and multiple stressors in water bodies* ..... 25
*3.2. Response of fish assemblages to multiple stressors* ..... 30
4. Discussion ..... 38
5. Conclusions ..... 45
6. References ..... 47
7. Appendix ..... 55
*a. Concepts and studies conducted within the Drava River Basin* ..... 55
*b. Additional maps* ..... 57
*c. Boxplots of stressor-indicator relationships* ..... 60
*d. Full result of BRT models* ..... 67
*e. Partial dependence plots of BRT models* ..... 69

## Tables

Table 1: Stressor variables and criteria for impact assessment categories according to Mühlmann (2013) and translation into stressor classes used for this thesis. .... 17
Table 2: Classification table for Austrian fish metrics. .... 19
Table 3: Description of biotic indicators (FIA metrics and other indicators) considered in this thesis. .... 20
Table 4: Description of stressor variable recoding and calculation of the new variables 'Stressor category and 'Stressor quantity'. .... 21
Table 5: Number and percentage of water bodies affected by different stressor quantities for all water bodies of the total basin/water bodies with fish sampling sites and separated by sub-basins Mura and Drava, fish zone and drainage area. Values in bold mark categories occurring more than 20 times in total. .... 29
Table 6: Number and percentage of water bodies affected by different stressor categories for all water bodies of the total basin/water bodies with fish sampling sites and separated by sub-basins Mura and Drava, fish zone and drainage area. Values in bold mark categories occurring more than 20 times in total. .... 29
Table 7: Results of the Random Forest model indicating goodness of fit, ranked variable importance (VIMP) and if indicator was selected for Boosted Regression Tree analysis. .... 32
Table 8: BRT results with percentage of explained variance, variable importance of the three most important predictors and interactions for model 1 (all stressors as predictors) and model 2 (all stressors plus fish zone as predictors). .... 33

# Figures

Figure 1: The DPSIR framework promoted by the European Environment Agency as an analytical framework to assess water issues (adopted from Friberg, 2014)........................................ 8
Figure 2: The MARS conceptual model (Hering et al., 2014). ........................................................ 11
Figure 3: MARS empirical model for the Austrian Drava/Mura River Basins. ............................ 12
Figure 4: The river network of Austria with delineation of the Drava and Mura River Basins... 15
Figure 5: Fish zones and fish sampling sites in the Drava and Mura River Basins considered for further analyses. ........................................................................................................ 18
Figure 6: Analytical design for this thesis including the analysis of stressor distribution and patterns, the descriptive analysis of the relationship between variables 'stressor category, 'stressor quantity' and selected indicators and the analysis to implement the MARS model for Drava and Mura River Basins.............................................................................................. 22
Figure 7: Frequency of water bodies with related fish sampling sites and the occurrence of single stressor intensities.............................................................................................. 25
Figure 8: Frequency of water bodies with related fish sampling sites and the occurrence of single stressor intensities)............................................................................................. 25
Figure 9: Water bodies affected by different stressor categories in the Drava and Mura River Basins.................................................................................................................... 27
Figure 10: Water bodies affected by different stressor quantities in the Drava and Mura River Basins.................................................................................................................... 28
Figure 11 a and b: Response of indicator 'population age structure' (AS) to variables 'Stressor category' and 'Stressor quantity'.................................................................................... 30
Figure 12 a and b: Response of indicator 'Fish Index Austria' (FIA) to variables 'Stressor category' and 'Stressor quantity'.................................................................................... 31
Figure 13 a and b: Response of indicator 'ecological status' (ES) to variables 'Stressor combination' and 'Stressor quantity'.............................................................................. 31
Figure 14: Proportion of variance explained by model 1 (stressor variables only) compared to model 2 (stressor variables and fish zone) for all fish based indicators as well as for the ecological status.......................................................................................................... 33
Figure 15: Distribution of the predictor importance based on the BRT models for the 16 indicators, separated by model (model 1 – stressors and model 2 – stressors and 'fish zone' (FIZ))........................................................................................................................ 34
Figure 16 a: Partial dependence plots showing the response of indicator 'population age structure' (AS) to single stressors and fish zone for model 1.......................................................... 35
Figure 17 b: Partial dependence plots showing the response of indicator 'population age structure' (AS) to single stressors and fish zone for model 2.......................................................... 35
Figure 18 a: Partial dependence plots showing the response of indicator 'Fish Index Austria' (FIA) to single stressors and fish zone for model 1. .......................................................... 36
Figure 19 b: Partial dependence plots showing the response of indicator 'Fish Index Austria' (FIA) to single stressors and fish zone for model 2. .......................................................... 36
Figure 20 a: Partial dependence plots showing the response of indicator 'ecological status' (ES) to single stressors and fish zone for model 1.................................................................... 37
Figure 21 b: Partial dependence plots showing the response of indicator 'ecological status' (ES) to single stressors and fish zone for model 2.................................................................... 37

# 1. Introduction

## 1.1. *General Introduction*

Across Europe, multiple human stressors impact aquatic ecosystems and their inhabiting communities, especially in rivers and streams. In the past, strong single stressors as organic pollution or flood protection were prevalent. Today, a complex mixture composed by hydrological, morphological, connectivity and chemical stressors resulting from hydropower generation, urban and agricultural land use, climate change and other factors impacts the functioning of aquatic ecosystems and services they provide (EEA, 2012a; Schinegger et al., 2012). To address these stressors and to improve the ecological conditions, effective management and restoration is needed, which requires knowledge on the relationship between stressors and biota.

In Europe, EU and member state legislation has been established to manage and protect running waters, especially under the EU Water Framework Directive (WFD), (European Comission, 2000), which demands the 'good ecological status' of all water bodies (i.e. related management units). This is addressed in 6-year planning phases and by use of multiple Biological Quality Elements (BQEs) for status assessment. In the WFD, beside benthic macroinvertebrates, macroalgae and phytoplankton, especially fishes are sensitive indicators for riverine ecosystems, as they show a significant response to various stressors (Ormerod, 2003; Pont et al., 2006). Europe's first River Basin Management Plans (RBMPs) from 2009 indicate that 56 % of water bodies in Europe fail to achieve the good ecological status (EEA, 2012b), as they are affected by a complex set of stressors. Thus, it is no longer sufficient to explain relationships assuming simple dose-response reactions of aquatic organisms. In a previous study, Schinegger et al. (2012) showed that degradation of European rivers by multiple stressors is widespread, that the relevance of stressors differs regionally and that especially in the Alpine regions of Europe, a combination of hydromorphological stressors (e.g. hydropeaking, impoundment, channelization etc.) dominates in riverine ecosystems.

The presence of multiple stressors is challenging for the management of aquatic ecosystems, as stressors often are interactive and not only additive, which implies that the effects of individual stressors may be underestimated (Crain et al., 2008; Hering et al., 2014). However, there is a lack of common understanding for and quantifiable thresholds of multiple stressor effects on the aquatic community, and international literature specifically on multiple hydromorphological stressors and related impacts on fish assemblages is rare (Schinegger et al., 2012).

This thesis therefore focuses on the distribution and patterns of human stressors and their impacts on fish assemblages in the Austrian Drava and Mura River Basins – catchments dominated by Alpine river types where hydromorphological stressors are prevalent. The specific aims of this thesis are i) to identify stressor distributions and patterns (stressor categories and stressor quantities) within the Drava and Mura River Basins; ii) to identify relevant indicators with a focus on fish based indicators responding to single and multiple stressors; iii) to analyse the effect of natural variability compared to stressors and iv) to identify stressor interactions.

## *1.2. Backgrounds*

**Stressors and the Driver-Pressure-State-Impact-Response (DPSIR) framework**

The term 'stressor' refers to the response on a changing factor in the abiotic or biotic environment of a system (Kolasa and Pickett, 1992; Odum, 1985; Underwood, 1989). This response exceeds the system's normal variation and consequently the stressor affects species at any organizational level, such as individuals, populations, communities or ecosystems in a beneficial or detrimental way (Ban et al., 2014; Underwood, 1989). Stressors are cause in a cause-and-effect chain of natural or human origin including biological interactions, human pressures and climate change (Omernik, 1995).

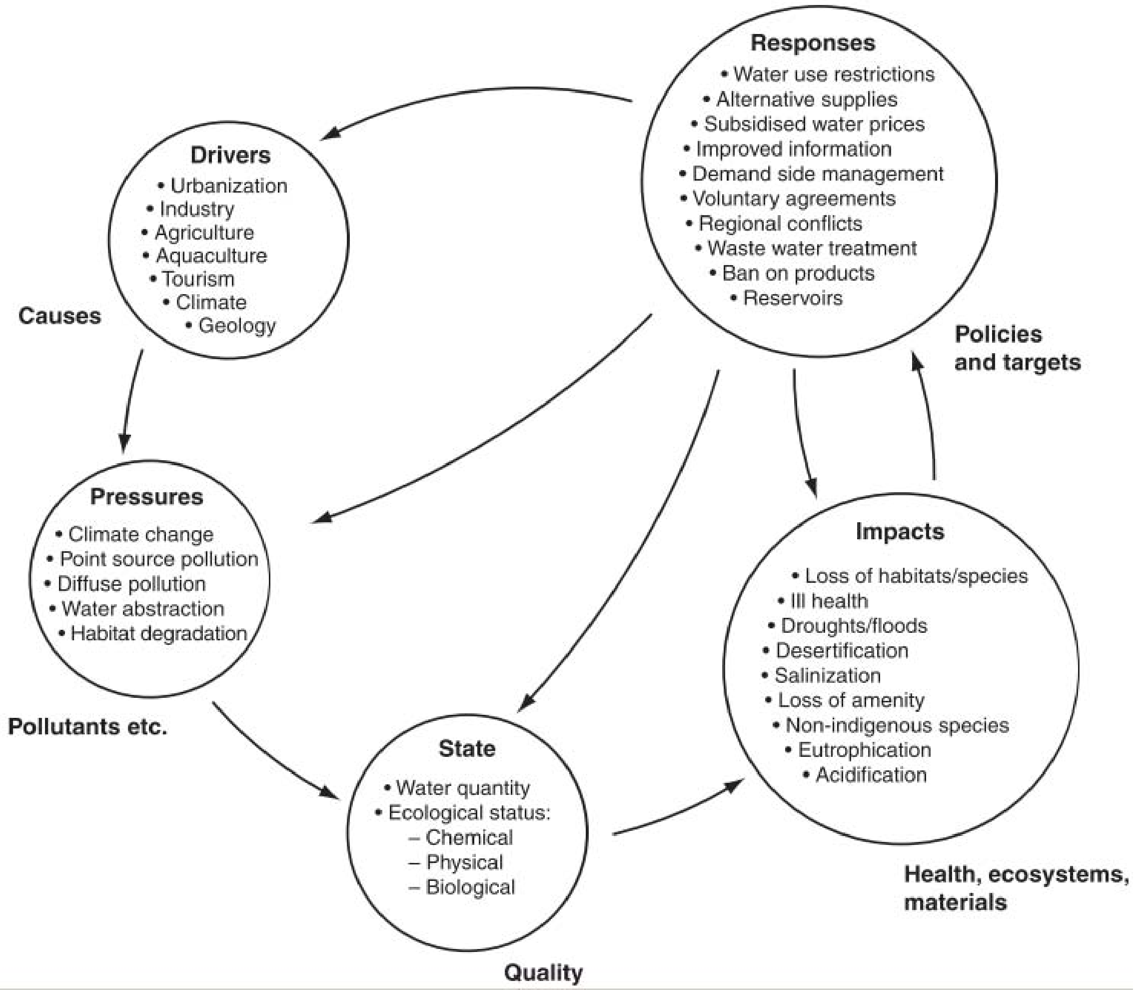


*Figure 1: The DPSIR framework promoted by the European Environment Agency as an analytical framework to assess water issues (adopted from Friberg, 2014).*

In contrast, the term 'pressure' is defined as a direct effect of a driver such as agricultural land use that causes e.g. point source pollution which impacts the state of the stream environment through changing, for example, water quality and ecological conditions (Friberg, 2010) and can put (multiple) stress on a system. A generic framework, i.e. 'Driver-Pressure-State-Impact-Response' (DPSIR) (figure 1) was promoted by the European Environment Agency (EEA, 1999) as an analytical structure for water issues and is integrated in the WFD assessment. It allows a comprehensive evaluation of issues through examination of relevant driving forces and pressures on the environment, the consequent state, its impacts, the resulting response, and of the linkages between each element in the framework (Friberg, 2014). The DPSIR framework is rarely utilized by applied scientists, who often use 'stress' and 'stressors' rather than 'pressure'. Thus, in the present work, I refer to pressures as stressors.

**Response of fish based indicators to stressors and current knowledge about the nature of multi-stressor-effects on biota**

Freshwater management needs sensitive indicators to measure ecosystem quality, as urgency for maintaining and restoring its integrity rises. Based on the idea of biotic integrity, an index was created by Karr (1981) (Index of Biotic Integrity, IBI) to evaluate the deviation of a population's condition from impacted to natural conditions. According to Culp et al. (2011), metrics are capable to analyse how human stressors and biota relate and interact, in order to differentiate human-induced disturbances and natural variability on different spatial scales. They build on trait-based bio-assessments, which seem better to reflect cause-effect patterns than taxonomically based methods (Archaimbault et al., 2010). Many metrics are based on the concept of ecological guilds. A guild defines a similar strategy of living in terms of habitat, reproduction, migration or feeding (Schiemer and Waidbacher, 1992). The metrics approach became very popular around the world and many metrics and indices were developed as indicators for the state of biotic integrity at different special scales (Bailey et al., 1998; Hering et al., 2006; Karr and Chu, 2000; Logez and Pont, 2011; Pont et al., 2006, Pont et al., 2009; Stoddard et al., 2008), such as the European Fish Index (EFI) in Europe (Fame Consortium, 2004; EFI+ Consortium, 2007) and the Austrian Fish index (FIA) (Haunschmid et al., 2006) on the national level.

Effects of hydromorphological changes on fishes as main indicator type of interest are complex and manifold. They include among others impacts on swimming performance, reduced juvenile fish recruitment, fish density, fish biomass or abundance due to altered resources in the ecosystem and in the worst case species disappearance (as described by Wolter et al., 2013 within the project REFORM[1]).

The current knowledge about multiple stressors and the related response of aquatic organisms is limited. Some authors addressed eutrophication, water chemistry and temperature in multi-stress analysis (e.g. Mantyka-Pringle et al., 2014; Weijters et al., 2009). However, there is still a lack in common and quantifiable understanding on multiple hydromorphological stress effects, such as morphological alterations, residual flow and connectivity disruption, hydropeaking and impoundments. Several studies on mostly different spatial scales found responses of fish assemblages to multi-stressor situations, including stressors combined with impoundments (Alonso et al., 2015; Marzin et al., 2012; Van Looy et al., 2014), connectivity disruption and thereby evoked habitat fragmentations by dams and barriers (Alonso et al., 2015; Falke et al., 2013; Van Looy et al., 2014), water abstractions and residual flow conditions (Lange et al., 2014), morphological alterations (Alonso et al., 2015; Marzin et al., 2012; Milly et al., 2008; Rolls et al., 2013; Van Looy et al., 2014) and hydropeaking (Schmutz et al., 2014; Vehanen, 2000). On the

[1] REFORM project (REstoring rivers FOR effective catchment Management); http://www.reformrivers.eu

European scale, Schinegger et al. (2013) and Trautwein et al. (2013) conducted first analyses, where the response of fish metrics to single and multiple stressors were investigated on a large and very general scale. This included hydromorphological-, connectivity- and water quality stressors, with some showing response dependent on various river types. Also scale plays a role in the response of biota to stressors as found by Mielach (2010) and Van Looy et al. (2014).

It is known that environmental factors as e.g. altitude, slope etc. influence the distribution of fish species and the implications accounting for ecosystem natural variability in the frame of biological assessment have been progressively outlined (Roset et al., 2007). Karr et al. (1986) first stressed the need to define the range of natural variability in stream fish assemblages, so that techniques to distinguish natural from anthropogenic variations can be developed. Roset et al. (2007) also state that this can be addressed by investigating relationships between a given metric and a descriptor of spatial variation, which is supposed to be among the main factors influencing fish assemblage organisation (e.g. river size, position within the longitudinal gradient). However, defining discrete ichthyo-regions and/or river types can also be considered, such as the zonation of riverine fish assemblages from the headwater to the mouth (Vannote et al., 1980), where fish species are associated with a specific fish zone. Within this concept, a type-specific biocenosis (Illies and Botosaneanu, 1963) e.g. trout-, grayling-, barbel- and bream zones correspond to a biocoenetic region (Epirhithral, Metarhithral, Hyporhithral, Epipotamal and Metapotamal) (sensu Huet, 1959), describing the longitudinal pattern of the composition of fish assemblages (Schmutz et al., 2000; Thienemann, 1925).

Another issue is the nature of multiple stressors, which is quite complex. In detail, additive effects on biota equal the sum of stressors' individual effects, synergistic interactions are present when multi-stressor effects exceed those of additive and antagonistic effects are lower than the sum of individual stressors (Crain et al., 2008; Folt et al., 1999). Only few studies take interactions of predictor variables into account (e.g. Lange et al., 2014; Roberts et al., 2013; Schmutz et al., 2014; Walters et al., 2013; Wenger et al., 2011), but this is ￼, but this is essential for efficient ecosystem management and restoration.

## 1.3. *The MARS project*

The project MARS (Managing Aquatic ecosystems and water Resources under multiple Stress)2 was funded by the European Union to support European water policies (e.g. the WFD) and was initiated to overcome knowledge gaps of multi-stressor effects on biota.

MARS operates at three spatial scales, the water body scale, the river basin scale and the European scale. There, impacts of stressors upon abiotic and biotic states, the mechanistic- and process understanding of stressor interactions and related influences on ecosystem services is examined. Within MARS, multiple stress conditions within 16 European River Basins, representing a wide range of regional characteristics, are analysed (work package 4). This thesis

[2] MARS project - funded by the European Union under the 7th Framework Programme, Contract No. 603378; http://www.mars-project.eu/index.php

[3] Sustainable Integrated Management of International River Corridors in SEE Countries; http://www.see-river.net

[4] Institut für Gewässerökologie, Fischereibiologie und Seenkunde; http://www.baw.at/index.php/igf-home.html

focuses on the Austrian Drava and Mura River Basins, a Central European case study of MARS dominated by hydromorphological alterations.

According to Ferreira et al. (2014), the aims of the river basin studies within MARS are:

- To characterize relationships between stressors, water quantity and quality, ecological responses, ecological functioning and ecosystem services.
- To test and validate these relationships in case-study river basins in different hydro-ecological and geo-climatic settings.
- To assess complex multi-stressor scenarios by testing and improving existing modelling techniques including full process-based models, simpler, linked process-based models and empirical/statistical models.
- To up-scale and generalize the results of the case studies, and demonstrate how the improved models can be used to guide RBMP and programmes of measures (PoM) for the WFD implementation.

To address multiple stressors, MARS introduced a conceptual and analytical framework (figure 2).

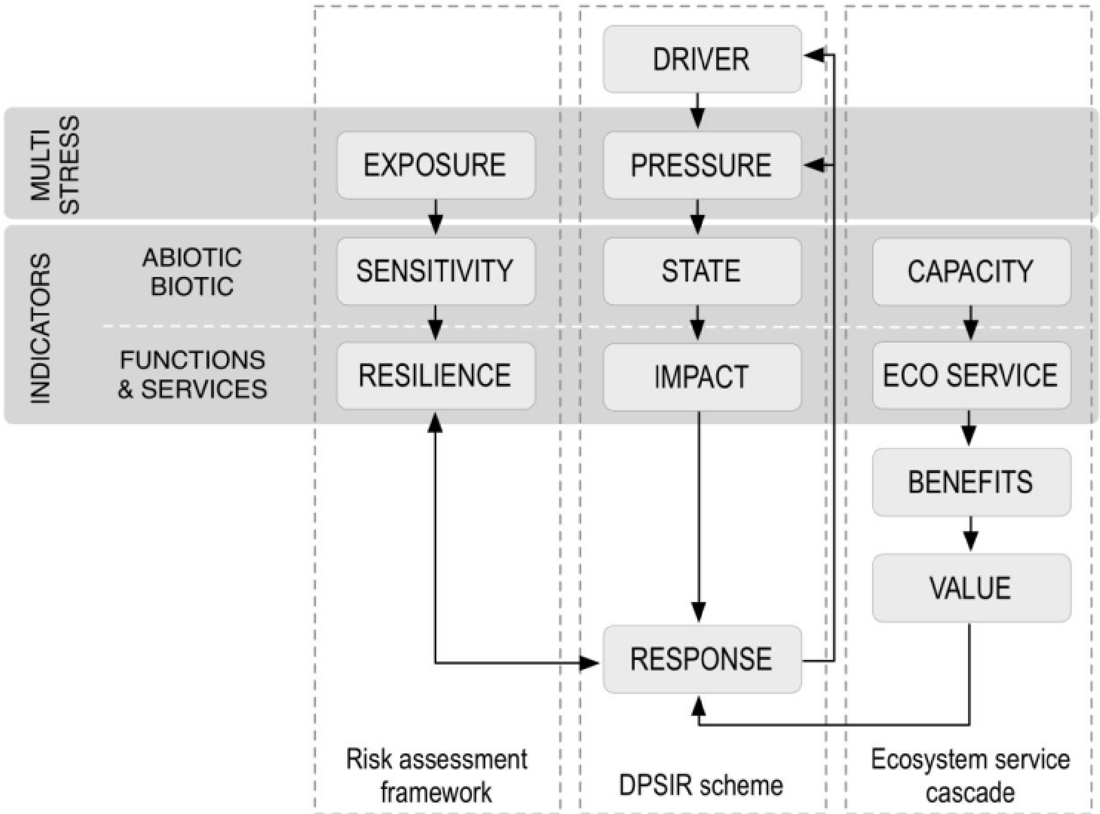


*Figure 2: The MARS conceptual model* (Hering et al., 2014).

This framework aims to provide required knowledge, understanding and tools on how stressors interfere and impact upon ecological status and ecosystem services. This is needed for developing effective RBMPs and shaping future environmental policies (Hering et al., 2014). The MARS conceptual model connects the risk assessment framework (i.e. the magnitude of stressors or combinations of single and multiple stressors) with the DPSIR scheme (i.e. response of the aquatic ecosystem) and with the concept of ecosystem services. The linkages between these frameworks are indicators, which are sensitive or resilient to stressors, ecosystem status and ecosystem capacity. The MARS conceptual model is implemented by the river basin case studies within MARS and subsequent within this thesis for the Austrian Drava and Mura River Basins (figure 3). The main idea is that drivers (D) (e.g. energy – hydropower production) cause pressures (P) (equivalent to stressors; e.g. dams, barriers and locks) and consequently affect water body state (e.g. connectivity loss, changes in the hydraulic regime – abiotic state), which impacts the ecosystem functioning (e.g. by reduction of fish biomass – biotic state). Consequently, ecosystem services are reduced and may demand for response through policies or management actions (R) (e.g. restoration). Within the MARS empirical models for the river basin approach, the focus of interest is on drivers, pressures (here stressors) as well as abiotic- and biotic states.

The results of river basin analyses are incorporated in other MARS work packages (WP), i.e.:

- Synthesizing stressors, scenarios and water management (WP 6).
- Developing stressor tools to support water resources management (WP 7).
- Supporting water managers and policy makers in the practical implementation of the WFD, related legislations and the Blueprint to Safeguard Europe's Water resources (WP 8).

To link stressors and indicators in this thesis, I used an empirical modelling approach for the Drava/Mura case study, based on the idea that the empirically observed levels of stress explain the response of the indicators.

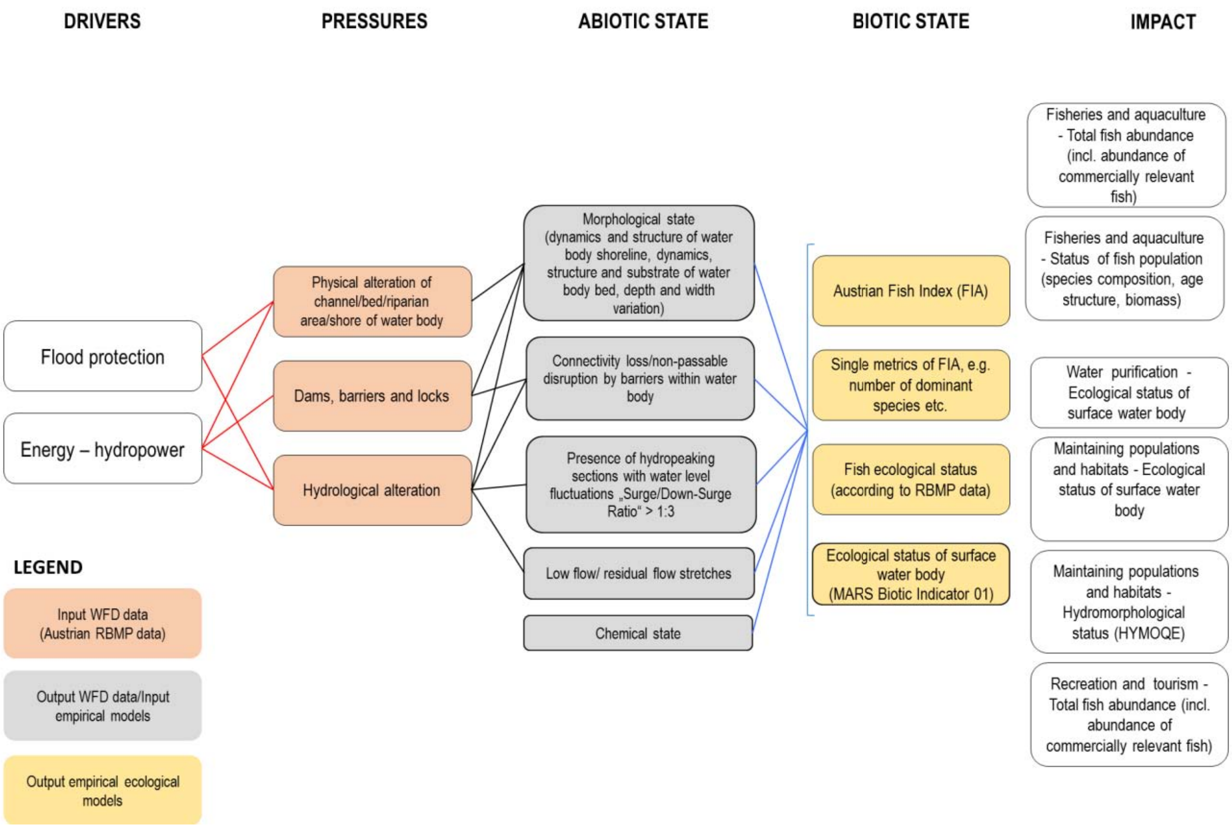


*Figure 3: MARS empirical model for the Austrian Drava/Mura River Basins.*

## 1.4. *Stressor situation in Austria and in the Drava and Mura River Basins*

In Austria, the last inventory assessment executed within the WFD implementation was carried out in 2013 (BMLFUW, 2013) and supported the most recent RBMP which was published in 2015 (BMLFUW, 2015). The inventory assessment aims at assessing the risk for each water body to fail the objective of the good ecological status in the years 2015, 2021 and 2027. This risk is defined by the results of a pressure assessment (compilation of pressures, in this thesis referred to as stressors), an impact assessment (evaluation of risk criteria by defining the impact of a stressor according to certain criteria) and by a risk assessment (verification of the impacts through a measured actual status of biota) (BMLFUW, 2013). The stressors assessed include physicochemical pollution (point source or diffuse source), hydromorphological alteration and other stressors, including invasive neobiota, predation, fishery and aquaculture, alterations of the sediment regime and climate change (BMLFUW, 2015).

In Austria, the inventory and status assessment revealed that in 2015, 49,4% of the Austrian surface water bodies river length fail the good ecological status and another 9,9% fail the good ecological potential (objective for water bodies designated as heavily modified and artificial according to the WFD) (BMLFUW, 2015).

Sources of risk are multiple – the risk for Austrian water bodies for 2021 is present as following: 21% due to residual flow, 8% due to impoundments, 2,8% due to hydropeaking, 32% due to morphological alterations, 46% due to connectivity disruption, 17% due to chemical point stressors and 25% due to chemical diffuse stressors. For Austria and especially the Drava and Mura River Basins, water quality issues are not priority in problems (Schmutz et al., 2008), as mainly multi-stress situations due to hydromorphological alterations occur (BMLFUW, 2015). Thus, hydromorphological stressors are the main focal issue of this thesis. They include hydrological alterations as hydropeaking, impoundment and residual flow (due to water abstraction). Further, morphological alterations and connectivity disruption due to migration barriers are here considered as hydromorphological stressors.

There is a long and huge interest in river restoration in various parts of Austria (summed up by Humpel, 2011; Kogler, 2008; Zitek et al., 2008) to improve ecological conditions. Especially in the Upper Drava River in the province of Carinthia (between Oberdrauburg and Spittal/Drau), multiple surveys and projects were conducted. These include the implementation of first river management concepts and multiple restoration measures, which are summarized in appendix a. For example, within the most recent project 'SEE River'[3], relevant outputs generated include a detailed concept of measures to be implemented at the Upper Drava River corridor ('Gewässerentwicklungskonzept') (Amt der Kärnter Landesregierung, 2014). However, within the scope of these projects and measures, specific knowledge on the effects of multiple stressors is lacking and thus has not been addressed in previous water management concepts.

Most recent studies which quantified the relationship between stressors and fish using national data revealed divergent responses of fish assemblages: In a first stressor-specific and multi-

[3] Sustainable Integrated Management of International River Corridors in SEE Countries; http://www.see-river.net

stressor analysis, Schmutz et al. (2008) identified land use, connectivity disruption, impoundment length and mean discharge among best predictors to describe the impact on fish assemblages. A specially strong response of fishes is visible for impoundments (Schmutz et al., 2010). In another thesis on "GIS-based Analyses of Pressure-Fish Relationships in Austrian Rivers on Different Spatial Scales", Mielach, (2010) confirms the reactiveness of fish metrics to different nationally identified stressors. Moreover, the development of the FIA is based on the evaluation of a set of hydromorphological stressor variables (Haunschmid et al., 2006). In my thesis, it is therefore interesting to see whether the actual data of the inventory assessment reaffirm these results for the FIA and its single metrics, as knowledge on most important influential variables is specifically important to identify priority of measures for hydromorphological restoration (Schmutz et al., 2010).

## *1.5. Research questions and hypotheses*

Based on the facts stated in the previous sections, this thesis aims to apply the MARS model and to identify the distribution and patterns of human stressors at the river basin scale. The focus is set on the Austrian Drava and Mura River Basins as an example for Alpine river catchments.

**This thesis aims to answer the following research questions:**

- Which distribution and patterns of stressors can be identified within the Austrian Drava and Mura River Basins?
  - Which stressor categories (single and multiple stressors) occur and which stressor quantities (no, single, multiple numbers of stressors) can be detected on a water body?
  - Where do stressors occur in terms of fish zone?
- How do these stressors affect fish based indicators and the ecological status?
- How does the factor 'fish zone' influence the response of fish based indicators and the ecological status?
- How do multiple stressors interact and is this reflected by the response of fish based indicators and the ecological status?

**These lead to the following hypotheses:**

- There is a response of fish based indicators and the ecological status to various stressors.
- The stressor category has an influence on the value of fish based indicators and on the ecological status (i.e. ecological integrity).
- With increasing stressor quantity, the value of fish based indicators and ecological status (representing ecological quality) changes.
- Beside stressors, the fish zone has an effect on the response of fish based indicators and the ecological status.
- Different stressors interact, this can be identified with fish based indicators and the ecological status.

# 2. Methods

## *2.1. Description of the study area*

The Austrian Drava and Mura River Basins are part of the Danube River Basin and comprise about 23.000 km² of size (12.800 km² and 10.300 km² each) (figure 4). The Mura River drains into the Drava River at the Croatian-Hungarian border. Both basins are located in the ecoregions Alps and Dinaric Western Balkan (Illies, 1978) and are representing the characteristics of Central European River Basins in MARS. The runoff of both river basins is mainly determined by nival, and glacial regimes in the Alps and by pluvial and pluvio-nival regimes in the Dinaric western Balkan regions (Fink et al., 2000).

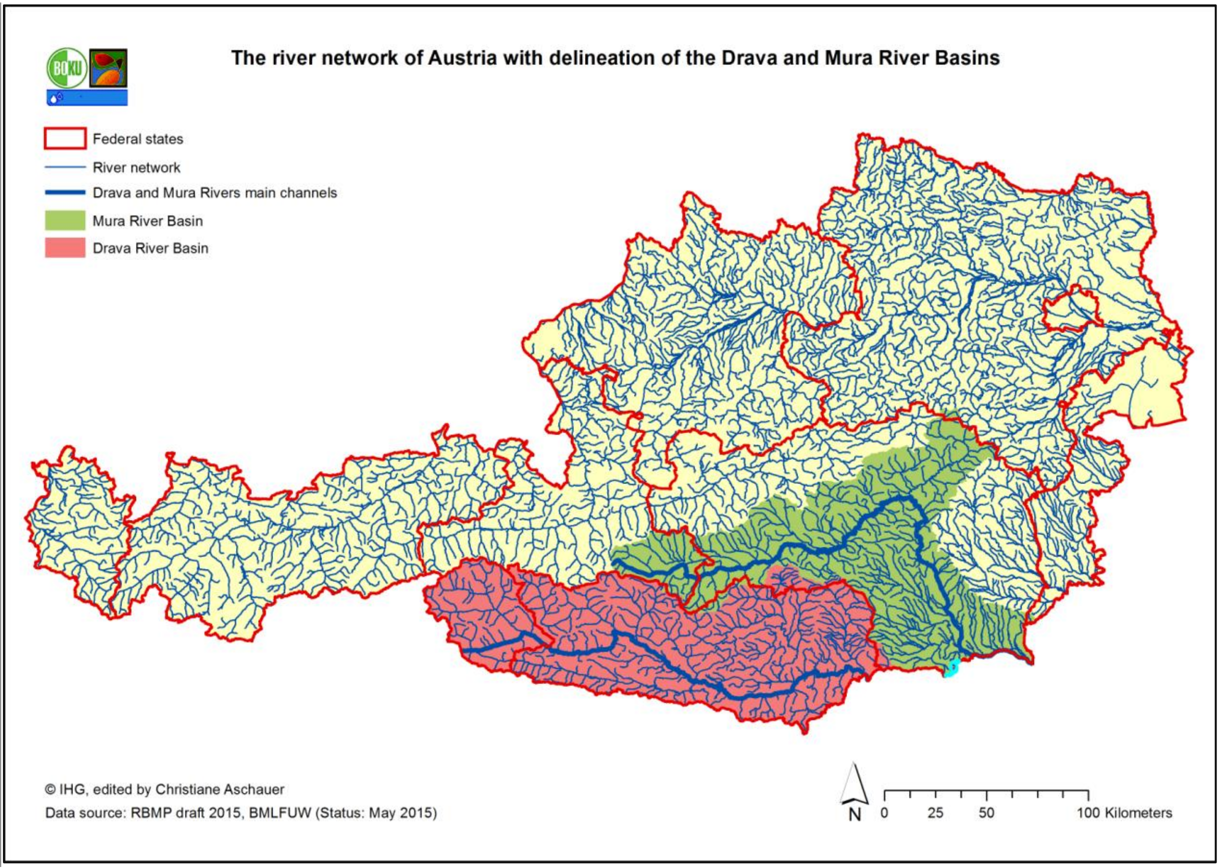


*Figure 4: The river network of Austria with delineation of the Drava and Mura River Basins.*

## *2.2. Environmental data*

The variable 'fish zone' gives information on the biocoenetic fish region and represents the fish species distributions over a longitudinal gradient of streams. This variable was derived from the RBMP dataset (BMLFUW, 2015; RBMP-DB, 2015). In the Fish Index Austria (FIA) methodology, fish zones are separated into multiple sub-regions (Epirhithral, Metarhithral, Hyporhithral small, Hyporhithral large, Epipotamal small, Epipotamal medium, Epipotamal large, Metapotamal). For the scope of the thesis, they were recombined to keep complexity manageable and to guarantee for a larger amount of fish sampling sites/water bodies per fish zone. Here, they comprise Epirhithral (1), Metarhithral (2), Hyporhithral (3) and Epipotamal (4).

## 2.3. *Stressor data*

The Drava and Mura River Basins include 2.419 water bodies out of the RBMP database, which are located within the natural or potential fish occurrence area as defined by the Quality Objective Ordinance Ecology (QZV Ökologie, 2010) and the RBMP database (RBMP-DB, 2015). Water bodies are the smallest units of the federal water management level and the scale of investigation of MARS and thus, in this thesis. After the general WFD classification (European Comission, 2000), water bodies are divided into inland waters (surface- and groundwater bodies) and transitional and coastal waters.

Surface water bodies are distinguished according to the WFD and the national RBMP (BMLFUW, 2015) in terms of their water body category (rivers versus lakes), physical and other distinctive features, state (based on the impact and risk evaluation) and whether they are highly modified or artificial water bodies.

For each water body, five hydromorphological stressors, i.e. 'residual flow' (R), 'morphological alteration' (M), 'connectivity disruption' (B), 'impoundment' (I) and 'hydropeaking' (H) were available in the Austrian RBMP database (RBMP-DB, 2015). These stressors were derived during the impact assessment ('Auswirkungsanalyse') carried out as part of the Federal Inventory Assessment 2013 ('Istbestandsanalyse 2013') for the 2$^{nd}$ Austrian RBMP. The stressors were coded in stressor intensity classes from A to D based on specific criteria (see table 1 and BMLFUW, 2013). Additionally, the stressor 'chemical status' (C) was derived from the Federal Inventory Assessment and the RBMP-database and coded in stressor intensity classes 1 to 3 (see table 1 and BMLFUW, 2013).

*Table 1: Stressor variables and criteria for impact assessment categories according to Mühlmann (2013) and translation into stressor classes used for this thesis.*

| Stressor intensity classes of the national impact assessment used in MARS model | Stressor classification used in stressor analysis | Stressors | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Impoundment (I) | | Hydropeaking (H) | | Residual flow (R) | Connectivity disruption (B) | Morphological alteration (M) | Chemical state (C)****** |
| | | River basin district <1.000km2 | River basin district >1.000km2 | Small & medium surface water bodies | Type "large rivers" | | Within fish habitat | | |
| **A (0)**<br>**No or very low impact** | **0**<br>**Less impacted** | No I | | No H | | No abstraction<br>or<br>abstraction according to QOO Ecology** §12 heel 2 | No B or passable without fish migration facility (e.g. ramp) | All 500m-sections within SWB = class 1***** | 1 |
| **B (1)**<br>**Low impact** | **0**<br>**Less impacted** | No I >500m & sum I <10% of surface water body (SWB) | | <1:3 or designated as "no significant H-impact"* | Very slight H or designated as "no significant H-impact"* | Abstraction with dotation order during full year or with dotation order during authorized abstraction period; according to QOO Ecology** §13 heel 2 values are met<br>or<br>abstraction at facilities authorized 1990-2010 according to specifications of ecological funcioning/good status | Limited passablility of B or B****passable due to fish migration facility & no additional non-passable length elements | <30% class 3-5***** | 2 |
| **C (2)**<br>**Possible significant impact** | **1**<br>**More impacted** | Single I 500-1.000m<br>or<br>sum of multiple I cover<br>10-30% of SWB | Single I 500-2.000m<br>or<br>sum of multiple I cover<br>10-30% of SWB | 1:3-1:5<br>or<br>H amplitude unnknown<br>or<br>designated as "significant H - present risk"* | Designated as "significant H - present risk"* | Abstraction with regulated dotation during the whole year or with regulated dotation within authorized period; values according to QOO Ecology** §13 heel. 2" are not met ***<br>or<br>abstraced dotation unknown | >=1 non-passable B | 30-70% class 3-5 & <30% class 4-5***** | 3 |
| **D (3)**<br>**Strong significant impact** | **1**<br>**More impacted** | Single I >1000m or sum of multiple I cover >30% of SWB | Single I >2000m or sum of multiple I cover >30% of SWB | >1:5<br>or<br>designated as "significant H - present risk"* | >each distinct flush<br>or<br>designated as "significant H - present risk"* | No or no dotation order during full year or no continuous dotation order during authorized abstraction period<br>or<br>water body sections, which fall dry due to insufficient dotation durich the whole year or during certain periods. | - | >70% class 3-5 or > 30% class 4-5***** | - |

* According to 'BOKU Hydropeakig-study' by Schmutz et. al (2013)
** Quality objective ordinance ecology
*** abstractions with MQRW < MJNQTnat or NQTRW < NQTnat
**** Barriers with functioning fish migration facilities and barriers with (possibly) limited passability
***** Classes according to 'Guidance on hydromorphological state assessment' by Mühlmann (2013)
****** Chemical status expressed in intensity classes 1-3 was selected instead of values proposed by impact assessment chemistry

## 2.4. Fish data

Fish sampling sites were available from the biocoenetic regions Epirhithral to Epipotamal (sensu Huet, 1959) (figure 5). Fish data were obtained from the 'Fish Database Austria' (FDBA) (FDBA, 2015), which is managed by the Institute for water ecology, fish biology and lake ecology (IGF)[4] of the Federal Office of Water management (BAW)[5]. It contains fish samples surveyed according to the decree on water body state survey (Gewässerzustandsüberwachungsverordnung, GZÜV). Fish sampling was conducted based on a standard sampling protocol (Haunschmid et al., 2010). Samples were available from years 2006 to 2014, which fits well to the stressor data, derived from Austrian RBMPs 2009 and 2015.

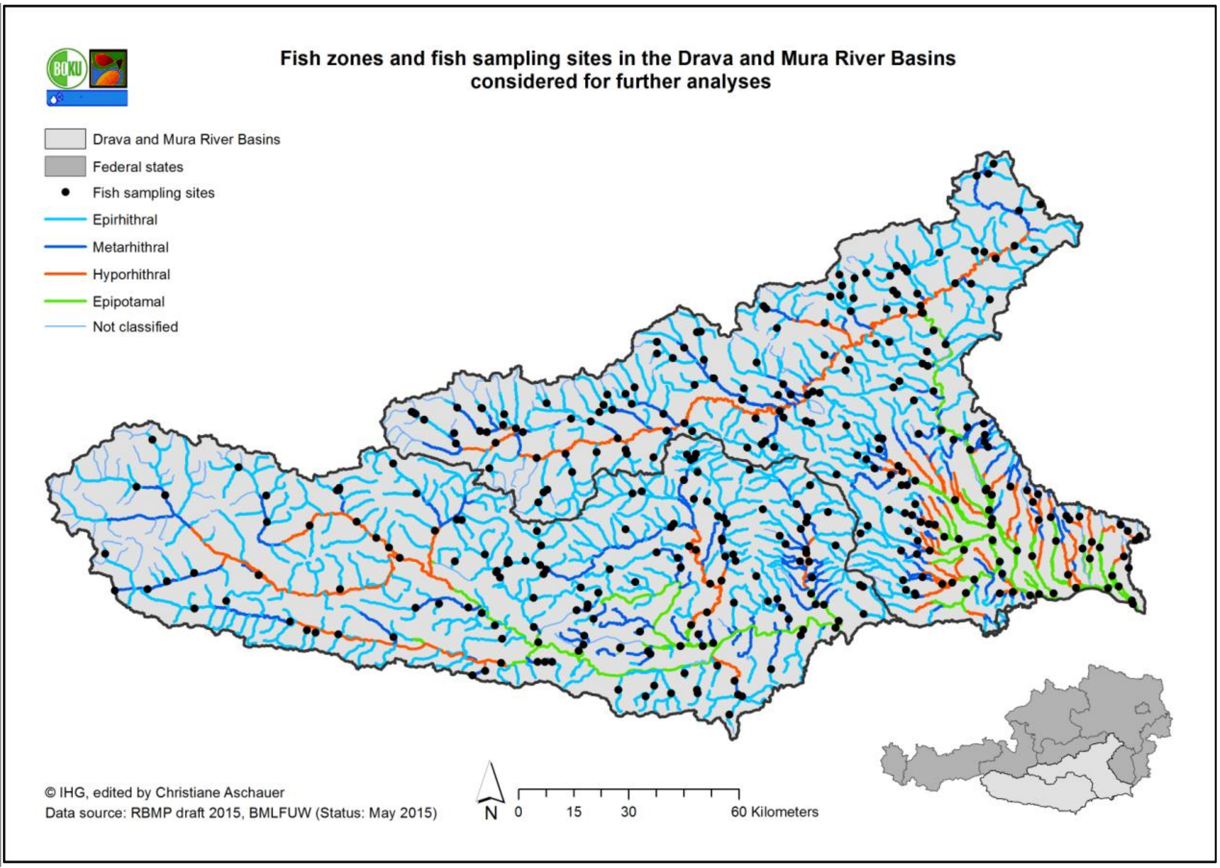


*Figure 5: Fish zones and fish sampling sites in the Drava and Mura River Basins considered for further analyses.*

The fish based indicators available for this thesis include the Fish Index Austria (FIA) and its single metrics, an IBI that was developed for the assessment of the fish-ecological status in Austria according to the WFD's needs. The FIA is composed of a number of core metrics. They include number of dominant species, number of subdominant species, number of rare species, number of habitat guilds (rheophil, limnophil, indifferent), number of reproductive guilds (lithophil, phytophil, psammophil), fish zonation index and population age structure of dominant and subdominant species (table 2). The assessment evaluation is based on the deviation between a predefined expected reference condition ('Leitbildkatalog' BAW IGF, 2015a) and the actual values observed (Haunschmid et al., 2006). Moreover, the fish biomass

[4] Institut für Gewässerökologie, Fischereibiologie und Seenkunde; http://www.baw.at/index.php/igf-home.html
[5] Bundesamt für Wasserwirtschaft; http://www.baw.at/

serves as 'knock-out' criterion, whereby sampling sites with less than 50 of 25 kg/ha are assigned to 'poor' or 'bad' ecological status, independent from the scores of the other metrics. The final FIA is calculated as weighted mean of grouped metrics (see table 2) ranging from WFD-class one (high status) to class five (bad status). A tool to calculate the FIA is provided by the IGF[6].

In addition to the FIA and related metrics described above, the final database for this thesis contains information on the number of occurring species (calculated as sum of actually caught dominant, subdominant and rare species) and the ecological state (derived from RBMP-DB) (see table 3 for a complete list of indicators). These variables were analysed in terms of their response to stressors and will later on be referred to as biotic indicators or fish based indicators and the ecological status.

*Table 2: Classification table for Austrian fish metrics.*

| Metric name | Metric ID | Evaluation class | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| Dominant species | %DS | 100% | 90-99 % | 70-89 % | 50-69 % | <50 % |
| Subdominant species | %SDS | 100-75% | 74-50% | 49-25% | <25% | 0 |
| Rare species | %RS | >49% | 49-20% | 19-10% | <10% | 0 |
| Habitat guilds | DEV_HG | none missing | 1 missing | 2 missing | > 2 missing | all missing |
| Reproductive guilds | DEV_RG | none missing | 1 missing | 2 missing | > 2 missing | all missing |
| Deviation Fish Zonation Index (FIZI) | DEV_FIZI | 0-0,3 | ≥0,3-0,6 | ≥0,6-0,9 | ≥0,9-0,1,2 | 1,2 |
| Age structure dominant species | AS_DS | 1 | 2 | 3 | 4 | 5 |
| Age structure subdominant species | AS_SDS | 1 | 2 | 3 | 4 | 5 |

The FDBA for Drava and Mura River Basins originally contained 525 fish samples at 465 sampling sites. The data had to undergo a filtering process, as multiple fish samples per water body and fish sampling site (of different years) occurred. This was performed in a stepwise procedure and selection was chosen as following:

1) A data extract from the RBMP-DB in January 2016 gave information on the fish samples, which were selected for the evaluation of the hydromorpholgical status evaluation (GZÜV-ID in field 'ZUST_BIOLOGIE_HYDROM_2015_MESSUNG' of table 'Monstertabelle'). The respective sample was selected as final sample for the associated water body (160 samples).
2) For remaining water bodies and fish samples, the samples with most recent date were selected (186 samples and unique sampling sites per water body).
3) A random selection function in R was used for selecting unique fish samples for the remaining water bodies (26 out of 58 samples).

Finally, 372 fish samples associated with a unique sampling site and linked to a unique water body remained for further analysis (figure 5).

[6] http://www.baw.at/index.php/igf-download/1692-fia-berechnungsfile.html

*Table 3: Description of biotic indicators (FIA metrics and other indicators) considered in this thesis.*

| Trait category | Indicator abbreviation | Description | Measurable indicator reaction with increasing stressor | N | Median (Range) |
|---|---|---|---|---|---|
| | | **FIA metrics** | | | |
| Biocoenosis | %DS | Percentage dominant species - fish species must occur in particular bioregion/biocoenetic region in high relative frequency | decrease | 372 | 100 (0-100) |
| Biocoenosis | %SDS | Percentage subdominant species - fish species must occur in particular bioregion/biocoenetic region in medium relative frequency | decrease | 372 | 0 (0-100) |
| Biocoenosis | %RS | Percentage rare species - fish species can occur in particular bioregion/biocoenetic region in low relative frequency | decrease | 372 | 0 (0-100) |
| Biocoenosis | EVAL_DS | Evaluation of dominant species | increase | 372 | 1 (1-5) |
| Biocoenosis | EVAL_SDS | Evaluation of subdominant species | increase | 372 | 1 (0-5) |
| Biocoenosis | EVAL_RS | Evaluation of rare species | increase | 372 | 3 (0-5) |
| Reproductive guild | DEV_RG | Deviation of actual present number of reproductive guilds from reference | increase | 372 | 1 (0-5) |
| Reproductive guild | EVAL_RG | Evaluation of the reproductive guilds | increase | 372 | 2 (1-5) |
| Trophic guild | BM | Biomass in kg/ha of native species and rainbow trout | decrease | 372 | 69.1 (0-1664,0) |
| Habitat guild | DEV_HG | Deviation of actual present number of habitat guilds from reference | increase | 372 | 0 (0-4) |
| Habitat guild | EVAL_HG | Evaluation of habitat guilds | increase | 372 | 1 (1-5) |
| Biocoenetic region | DEV_FIZI | Deviation of actual fish zonation index from reference | increase | 372 | 0,1 (0-5.7) |
| Age structure | AS_DS | Evaluation of length-frequency diagram of actual present dominant species | increase | 372 | 1 (0-10) |
| Age structure | AS_SDS | Evaluation of length-frequency diagram of actual present subdominant species | increase | 372 | 0 (0-9) |
| Age structure | EVAL_AS_DS | Evaluation of length-frequency diagram of actual present dominant species | increase | 372 | 2,3 (1-5) |
| Age structure | EVAL_AS_SDS | Evaluation of length-frequency diagram of actual present subdominant species | increase | 372 | 3,5 (1-5) |
| Age structure | AS | Total evaluation of population age structure of dominant and subdominant species | increase | 372 | 3 (1-5) |
| Guilds | GUILDS | Total evaluation of habitat guilds and reproductive guilds | increase | 372 | 1,5 (1-5) |
| Dominance | DOMIN | Total evaluation of dominance expressed by FIZI | increase | 372 | 1 (1-5) |
| Species | SPEC | Total evaluation of percent of dominant, subdominant and rare species | increase | 372 | 3 (1-5) |
| Species composition | SPCOM | Total evaluation of species composition evaluated by SP and GUILDS | increase | 372 | 1,9 (1-5) |
| | | **Other indicators** | | | |
| | ES | Ecological status of water body | increase | 329 | 3 (1-5) |
| | FIA | Fish Index Austria | increase | 372 | 2,5 (1-5) |
| | NSP | Total number of species caught at site | increase, decrease | 372 | 2 (0-26) |

## 2.5. *Distribution and patterns of single and multiple stressors in water bodies*

To perform an analysis on distribution and patterns of single and multiple stressors, original stressor intensity classes from the national impact assessment were recoded according to the following scheme:

- Intensity classes A and B were associated with value 0 (less impacted)
- Intensity classes C and D were associated with value 1 (more impacted)

In a second step, stressors classified as '1/more impacted' were summed up and combined into two new variables for each water body - these are 'Stressor category' and 'Stressor quantity' (for an example see table 4). Stressor category shows the occurrence of single and multiple stressors. Stressor quantity informs whether no, single, or multiple (double, triple, fourfold, fivefold) stressors occur at a water body. The analysis on stressor distribution and patterns was performed for all water bodies of the Drava and Mura River Basins (2.419 water bodies) and separately for those water bodies where fish sampling sites were available (372 water bodies). From here on, the Drava and Mura River Basins are referred to as 'total basin'.

*Table 4: Description of stressor variable recoding and calculation of the new variables 'Stressor category and 'Stressor quantity'.*

| Water body ID | Stressors | | | | | | | | | | | | Stressor category | Stressor quantity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | M | | I | | R | | H | | B | | C | | | |
| | IA | 01 | IA | 01 | IA | 01 | IA | 01 | IA | 01 | IA | 01 | | |
| 902340003 | C | 1 | B | 0 | C | 1 | A | 0 | C | 1 | A | 0 | MxRxB | 3 |

M… Morphological alterations; I… Impoundment; R… Residual flow; H… Hydropeaking;
B… Connectivity disruptions; C… Chemical status
IA… Stressor intensity class of the national impact assessment
01… Classification as less (0) and more (1) impacted

The variable recoding and calculation process was performed with statistical software R version 3.1.3 (R Development Core Team, 2015), graphs were plotted using the 'ggplot2' package (Wickham, 2009), the geospatial analysis was executed using ESRI's ArcGIS 10.2.2 software (ESRI, 2011).

## 2.6. *Response of fish assemblages to multiple stressors*

The selected modelling approach is based on the MARS cookbook[7], which was developed to give guidance for MARS analysis of multiple stressors and to guarantee a common strategy for reaching the MARS objectives. It proposes a stepwise procedure by applying Boosted Regression Trees (BRTs), Random Forest (RF) and Generalized Linear Models (GLMs) for quantifications of the stressor-response relationships.

In this thesis, the analytical approach to investigate the relationship between human stressors

[7] Preparation for the WP4 data analysis workshop in Tulcea, Romania: a cookbook for analysing the response of benchmark indicators to multiple stressors (unpublished, contributors: Pedro Segurado, Christian Feld, Cayetano Gutierrez-Canovas, Lindsay Banin, 2015)

and fish assemblages (as biotic indicators) was divided into two parts (see figure 6).

First, a descriptive analysis of the relationship between the variables 'Stressor category, 'Stressor quantity' and selected indicators was conducted with the use of boxplots.

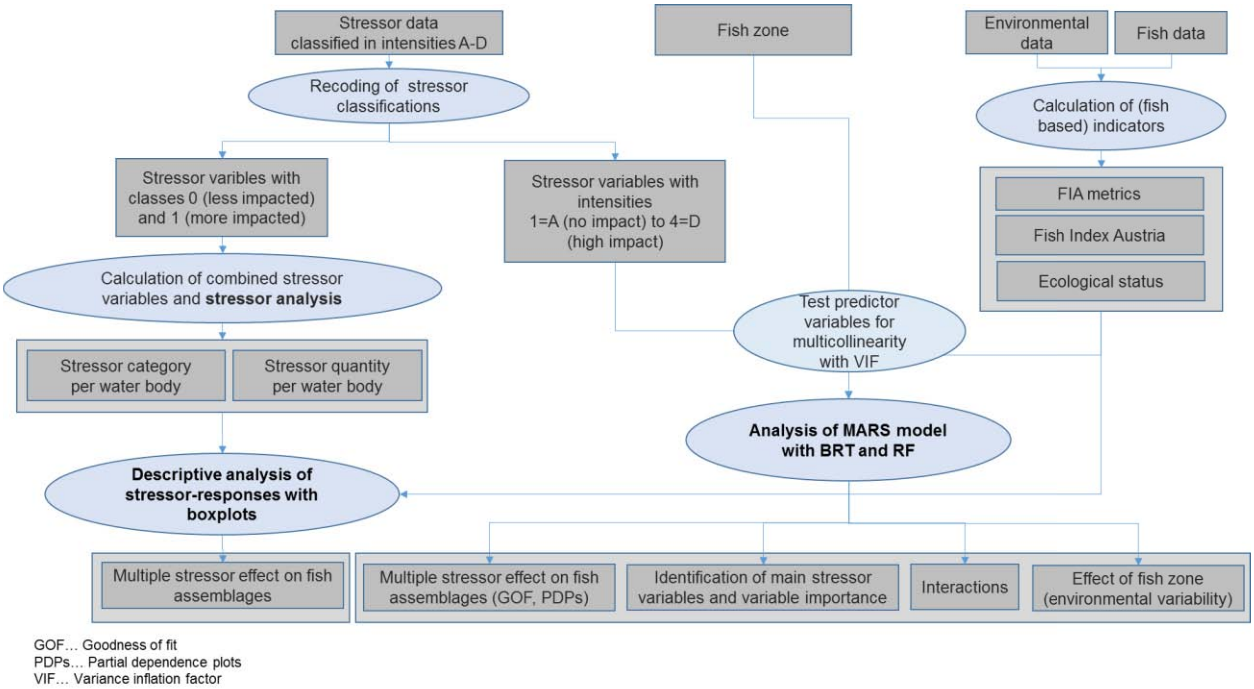


*Figure 6: Analytical design for this thesis including the analysis of stressor distribution and patterns, the descriptive analysis of the relationship between variables 'stressor category, 'stressor quantity' and selected indicators and the analysis to implement the MARS model for Drava and Mura River Basins.*

Statistical methods for modelling stressor-indicator relationships are manifold and include among others rather descriptive explanations without quantifications of multiple impacts (Cunjak et al., 2013; Schinegger et al., 2013). Machine learning approaches such as BRTs (Clapcott et al., 2012), conditional tree forest models (Nelson et al., 2009), Bayesian belief networks (Mantyka-Pringle et al., 2014; Roberts et al., 2013) and linear models are frequently applied. They include general linear models (De Zwart et al., 2006; Lange et al., 2014; Van Looy et al., 2014) and linear and logistic regressions (e.g. Johnson et al. 2009; Ayllón et al. 2009; Wenger et al. 2011; Walters et al. 2013). An advantage of machine learning methods such as BRTs and RF (Breiman, 2001) is that they can handle mixed normal, categorical and continuous predictor variables. Further, they allow missing values in the data, no transformations are required (parametric data), outliers are accepted, interaction effects between predictors are handled, and non-linear relationships are also allowed (Elith et al., 2008; Mercier et al., 2011). However, ecological hypothesis testing in order to relate empirically and observed phenomena to explanatory variables (such as stressor effects on biota) is supposed to be more suitable with regression-based analytical tools, such as GLMs (Argillier et al., 2014).

Thus, the second part of my analytical approach addresses the MARS modelling framework. Within MARS, BRTs aim to identify the stressor's hierarchy in the dataset as well as interactions of stressors. The variable hierarchy (in terms of ranking and contribution to the overall variance explained) is important, as it later on affects the ranking and selection of stressor variables to be included in the GLM.

In contrast, the benefit or running RF is that it may further contribute understanding the hierarchy of stressors. The outputs of BRTs and RF measure the contribution of multiple predictor variables to one single output variable and the goodness of fit (GOF) (% variance explained). Additionally, interaction terms and plots of the fitted function (partial dependence) are derived from the BRT model. Partial dependence plots (PDPs) show the fitted response of indicators to predictors. They give guidance on shape of fitted surface and are available as boxplots, as predictors in this thesis are categorical and ordinal data. They are showing the values of response variables that have been predicted by models and were fitted to the dataset. This enables to identify patterns of metric responses and can therefore help to set potential thresholds at which the metric value sharply changes (Feld et al., 2016; Hering et al., 2013). For further details on BRTs, see Breiman 2001; Friedman 2001; Elith et al. 2008; Elith and Leathwick 2016.

Before running BRTs and RF, the variance inflation factor (VIF) as a descriptor of collinearity among predictor variables was calculated for further variable selection. This index measures the extent of increase in variance of an estimated regression coefficient due to collinearity. To be on the safe side, the threshold was set at >8, as collinearity imposes serious flaw upon a regression model if the descriptors show a VIF >10 (Zuur et al., 2007).

For BRT, two models were then run:

- Model 1 examined the response of indicators to all six stressor variables (H, M, C, B, I, R see table 1) giving information on the suitability to indicate ecosystem integrity (Karr, 1991).
- Model 2 adds the variable fish zone (FIZ) to the set of stressor variables as predictor to explore the effect of natural variability.

For BRT analysis, model parameters were set as follows:

- Tree complexity was fixed at level 2, as it sets the order of interactions.
- The learning rate determines the weight applied to individual trees and was tuned for each model assuring that at least 1000 trees were fitted.
- The bag fraction is the proportion of observations, which are used for the model when selecting variables. It was set to level 0.5.
- The response variable's family type was selected according to their nature as 'Gaussian' for continuous and as 'Poisson' for count data.

For RF analysis, model parameters were set as following:

- A forest of 2000 trees was built according to the cumulative out-of-bag (OOB) error rate.
- The maximum depth allowed for a tree was set at 5 (nodedepth).
- The number of variables per level was set at 3 (mtry).

Analyses were performed in R version 3.1.3 (R Core Team, 2015) using the 'gbm' package of Ridgeway (2013) for BRTs and RF was carried out using the 'randomForestSRC' package of

Ishwaran and Kogalur (2014). The MARS empirical modelling approach includes a quantification of multiple stressor effects on biotic indicators by running GLMs. This study accounts for a preliminary and exploratory analysis to quantify stressor-response relationships with the most recent Austrian RBMP-data with BRTs and RF. Running GLMs is thus not part of this thesis, as complexity would surmount the scope of this present work. However GLMs will be included in a following step in the implementation of the MARS model.

# 3. Results

## 3.1. *Distribution and patterns of single and multiple stressors in water bodies*

### Occurrence of single stressors

The RBMP-DB includes data on single stressor intensities (figure 7) that were aggregated to categories 'less impacted' (class 0) and 'more impacted' (class 1) (figure 8). In the total basin, water bodies were mostly affected by connectivity disruptions (B) in 293 water bodies. Morphological alterations (M) were detected in 153 water bodies and water abstractions (leading to residual flow sections, R) in 127 water bodies. In only a few cases, category 'more impacted' was present in water bodies with fish sampling sites: For hydropeaking (H) 11 water bodies, for impoundment (I) 22 water bodies and for the chemical status (C) 4 water bodies.

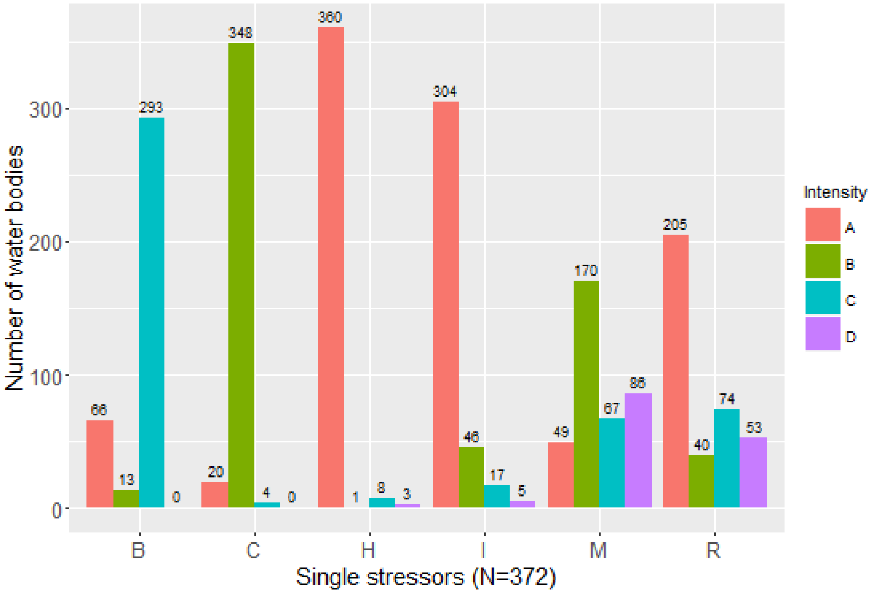


*Figure 7: Frequency of water bodies with related fish sampling sites and the occurrence of single stressor intensities.*

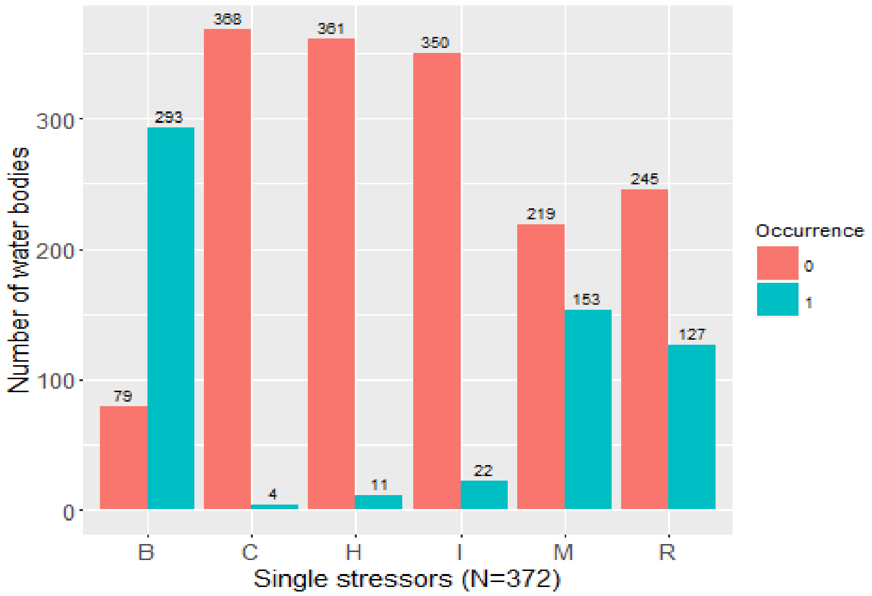


*Figure 8: Frequency of water bodies with related fish sampling sites and the occurrence of single stressor intensities).*

**Distribution and patterns of variable 'Stressor category'**

The conducted descriptive analysis revealed that 28% of water bodies in the Drava and Mura River Basins are impacted by single, 27% by multiple stressors and only 44% face no or lower human stress (noS) (table 5). Among the water bodies where fish were sampled, only 9% are under low or no stress and 91% are significantly or highly impacted (according to the stressor intensity classes of the national impact assessment, see also table 1).

In both river basins, 28 stressor categories (single and multiple stressors) are observed, whereas in water bodies with fish sampling sites, 26 stressor categories are present. There are however only five categories of single and multiple stressors which occur in at least 20 water bodies (without and with related fish sampling sites). These include the single stressors connectivity disruption (B), morphological alterations (M) and the multiple stressor categories morphological alteration combined with connectivity disruption (MB), connectivity disruption combined with residual flow (BR) as well as morphological alteration combined with connectivity disruption and residual flow (MBR).

In the following description of results, the focus is set on the distribution and patterns of stressors within water bodies of the total basin, presenting the stressor situation (first value). The second value after the slash informs on results for water bodies where fish sampling sites were available.

In terms of fish zone, a large majority of water bodies are situated in zone Epirhithral 1.815/195. The fish zone Metarhithral represents 380/88 water bodies, the Hyporhithral 155/44 and the Epirhithral 95/43 water bodies. For the five most frequently occurring categories of single and multiple stressors, the following patterns were found: In Epirhithral, connectivity disruption (B) as single stressor is dominating with an occurrence of 23%/35% of the water bodies. This is followed by a combination of connectivity disruption and residual flow (BR) with 10%/15% occurrence and connectivity disruption combined with morphological alteration (MB) in 11%/25% of water bodies. In Metarhithral, also connectivity disruption (B) dominates with 18%/23% of water bodies affected, combined morphological alteration and connectivity disruption (MB) occur in 16%/24% and connectivity disruption combined with residual flow (BR) in 9%/20% of water bodies. For Hyporhithral, the patterns change with 17%/23% of water bodies affected by morphological alterations combined with connectivity disruption (MB), only 15%/9% by connectivity disruption (B), 14%/18% by morphological alteration (M) and 8%/11% by connectivity disruption combined with residual flow (BR). In Epipotamal, 24/26% of water bodies are affected by morphological alteration combined with connectivity disruption (MB), 17%/14% by single morphological alteration (M) and 11%/12% by connectivity disruption (B) only.

Water bodies affected by connectivity disruption (B) and connectivity disruption combined with residual flow (BR) decrease from Epirhithral to Epipotamal. Numbers of water bodies impacted by morphological alteration (M) only or combined with connectivity disruption (MB) increase. An overall combination of connectivity disruption together with morphological alteration and residual flow (MBR) are most present in Metarhithral (7%/13%) and Hyporhithral

(5%/7%). Water bodies with no or low stress can be found to 48%/12% in the Epirhithral, in 36%/2% of Metarhithral, in 35%/2 of Hyporhithral and in 28%/19% of Epipotamal. Thus, more water bodies are classified as less impacted upstream than downstream.

Figure 9 shows the spatial location of the most frequently occurring stressor categories in water bodies where fish were sampled.

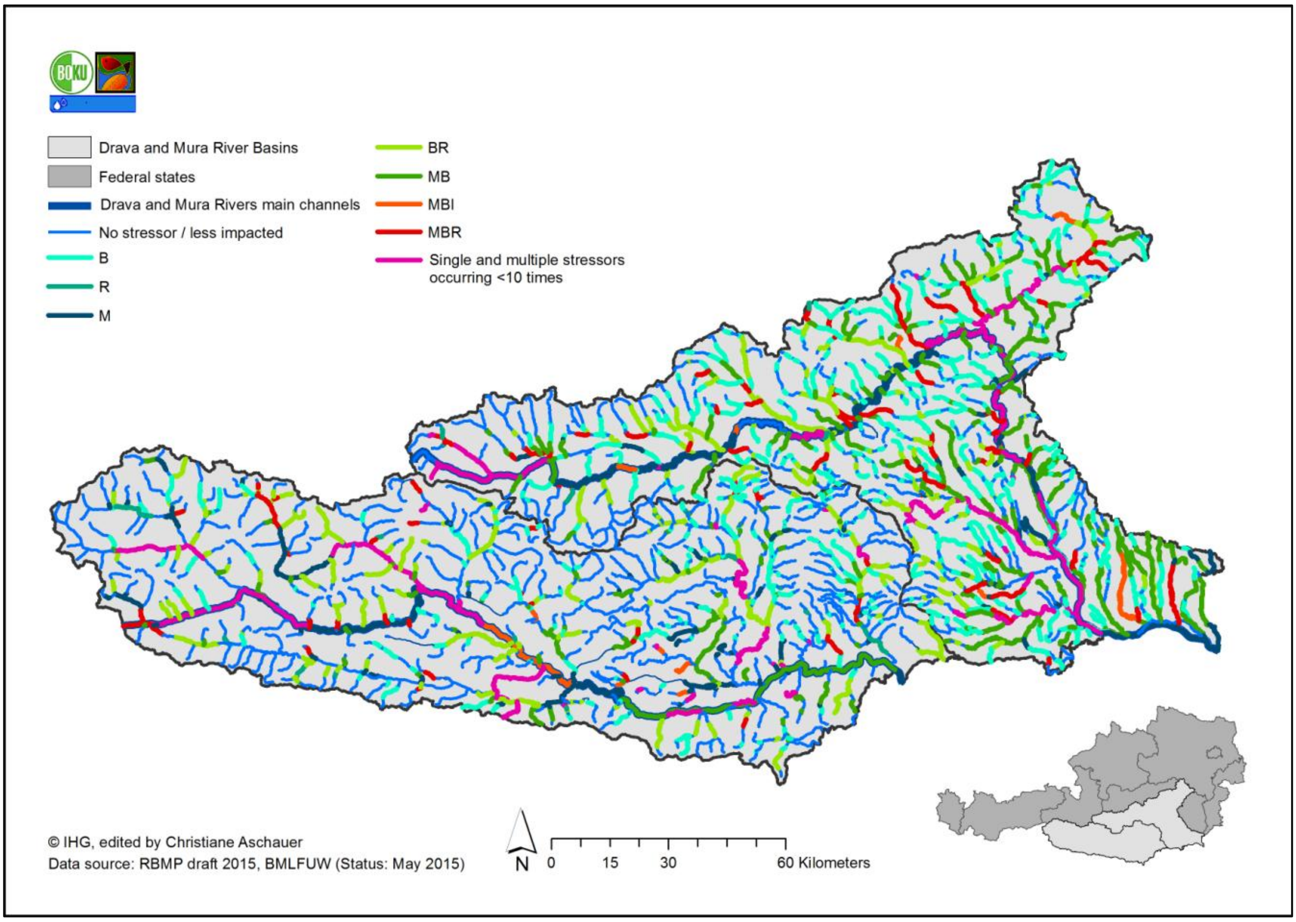


*Figure 9: Water bodies affected by different stressor categories in the Drava and Mura River Basins.*

**Distribution and patterns of variable 'Stressor quantity'**

In the total basin, up to 5 stressors co-occur at a water body. When analysing the stressor quantity, clear patterns could be observed for all water bodies of the total basin/water bodies with fish sampling sites available: One or two stressors per water body are most frequently present and account together for 51%/76% of the cases. Three to five stressors per water body account for only 6/14% percent. The analysis of the total basins' water bodies showed the following distribution and patterns: The proportion of less impacted sites (i.e. low number of stressor quantity) decreases from Epirhithral to Epipotamal (from 48% to 28%). In water bodies where fish sampling sites are located, less impacted water bodies are most present in Epirhithral and Epipotamal (31% together) and only few less impacted water bodies are present in Meta- and Hyporhithral (4%). The proportion of water bodies affected by single and double stressors account for the largest amount and approximately remain the same between fish zones (22-32%/30-34%). The occurrence of threefold stressors was most frequently observed in

Metarhithral, mostly due to the stressor category MBR. Four- and fivefold stressors are very rare, only 16/10 water bodies are affected by this stressor quantity.

Figure 10 shows the spatial location of the most frequently occurring stressor quantities in water bodies where fish were sampled.

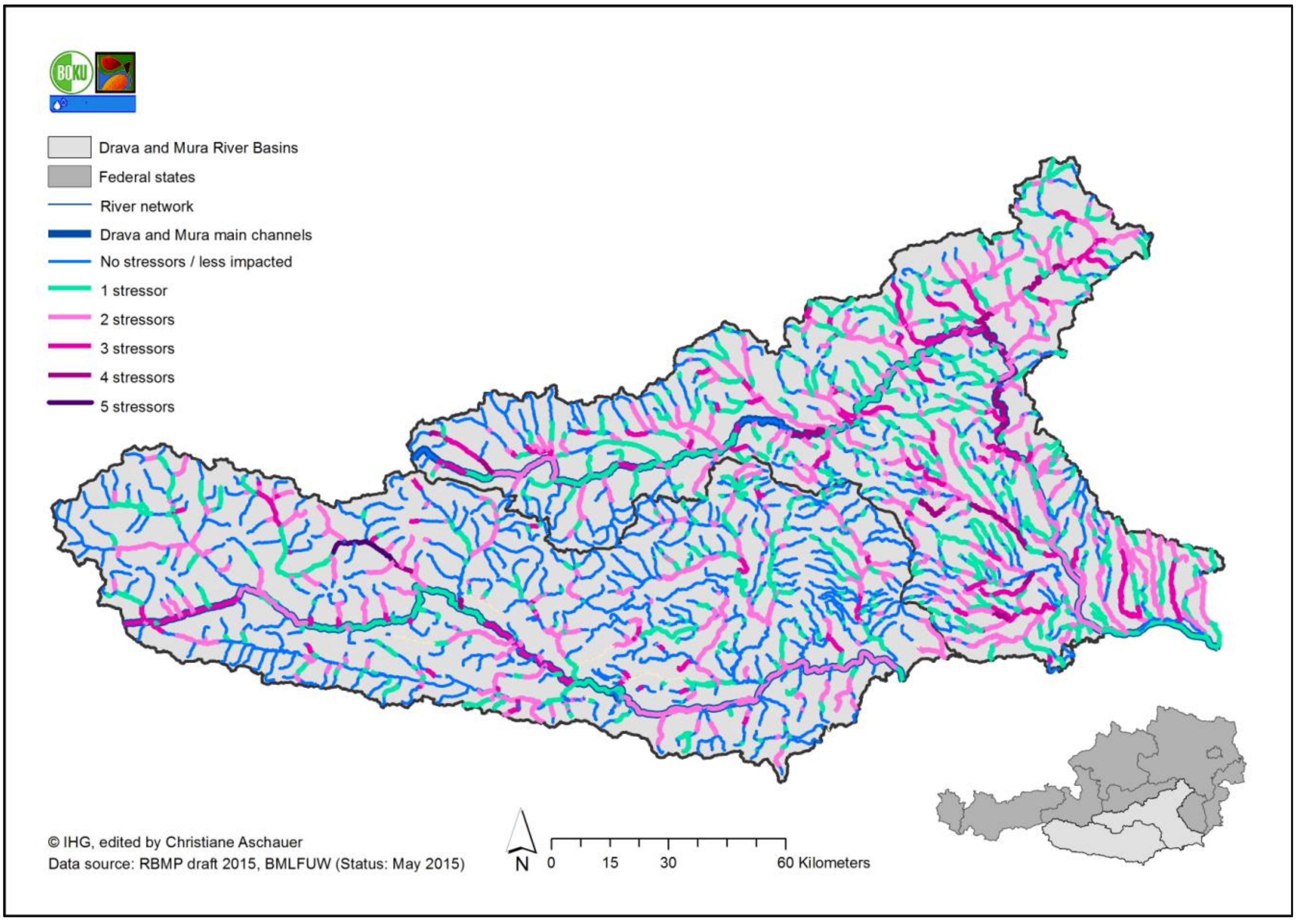


*Figure 10: Water bodies affected by different stressor quantities in the Drava and Mura River Basins.*

Additional maps are available in appendix b.

Tables 5 and 6 show the results of the stressor analysis. They give information on the number and percentage of water bodies of the total basin/water bodies with fish sampling sites affected by different stressor categories and quantities. Results were separated by sub-basin, fish zone and drainage area.

*Table 6: Number and percentage of water bodies affected by different stressor categories for all water bodies of the total basin/water bodies with fish sampling sites and separated by sub-basins Mura and Drava, fish zone and drainage area. Values in bold mark categories occurring more than 20 times in total.*

| Stressor category | Total catchment | | | | | | | | | | | | | | | | | Sampling sites | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total | | Mura | Drava | EpiR | | MetaR | | HypoR | | EpiP | | < 10 km² | 10 - 100 km² | 101 - 1000 km² | 1001 - 10000 km² | no asignment | Total | | Mura | Drava | EpiR | | MetaR | | HypoR | | EpiP | | < 10 km² | 10 - 100 km² | 101 - 1000 km² | 1001 - 10000 km² |
| | N | % | N | N | N | % | N | % | N | % | N | % | N | N | N | N | N | N | % | N | N | N | % | N | % | N | % | N | % | N | N | N | N |
| **noS** | **1065** | **44** | **377** | **688** | **822** | **48** | **135** | **36** | **39** | **25** | **27** | **28** | **2** | **24** | **5** | **2** | **0** | **34** | **9** | **9** | **25** | **23** | **12** | **2** | **2** | **1** | **2** | **8** | **19** | **2** | **24** | **5** | **2** |
| **B** | **507** | **21** | **318** | **189** | **387** | **23** | **70** | **18** | **24** | **15** | **10** | **11** | **11** | **76** | **11** | **1** | **1** | **99** | **27** | **55** | **44** | **69** | **35** | **20** | **23** | **4** | **9** | **5** | **12** | **11** | **76** | **11** | **1** |
| **M** | **116** | **5** | **43** | **73** | **50** | **3** | **26** | **7** | **21** | **14** | **16** | **17** | **2** | **8** | **9** | **4** | **1** | **23** | **6** | **14** | **9** | **2** | **1** | **7** | **8** | **8** | **18** | **6** | **14** | **2** | **8** | **9** | **4** |
| R | 17 | 1 | 3 | 14 | 11 | 1 | 1 | 0 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 0 | 1 | 6 | 2 | 1 | 5 | 3 | 2 | 0 | 0 | 0 | 0 | 2 | 5 | 2 | 2 | 2 | 0 |
| H | 5 | 0 | 4 | 1 | 0 | 0 | 2 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 1 |
| I | 5 | 0 | 2 | 3 | 1 | 0 | 1 | 0 | 2 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 1 |
| C | 5 | 0 | 0 | 5 | 3 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 1 |
| **MB** | **283** | **12** | **196** | **87** | **171** | **10** | **59** | **16** | **27** | **17** | **23** | **24** | **3** | **60** | **8** | **1** | **2** | **72** | **19** | **58** | **14** | **30** | **15** | **21** | **24** | **10** | **23** | **11** | **26** | **3** | **60** | **8** | **1** |
| **BR** | **241** | **10** | **97** | **144** | **190** | **11** | **36** | **9** | **12** | **8** | **2** | **2** | **4** | **45** | **21** | **2** | **2** | **72** | **19** | **35** | **37** | **48** | **25** | **18** | **20** | **5** | **11** | **1** | **2** | **4** | **46** | **21** | **2** |
| MI | 7 | 0 | 6 | 1 | 2 | 0 | 0 | 0 | 2 | 1 | 3 | 3 | 0 | 0 | 1 | 3 | 2 | 4 | 1 | 4 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 7 | 0 | 0 | 1 | 3 |
| MR | 7 | 0 | 0 | 7 | 3 | 0 | 3 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 2 | 1 | 0 | 2 | 0 | 0 | 1 | 1 | 1 | 2 | 0 | 0 | 0 | 0 | 1 | 1 |
| BI | 6 | 0 | 2 | 4 | 2 | 0 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| MH | 4 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 4 | 3 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 2 | 5 | 0 | 0 | 0 | 0 | 1 | 1 |
| MC | 2 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| RC | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **MBR** | **97** | **4** | **60** | **37** | **57** | **3** | **26** | **7** | **8** | **5** | **3** | **3** | **0** | **19** | **11** | **0** | **3** | **30** | **8** | **23** | **7** | **15** | **8** | **11** | **13** | **3** | **7** | **1** | **2** | **0** | **19** | **11** | **0** |
| MBI | 14 | 1 | 7 | 7 | 2 | 0 | 8 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 0 | 0 | 3 | 4 | 1 | 1 | 3 | 1 | 1 | 2 | 2 | 0 | 0 | 1 | 2 | 2 | 2 | 0 | 0 |
| MIR | 4 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 2 | 1 | 3 | 3 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 2 | 5 | 0 | 0 | 2 | 1 |
| BRC | 8 | 0 | 0 | 8 | 7 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 3 | 2 | 1 | 0 | 2 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| MBH | 3 | 0 | 2 | 1 | 1 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 3 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| BIR | 3 | 0 | 1 | 2 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 3 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| BHR | 2 | 0 | 2 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 3 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| MIH | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 3 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 1 | 0 |
| MBIR | 9 | 0 | 8 | 1 | 1 | 0 | 1 | 0 | 5 | 3 | 2 | 2 | 0 | 1 | 2 | 2 | 4 | 5 | 1 | 5 | 0 | 1 | 1 | 0 | 0 | 2 | 5 | 2 | 5 | 0 | 1 | 2 | 2 |
| MBRC | 3 | 0 | 0 | 3 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 4 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| MBHR | 2 | 0 | 2 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 2 | 0 | 4 | 2 | 1 | 2 | 0 | 0 | 0 | 1 | 1 | 1 | 2 | 0 | 0 | 0 | 0 | 2 | 0 |
| MIHR | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 4 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 1 |
| MBIHR | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 5 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 1 | 0 |
| **Sum** | **2419** | **100** | **1137** | **1282** | **1715** | **100** | **380** | **100** | **155** | **100** | **95** | **100** | **26** | **241** | **82** | **22** | **67** | **372** | **100** | **215** | **157** | **195** | **100** | **88** | **100** | **44** | **100** | **43** | **100** | **26** | **242** | **82** | **22** |

N…Total number of sites, %...Percentage of total sites, MUR…Mura, DRA…Drava, EpiR…Epirhithral, MetaR…Metarhithral, HypoR…Hyporhithral, EpiP…Epipotamal
noS…no/low stressor, B…Connectivity disruption, M…Morphology, R…Residual flow, H…Hydropeaking, I…Impoundment, C…Chemical status
Combined capital letters…multi-stressor situation e.g. MI…impact by morphological alterations and impoundment occur at water body

*Table 5: Number and percentage of water bodies affected by different stressor quantities for all water bodies of the total basin/water bodies with fish sampling sites and separated by sub-basins Mura and Drava, fish zone and drainage area. Values in bold mark categories occurring more than 20 times in total.*

| Stressor quantity | Total catchment | | | | | | | | | | | | | | | | | Sampling sites | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Total | | Mura | Drava | EpiR | | MetaR | | HypoR | | EpiP | | < 10 km² | 10 - 100 km² | 101 - 1000 km² | 1001 - 10000 km² | no asignment | Total | | Mura | Drava | EpiR | | MetaR | | HypoR | | EpiP | | < 10 km² | 10 - 100 km² | 101 - 1000 km² | 1001 - 10000 km² |
| | N | % | N | N | N | % | N | % | N | % | N | % | N | N | N | N | N | N | % | N | N | N | % | N | % | N | % | N | % | N | N | N | N |
| **0** | **1065** | **44** | **377** | **688** | **822** | **48** | **135** | **36** | **39** | **25** | **27** | **28** | **2** | **24** | **5** | **2** | **0** | **34** | **9** | **9** | **25** | **23** | **12** | **2** | **2** | **1** | **2** | **8** | **19** | **2** | **24** | **5** | **2** |
| **1** | **655** | **27** | **370** | **285** | **452** | **26** | **101** | **27** | **50** | **32** | **30** | **32** | **15** | **86** | **22** | **8** | **6** | **131** | **35** | **70** | **61** | **74** | **38** | **27** | **31** | **15** | **34** | **13** | **30** | **15** | **86** | **22** | **8** |
| **2** | **551** | **23** | **303** | **248** | **371** | **22** | **102** | **27** | **46** | **30** | **28** | **29** | **7** | **105** | **33** | **8** | **16** | **153** | **41** | **99** | **54** | **78** | **40** | **41** | **47** | **19** | **43** | **15** | **35** | **7** | **107** | **32** | **8** |
| **3** | **132** | **5** | **77** | **55** | **68** | **4** | **39** | **10** | **12** | **8** | **7** | **7** | **2** | **25** | **16** | **1** | **24** | **44** | **12** | **30** | **14** | **19** | **10** | **16** | **18** | **4** | **9** | **5** | **12** | **2** | **24** | **17** | **1** |
| 4 | 15 | 1 | 10 | 5 | 2 | 0 | 3 | 1 | 7 | 5 | 3 | 3 | 0 | 1 | 5 | 3 | 16 | 9 | 2 | 7 | 2 | 1 | 1 | 2 | 2 | 4 | 9 | 2 | 5 | 0 | 1 | 5 | 3 |
| 5 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 5 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 1 | 0 |
| **Sum** | **2419** | **100** | **1137** | **1282** | **1715** | **100** | **380** | **100** | **155** | **100** | **95** | **100** | **26** | **241** | **82** | **22** | **67** | **372** | **100** | **215** | **157** | **195** | **100** | **88** | **100** | **44** | **100** | **43** | **100** | **26** | **242** | **82** | **22** |

N…Total number of sites, %...Percentage of total sites, MUR…Mura, DRA…Drava, EpiR…Epirhithral, MetaR…Metarhithral, HypoR…Hyporhithral, EpiP…Epipotamal

## *3.2. Response of fish assemblages to multiple stressors*

**Descriptive analysis of the relationship between human stressors and fish assemblages**

In terms of fish assemblage response to stressors, figures 11 to 13 show the response of three selected fish based indicators 'population age structure' (EVAL_AS), 'Fish Index Austria' (FIA), 'ecological status' (ES) to the aggregated stressor variables 'Stressor category' and 'Stressor quantity' representing the occurrence of single and multiple stressors.

The indicators respond in a similar way to 'Stressor category' and 'Stressor quantity. For single stressors, the strongest results can be observed for residual flow (R) followed by morphological alteration (M) and for stressor category morphological alteration combined with connectivity disruption, impoundment and residual flow (MBIR). Here, most values are associated with evaluation classes 3 and 4. Connectivity disruption (B) alone doesn't seem to change the indicator value compared to category less impacted (noS) with a median between evaluation class 2 and 3. Water bodies affected by stressor categories connectivity disruption combined with residual flow (BR), morphological alteration combined with connectivity disruption (MB) as well as morphological alteration combined with connectivity disruption and residual flow (MBR) have a wide value range from the 1st to 3rd quartile of the box for these indicators. Ecosystem integrity decreases (higher values on x axis) with increasing stressor quantity.

Boxplots for all biotic indicators are available in appendix c.

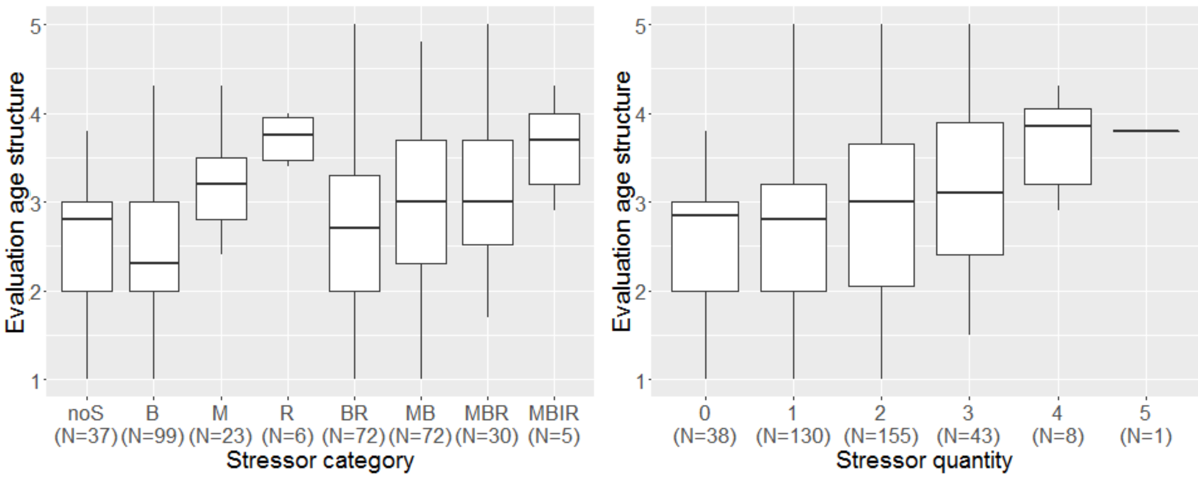


*Figure 11 a and b: Response of indicator 'population age structure' (AS) to variables 'Stressor category' and 'Stressor quantity'.*

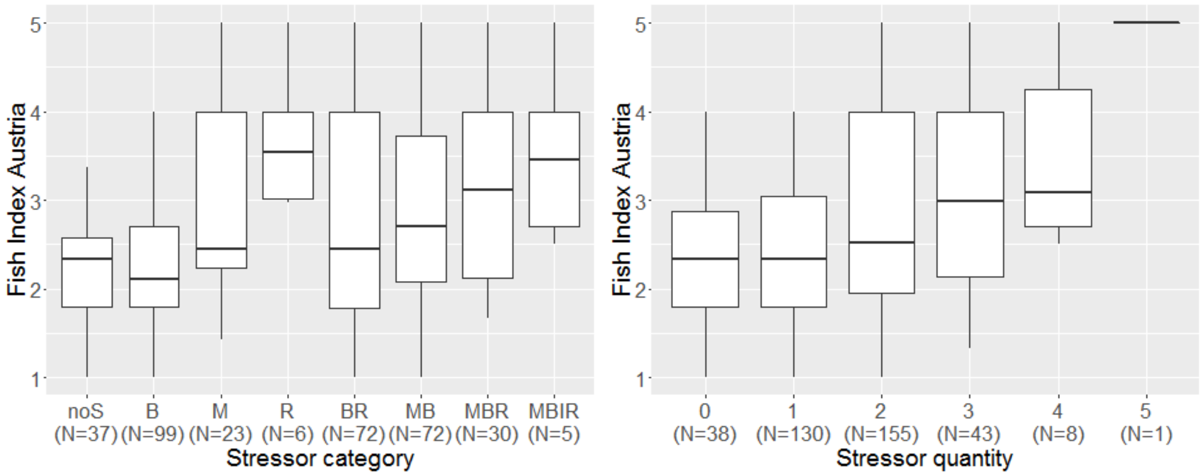


*Figure 12 a and b: Response of indicator 'Fish Index Austria' (FIA) to variables 'Stressor category' and 'Stressor quantity'.*

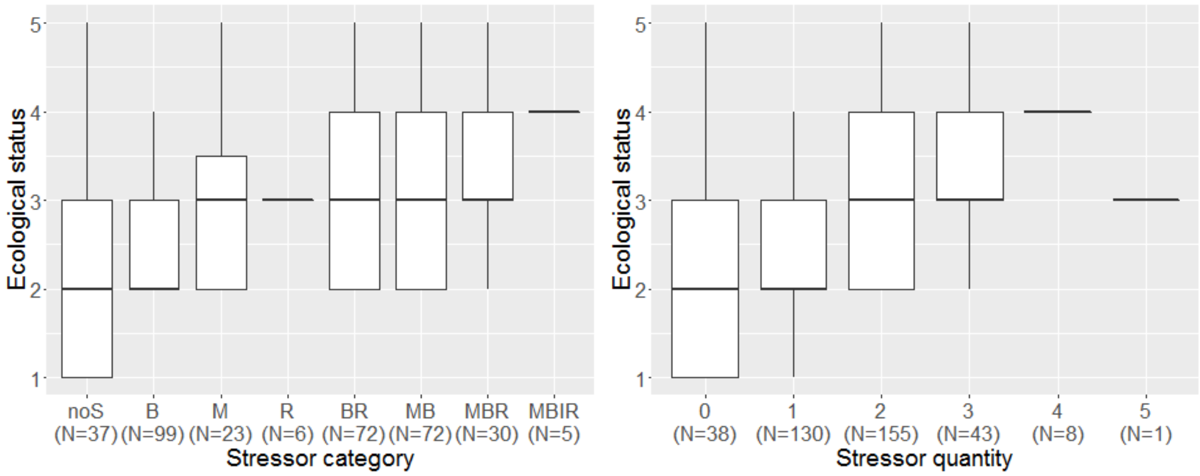


*Figure 13 a and b: Response of indicator 'ecological status' (ES) to variables 'Stressor combination' and 'Stressor quantity'.*

**Analysis of the relationship between multiple human stressors and fish assemblages following the MARS modelling approach**

The outputs of the Random Forest (RF) analysis (table 7) include the goodness of fit and the ranked variable importance. These criteria were used to select indicators to be further investigated by Boosted Regression Trees (BRTs) in the next step. I chose indicators that were most promising in terms of goodness of fit (highest values).

RF and BRT ranked variable importance (VIMP) of 'ecological status' (ES) 'Fish Index Austria' (FIA) and 'age structure of dominant and subdominant species' (AS_DS, AS_SDS) were in compliance for the three most important variables. In 'age structure' (AS) this was the case the first and second important predictors. The comparison of Goodness of Fit (GOF) between the two methods revealed, that BRTs always exceeded the results of RF. This observation was also made among the other MARS river basins (as discussed during a modelling workshop in Lisbon in December 2015). This is why a common agreement on focusing on the results of BRTs arose.

*Table 7: Results of the Random Forest model indicating goodness of fit, ranked variable importance (VIMP) and if indicator was selected for Boosted Regression Tree analysis.*

| Indicator | Goodness of fit | Ranked VIMP | In BRT models | Indicator | Goodness of fit | Ranked VIMP | In BRT models |
|---|---|---|---|---|---|---|---|
| BM | -1,4 | I,R,C,H,C,M | | AS_DS | 20,4 | B,I,M,R,C,H | x |
| %DS | -1,0 | R,M,C,B,H,I | | AS_SDS | 26,0 | B,I,M,R,C,H | x |
| EVAL_DS | 2,8 | R,M,H,B,C,I | x | EVAL_AS_DS | 5,7 | M,R,C,B,I,H | x |
| %SDS | 0,5 | M,I,C,B,H,R | | EVAL_AS_SDS | 13,0 | M,I,C,H,B,R | x |
| EVAL_SDS | 5,6 | M,C,I,H,R,B | x | SP | -0,4 | R,M,H,I,B,C | |
| %_RS | -4,1 | C,B,H,M,R,I | | GUILDS | 4,1 | R,B,M,I,H,C | x |
| EVAL_RS | -3,0 | I,H,B,C,R,M | | SPCOM | 3,9 | R,M,H,I,B,C | x |
| DEV_HG | 4,5 | M,H,B,C,I,R | x | DOM | 0,9 | R,B,M,H,I,C | |
| EVAL_HG | -0,1 | M,R,B,C,H,I | x | AS | 10,9 | M,R,C,B,I,H | x |
| DEV_RG | 13,7 | I,B,H,M,R,C | x | FIA | 5,4 | M,R,C,B,I,H | x |
| EVAL_RG | 8,0 | I,B,R,H,M,C | x | ES | 22,2 | R,C,M,I,B,H | x |
| DEV_FIZI | -2,8 | R,M,B,C,I,H | x | | | | |

M…Morphological alteration, B…Connectivity disruption, R…Residual flow, I…Impoundment, H…Hydropeaking, C…Chemical status

In total, 16 biotic indicators were analysed in two BRT models (table 8 and Appendix d and e). The variance explained by predictors ranged from 9,2% to 34,8% in model 1 (without variable fish zone), and from 13,7% to 76,9% in model 2 (including variable fish zone). The inclusion of variable fish zone increased the percentage of variance explained for almost all indicators (model 2 versus model 1) (figure 15 and table 8). For example, the percentage of variance explained almost doubled such as for 'population age structure of dominant species' (AS_DS) from 34,8% to 76,9%. For metrics 'deviation of habitat guilds' (DEV_HG) and 'evaluation of habitat guilds' (EVAL_HG), the goodness of fit increased from about 10% to over 50%. For metrics 'evaluation subdominant species' (EVAL_SDS), 'ecological status' (ES), 'population age structure' (AS) and 'evaluation age structure dominant species' (EVAL_AS_DS), only a slight increase in explained variance was observed. On average, the explained variance for age structure metrics (AS_DS, AS_DSD, EVAL_AS_DS, EVAL_AS_SDS, AS) was higher compared to the other FIA metrics in model 1.

*Table 8: BRT results with percentage of explained variance, variable importance of the three most important predictors and interactions for model 1 (all stressors as predictors) and model 2 (all stressors plus fish zone as predictors).*

| | | Model 1 | | | Model 2 | | |
|---|---|---|---|---|---|---|---|
| **Indicator** | **Direction of reaction** | **%** | **VIMP** | **Interactions** | **%** | **VIMP** | **Interactions** |
| EVAL_SDS | increase | 9,4 | M(65), R(18), I(11) | | 13,7 | FIZ(46), M(35), R(12) | |
| DEV_RG | increase | 15,1 | I(55), B(17), M(15) | | 34,5 | FIZ(67), I(13), R(10) | |
| EVAL_RG | increase | 16,1 | I(43), R(21), B(21) | | 32,4 | FIZ(68), R(12), I(10) | |
| DEV_HG | increase | 9,2 | M(63), B(13), I(12) | | 69,8 | FIZ(90), M(3), I(3) | |
| EVAL_HG | increase | 10,1 | M(48), R(31), B(9) | | 53,5 | FIZ(83), R(9), M(5) | |
| GUILDS | increase | 14,0 | M(30), R(27), I(23) | | 38,6 | FIZ(78), R(11), M(6) | |
| DEV_FIZI | increase | 10,0 | R(47), M(34), I(13) | | 15,3 | FIZ(75), R(14), M(7) | |
| AS_DS | increase | 34,8 | M(37), B(27), I(24) | BxM | 76,9 | FIZ(82), M(9), B(5) | |
| AS_SDS | increase | 29,6 | I(45), B(33), M(18) | BxM | 62,4 | FIZ(81), B(8), I(7) | |
| EVAL_AS_DS | increase | 12,9 | M(39), R(33), I(12) | | 16,1 | FIZ(54), R(19), M(18) | |
| EVAL_AS_SDS | increase | 17,4 | M(63), I(16), R(10) | | 32,2 | FIZ(67), M(20), R(6) | FIZxM |
| AS | increase | 20,3 | M(41), R(30), I(11) | RxM | 21,9 | FIZ(51), M(22), R(19) | |
| SPCOMP | increase | 14,2 | M(35), R(33), I(19) | | 27,4 | FIZ(71), R(15), M(9) | |
| FIA | increase | 10,9 | M(40), R(26), C(13) | | 18,1 | FIZ(61), R(17), M(14) | |
| ES | increase | 30,0 | R(39), M(34), C(19) | | 34,9 | R(31), FIZ(22), M(22) | |

M…Morphological alteration, B…Connectivity disruption, R…Residual flow, I…Impoundment,
H…Hydropeaking, C…Chemical status, FIZ…Fish zone

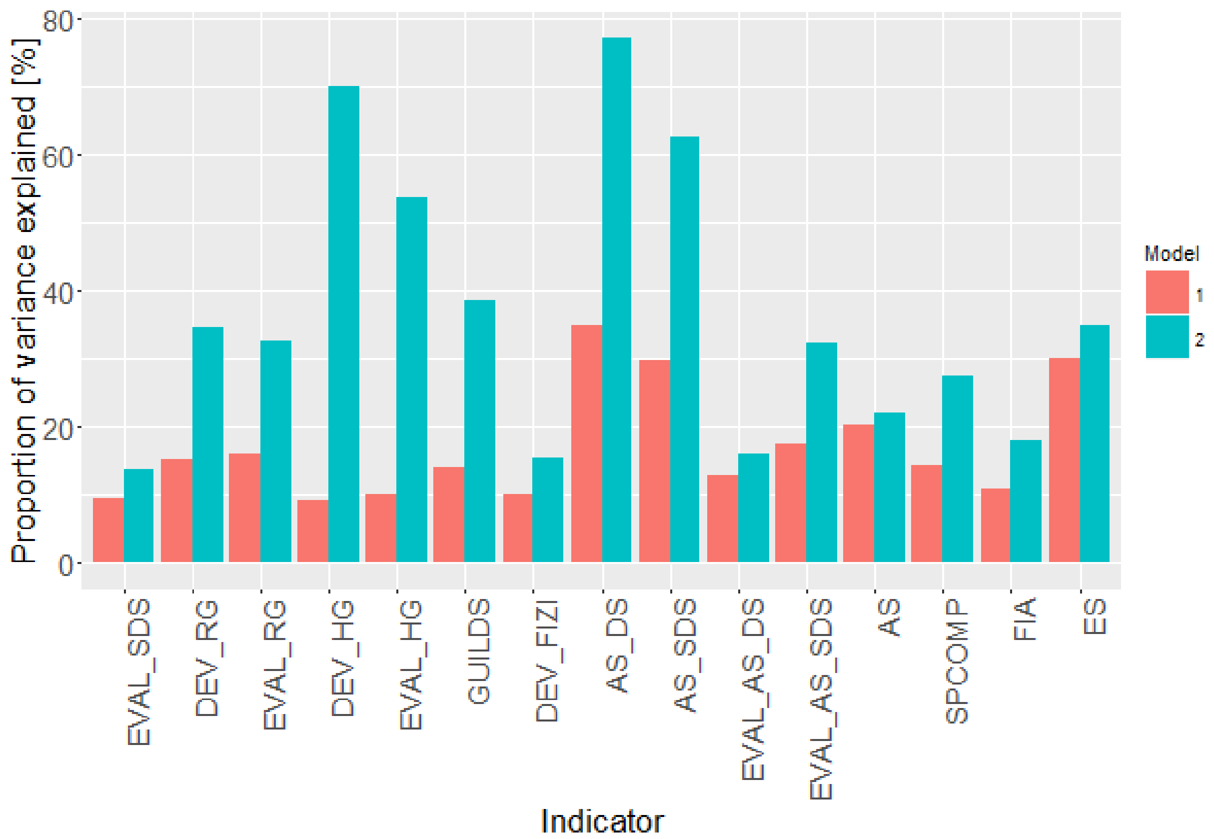


*Figure 14: Proportion of variance explained by model 1 (stressor variables only) compared to model 2 (stressor variables and fish zone) for all fish based indicators as well as for the ecological status.*

Five out of 6 stressors were selected as most important predictors with different rankings (VIMP) for explaining the response of biotic indicators in model 1 (table 8 and figure 16). The highest share of explained variance was observed for morphological alteration (M) followed by residual flow (R), impoundment (I), connectivity disruption (B) and chemical status (C). Hydropeaking was never among the three most important variables contributing to the models. In model 2, the fish zone (FIZ) was the predictor with the highest VIMP in almost all biotic indicator models, accounting for most of the variation with a mean and median of about 50% for all indicators (figure 16). The only exception is the 'ecological status' (ES) (table 7). Besides 'fish zone' (FIZ), stressors morphological alteration (M) and residual flow (R) are the selected variables contributing to the models' explanatory power. Figure 16 shows boxplots of the distribution of variable importance of the predictors for all indicators, separated by model (1 and 2).

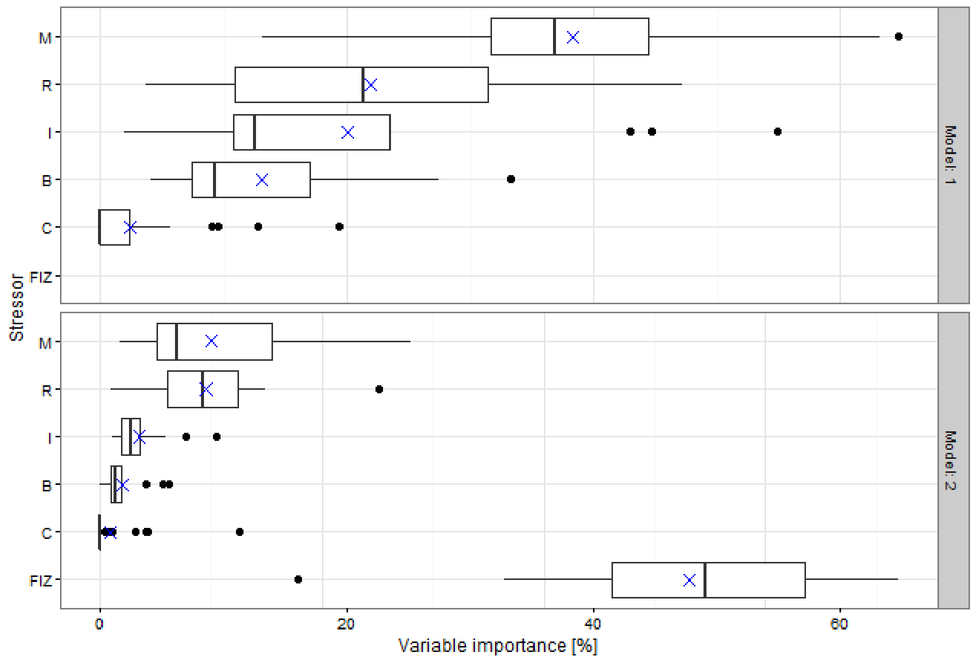


*Figure 15: Distribution of the predictor importance based on the BRT models for the 16 indicators, separated by model (model 1 – stressors and model 2 – stressors and 'fish zone' (FIZ)).*

Relevant pairwise stressor interactions include connectivity disruption (B) with morphological alteration (M) for AS_DS, AS_SDS and NSP and residual flow (R) with morphological alteration (M) in model 1. Fish zonation (FIZ) with morphological alteration (M) was most relevant for AS in model 2 (table 8).

As stated before, partial dependence plots (PDPs) are another outcome of BRT analysis. Figures 16 to 18 show PDPs for the two fish based indicators 'age structure' (AS) and 'Fish Index Austria' (FIA) and the indicator 'ecological status' (ES), for both models 1 and 2 (see appendix e for complete results for all indicators).

The gradient in intensity classes (1-4) in morphological alteration (M) increased with rising stress by visual observation in all selected indicators, especially in model 1 (figures 16a to 28a) where M was ranked first or second by VIMP (table 8). For stressor connectivity disruption (B), there is no clear trend and in most models intensity class B (according to table 1) represents the proportion of highest values whereas class A and B are fitted significantly lower. For chemical status (C) and stressor impoundment (I), the three indicators propose a slight increase in fitted values with increasing stress. Visually, no consistent response to increasing stressor intensity for hydropeaking (H) and residual flow (R) could be observed.

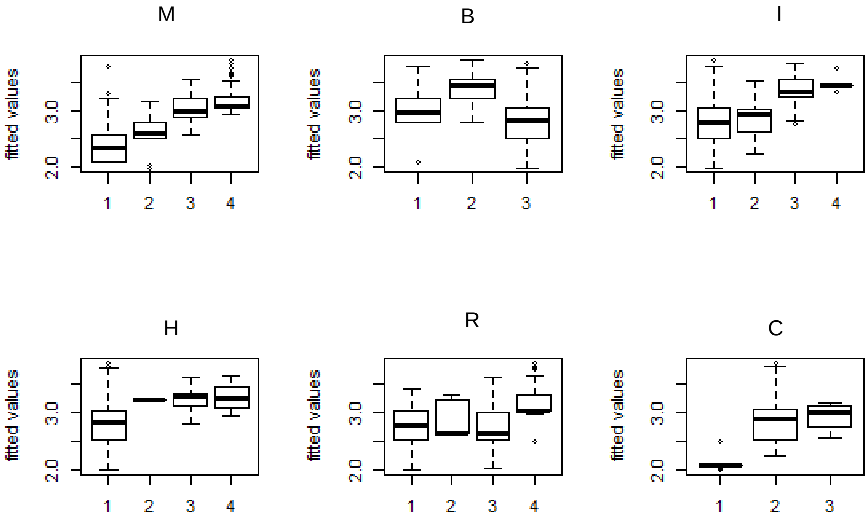


*Figure 16 a: Partial dependence plots showing the response of indicator 'population age structure' (AS) to single stressors and fish zone for model 1.*

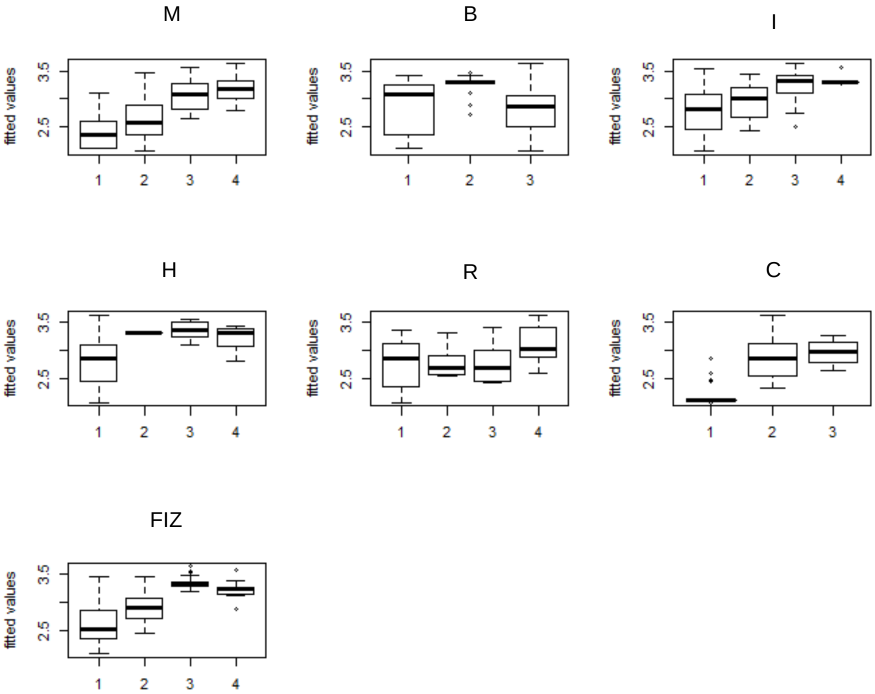


*Figure 17 b: Partial dependence plots showing the response of indicator 'population age structure' (AS) to single stressors and fish zone for model 2*

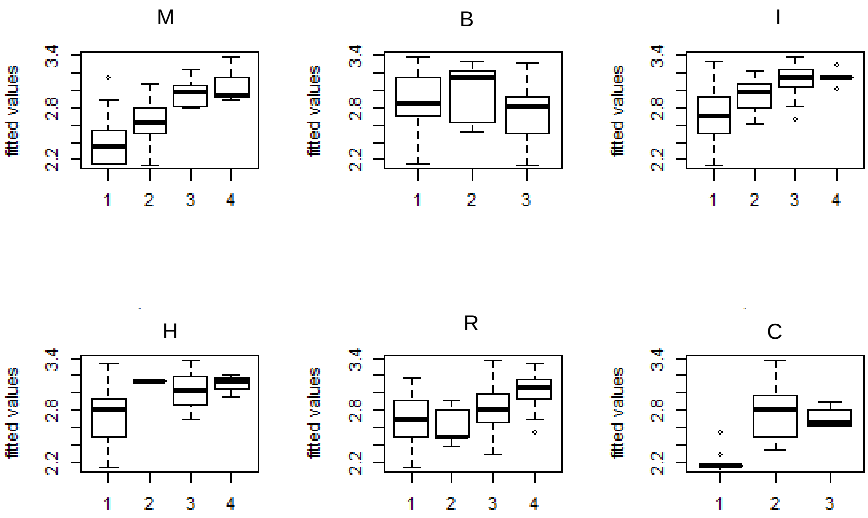


*Figure 18 a: Partial dependence plots showing the response of indicator 'Fish Index Austria' (FIA) to single stressors and fish zone for model 1.*

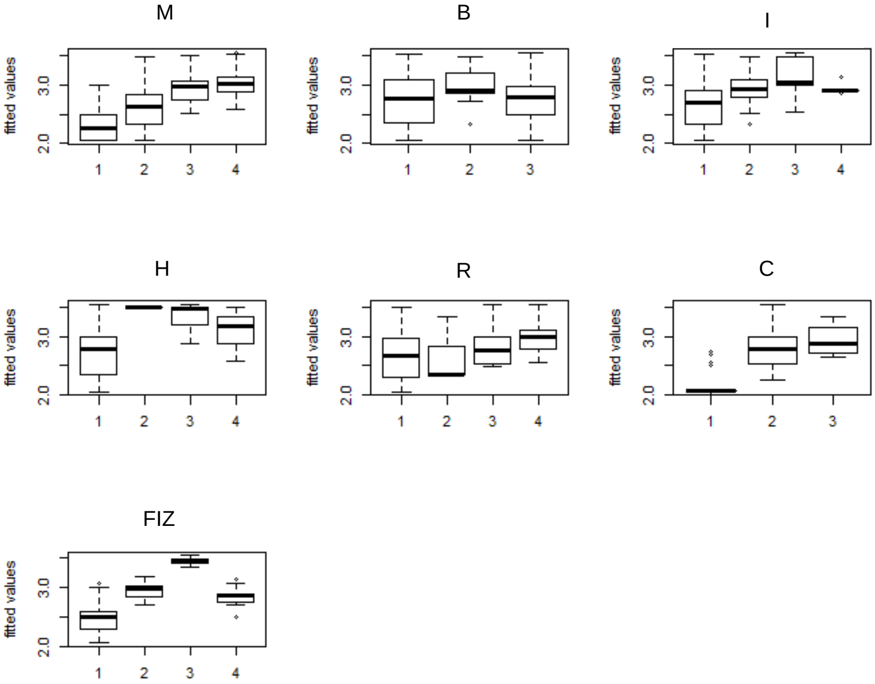


*Figure 19 b: Partial dependence plots showing the response of indicator 'Fish Index Austria' (FIA) to single stressors and fish zone for model 2.*

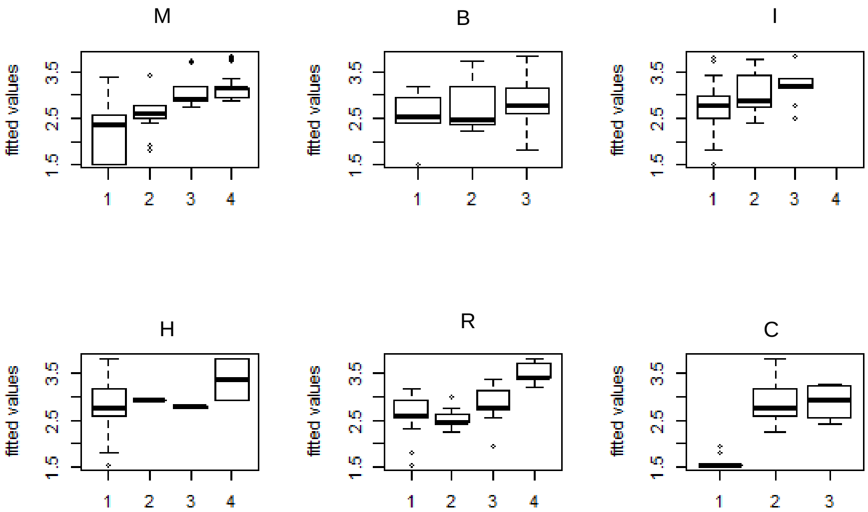


*Figure 20 a: Partial dependence plots showing the response of indicator 'ecological status' (ES) to single stressors and fish zone for model 1.*

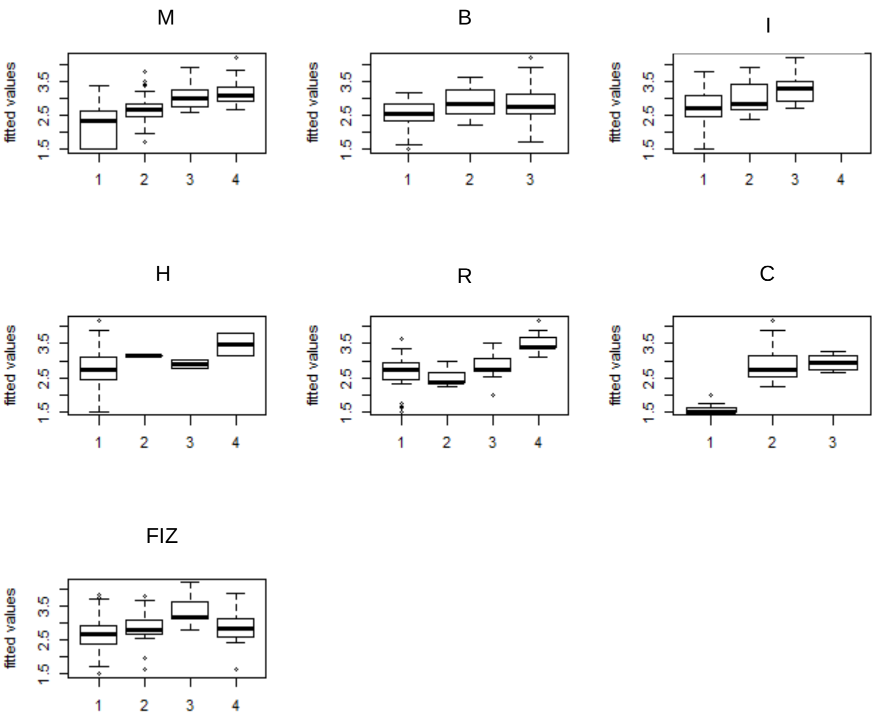


*Figure 21 b: Partial dependence plots showing the response of indicator 'ecological status' (ES) to single stressors and fish zone for model 2.*

# 4. Discussion

This thesis investigates the distribution and patterns of human stressors and the related response of fish indicators and ecological status to these stressors. The results show consistent response patterns for some indicators. This work therefore represents a valuable step in investigating stressor distribution and patterns as well as stressor-indicator relationships in the Austrian Drava and Mura River Basins. Conclusions drawn will help exploring multi-stressor management farther, within Austria and especially other Alpine river basins in Europe.

In the following paragraphs, I discuss selected indicators with a focus on 'Fish Index Austria' (FIA), which is used for evaluating the fish ecological status on the national level and the metric 'species age structure' (EVAL_AS), which is part of the FIA scheme (one single metric of the index). Further, 'ecological status '(ES) is discussed, as this is a common "benchmark" indicator across all 16 investigated river basins within the MARS project.

**Distribution and patterns of single and multiple stressors in water bodies**

The intent of the conducted stressor analysis was to describe the distribution and patterns of stressors occurring in the Austrian Drava and Mura River Basins with the most current data available from the RBMP 2015. The intensity classes of the impact assessment categories were aggregated to more and less impacted water bodies, in order to identify categories of single and multiple stressors and to calculate the category and intensity of stressors occurring at each water body (as defined in section 'methods').

My findings show that only five single and multiple stressor categories occur at least 20 times in the investigated total basin. A pattern frequently identified the number of water bodies impacted by connectivity disruption (B) and by connectivity disruption combined with residual flow (BR), decreasing from Epirhithral to Epipotamal. In contrary, the number of water bodies where the stressor morphological alteration (M) or morphological alteration combined with connectivity disruption (MB) occurs do increase from Epirhithral to Epipotamal. This can be explained with the fact that in higher elevated areas of the total basin, multiple barriers were constructed for flood protection, torrent control and hydropower production. Headwater streams are often naturally straightened, therefore morphological alterations are not as significant in contrast to medium gradient streams and lowland rivers (Hyporhithral and Epipotamal), which naturally were braided or meandering, but were regulated by humans for agricultural and urban land use.

The stressor analysis can support river basin managers to identify water bodies, which are degraded by the same stressor categories to apply suitable restoration measures. Moreover, future developments in terms of single and multiple stressors can be compared with today's situation.

**Relationship between human stressors and fish assemblages**

The boxplots of the descriptive analysis of multi-stressor-response patterns showed divergent results. The indicators 'Fish Index Austria' (FIA) and 'ecological status' (ES) resulted in very similar patterns in their responses to the variable 'stressor category'. This may be explained by the fact that the FIA contributes to the Austrian national assessment of ecological status as one important Biological Quality Element (others are benthic macroinvertebrates, phytobenthos and macrophytes). The metric 'evaluation age structure' (AS) showed a response to the same stressor patterns as FIA and ES, which confirms that this indicator is firm and highly relevant for the evaluation of the FIA and ES. In water bodies affected by residual flow (R), I expected a 'rhithralization-effect' and thus, a decrease of fish zonation index value (DEV_FIZI, see appendix c figure A12), accompanied by a shift in community structure. However, my results are unclear. It has to be kept in mind that this result builds on only five observations. Other categories combined with residual flow occur in less than 5 water bodies. Still, the indicator DEV_FIZI showed a slight increase when stressor R was present.

Due to the required step of aggregating stressor data to derive variable 'stressor category', the response of biota may be similar in strength and characteristics for multiple stressors with low intensities as to few stressors with high intensities. Other studies tried to reflect this issue by creating 'pressure indices' (Schinegger et al., 2013; Unterberger, 2014), however this is not addressed by my analysis.. Nonetheless, a general trend of decreasing ecosystem integrity with increasing number of stressors ('Stressor quantity') was visually observed in this thesis for all metrics, implying the necessity to remove impacts due to occurring single and multiple stressors from water bodies.

Random Forest (RF) models served as indicator-pre-selector for Boosted Regression Trees (BRTs) and as an additional comparative modelling approach to BRTs according to the MARS cookbook. I assumed high confidence of the methods and models, when patterns in terms of variable importance (VIMP) of the most important predictors and goodness of fit (GOF) between RF and BRT were equal. This is the case for all indicators in focus (AS, FIA, ES) and those with overall highest GOF (AS_DS, AS_SDS, ES).

As stated in the introduction, human stressors in riverine ecosystems, particularly morphological alterations, impoundments, residual flow, hydropeaking, connectivity disruption and chemical stressors are recognized to influence fish communities. The picture of ecological responses to human stressors in my results is divergent. In general, most biotic indicators reflect lower ecosystem integrity when single and multiple stressors were present. As shown in the results section, the variance explained by stressors ranged from 9 to 35 %. This may seem very low, however, literature on fish models for lotic systems confirm similar values and stress the lack of explanation in stressor-indicator relationships (Nõges et al., 2015).

In model one, indicators that responded strongest to the selected stressors were 'age structure of dominant and subdominant species' (AS_DS, AS_SDS) and 'ecological status' (ES). In model 2, AS_DS, 'deviation of habitat guilds' (DEV_HG) and AS_SDS showed strongest responses. Even though goodness of fit diverged between model 1 and 2, three out of four selected indicators with highest GOF were the same in both models, thus overlap. This implies strong relationships and high explanatory potential. Thus, these indicators are a promising starting point for further analysis within MARS basin analyses.

**Role of stressors contributing to the models**

Morphological alteration was found to be the main stressor shaping the response of biotic indicators in most BRT models. For the development of the FIA, river straightening as one feature of morphological change showed medium suitability to characterize indicator response, as shown by Haunschmid et al. (2006). The same author shows that metrics 'deviation of habitat guilds' (DEV_HG) and 'subdominant species age structure' (AS_SDS) responded to this stressor. My thesis (based on the same metrics) confirms these results: Stressor morphological alteration (M) was selected as the most important variable and the visually observed PDPs showed a shift in fitted values with increasing stressor intensity (figure 16 a). Thus, this stressor was well identified by the above-mentioned indicators. In general, various parameters determine morphological alterations. The four-level evaluation of morphological alterations (M) in this thesis builds on underlying features of the River Basin Management Plan database (RBMP-DB, 2015). These include the assessment of channel geometry-, riverbed and flow characteristics, the water-land transition zone, the condition of river bank and riparian zone as well as the vegetation of the adjacent area. In previous studies, different characteristics of morphological alterations, such as channelization, cross section alteration, embankment (Schinegger et al., 2013) or surrogates, such as human land use in the riparian corridor (Marzin et al., 2013; Schmutz et al., 2008; Trautwein et al., 2011) were investigated and have shown significant responses of metrics to this stressor. I therefore suppose that a set of stressor variables with a larger range of intensity values may contribute to better explaining mechanistic functions in ecological relationships. Moreover, instead of using an aggregated evaluation for morphology, the fundamental variables assessed within the national inventory assessment may increase the power of the models and improve interpretability.

Beside this, multi-stressor responses may identify interactions, which were discovered in this thesis between stressors morphological alteration (M) and connectivity disruption (C) for AS_DS and AS_SDS. In literature, I found no evidence for these interactions. Further, I would expect interactions between stressors morphological alteration and hydropeaking, especially in the Drava River Basin - as described by Schmutz et al. (2015), who found interactive effects between habitat characteristics and ramping rate. Based on my results, I assume that the amount of water bodies affected by hydropeaking in my investigation area is too low to considerably contribute to the models (only 11 water bodies were affected by hydropeaking, with intensity classes C (3) or D (4), as shown in figure 8). Although related impacts of hydropeaking on fish are well known already (Saltveit et al., 2001; Schmutz et al., 2014; Scruton et al., 2008), this low number of cases leads to a lack of intensity range for stressor hydropeaking, which may also be the reason why this stressor was not contributing to the models. Similarly, only four water bodies with high chemical stress (status class 3) occur in the dataset. However, chemical- and water quality stressors are not a big issue in Austria's rivers any more, thanks to sufficient wastewater treatment and emission regulations. Nonetheless, the response of the biota visually observed in PDPs always showed degraded conditions with increasing stressor intensity. Also this stressor was selected third by VIMP ranking in ES and FIA.

Further, twenty-two water bodies are impacted by impoundments, with intensities in categories C (3) and D (4). This stressor contributed on average 20% to variable importance of the BRT models. In comparison to other stressors, multiple authors observed strong responses of fish assemblages to impoundments (e.g. Van Looy et al., 2014; Schmutz et al., 2008). Marzin et al. (2013) identified the presence of impoundments as being a significant stress factor driving the response of fish indicators. The impact of impoundments is large, as a lotic system is changed to stagnant waters characterized by reduced flow velocities, bank fixations, reduced channel variations, disconnection of inflows and changes in sediment regime altering river functioning (Baxter, 1977; Tiemann et al., 2004). For Austrian water bodies, Schmutz et al. (2010) clearly showed that an increasing percentage of impoundments per water body leads to a decreasing ecological status ($R^2$ 0,97). In another study using regression trees, Schmutz et al. 2007a observed that impoundment length and mean discharge were the most important variables in terms of explained variance of a biotic index. In my study, the PDP results of FIA agree with previous findings of that author, showing a lower FIA for no or short impoundment lengths (<300m in previous findings, <500m in my study) compared to long ones. However, this predictor (I) was not among the most important variables selected for explaining the response of the FIA and neither for ES. Instead, guild metrics, especially metrics associated with reproduction were sensitive to this stressor type where it accounted for the main part in variability explained by the model (see table 8 and appendix e). This may indicate the shift from a lotic to a lentic system. In metric age structure (EVAL_AS), impoundments accounted for 11% of the variable importance and a slight shift from class A (1) and B (2) to C (3) and D (4) in fitted values was detected (figure 18 a). This may be due to the parallel occurrence of unsuitable instream habitats expressed by morphological alterations, which might be limiting habitats for juvenile fish as possible reason for bad age structure evaluations.

The impacts of residual flow in combination with other stressors have rarely been addressed in multi-stressor literature (and only in experimental studies, e.g. of Lange et al. (2014)), but studies especially for headwater and medium gradient rivers are missing. In my thesis, the variable importance (VIMP) of residual flow (R) and thus its contribution to the power of the models was often high: e.g. 39% of VIMP in ES or 30% of VIMP in EVAL_AS. I expected an increase in stressor intensity class with increasing indicator value. However this was not the case for the explored indicators and associated PDPs showed no clear trend. These results go in line with another Austrian study conducted by Schmutz et al. (2008). The authors were not able to reveal significant response of fish metrics to multiple stressors including residual flow, the only reactive component was the mean annual daily low flow (MNJQt) of below or above 40%. This feature approximately corresponds to the separation of stressor intensity classes A (1) and B (2) versus C (3) and D (4) within my study. Reasons for the missing gradients are manifold and some may be explained by the following assumptions: literature describing the development of the FIA (Haunschmid et al., 2006) revealed no evidence of significant metric reaction to residual flow. Thus, the developed index and associated metrics may not be sensitive to this stressor category. Moreover, negative consequences of residual flow depend on many other influences, such as the river type and river-reach morphology as assumed by Holzapfel et al. (2014). Again, a set of more precise predictor variables such as percentage of abstracted residual flow may be worth exploring, as they might better explain the response in biotic indicators.

For stressor connectivity disruption (C), class A indicates that no barriers are present in the water body or barriers are passable without fish migration facilities. In class B of the national impact assessment, passability is limited or only assured by fish migration facilities and in class C there are one or more non-passable barriers occurring in a water body. The variable B provokes high uncertainty due to divergent results. Although ranking of VIMP is sometimes high (e.g. in indicators AS_DS, AS_SDS), PDP patterns don't show the expected results – that were an increasing intensity class (A (1) to C (3)) with decreasing ecological integrity. Nevertheless, migration barriers are known to affect fish communities, as they degrade habitats and fragment populations, which leads to reduced productivity and genetic isolations (Meldgaard et al., 2003; Santucci et al., 2005). As water bodies in this analysis show a huge variation in length (from less than 1 km to over 46 km in the dataset with fish sampling sites), it is questionable whether the considered variable C (i.e. only identifying if there is an impassable barrier or not) is able to detect a fish ecological response to this stressor.

To summarize, most indicators suggest a significant difference between low and high stress-levels for some stressors, i.e. morphological alteration (M), impoundment (I) and chemical status (C). This confirms that the metrics are suitable to identify ecosystem integrity for such stressors. However, others don't contribute sufficiently to the model for reasons of data quantity, predictor unsuitability or characteristics of indicators, which further have to be investigated. An adapted methodological approach may help exploring the situation in the Drava and Mura River Basins and the Austrian RBMPs 2015 further, by improving goodness of fit and interpretability of the contributing predictors and interactions.

**Influence of stressor distribution along fish zones**

As stated before, one model in this thesis incorporated 'fish zone' (FIZ) as predictor variable. My findings revealed a notably strong response of fish based indicators to the variable 'fish zone' at the river basin scale. This descriptor was much better correlated to fish based indicators than the stressors and accounts for a large proportion of the explained variability of assemblage composition among water bodies. This suggests that the stressor variables were less influential compared to the FIZ. There are two approaches for interpretation:

The fish zone represents a purely biotic concept reflecting the length zonation of streams based on typical biocenosis (Illies and Botosaneanu, 1963) which include the regions Epirhithral to Epipotamal in the Drava and Mura River Basins. Huet (1959) correlated biocoenotic regions with slope and width, thus factors of natural variability. Fish species have preferences to abiotic features. Other aspects, such as water temperature are not considered in the scheme of Huet (1959). In Austria, fish zones were mapped by Schmutz and Melcher (2001) for water bodies > 500 km² and subdivided specific regions (Hyporhithral and Epipotamal) into sub-regions. For the development of the FIA, Haunschmid et al. (2006) set criteria for the sub-regions based on mean discharge and river width. FIA metrics incorporate natural variability as they are calculated through the deviation from a predefined reference condition ('Leitbild') per fish zone and ecoregion (e.g. percentage of actual occurring dominant species compared to the reference) and the reference is adapted in large river to local specifications ('Adaptiertes Leitbild'). The reference builds on information of historic data, recent fish samples and expert knowledge. However, the same authors stress that the boundaries between regions are somehow arbitrary as in nature there is always a continuous shift. Thus, I assumed that natural variability determined a certain extent of the fish assemblage response.

The second idea is based on the assumption that stressors increase along the longitudinal range of fish zones. The results of partial dependence plots (see figures 18 b to 20 b and appendix e) show, that the ecological quality of FIZ 1 (Epipotamal) is always higher than the one of other fish zones. In terms of quantity, less stressors occur in this fish zone, which is supported by the results from the stressor analysis, where the percentages of four- and fivefold stressors are higher in FIZ 2 to 4. For example, stressor types H, C and I do not or only rarely occur in FIZ 1 according to the stressor analysis (see tables 5 and 6). Also, I assume that impacts caused by stressors are differing depending on the FIZ. Indicator responses e.g. to morphological alterations may be lower in upstream regions, which are often naturally straightened (as shown by Niemeyer-Lüllwitz and Zucchi (1985)) and thus e.g. bank fixations would not significantly change habitat quality. The patterns of other FIZ are divergent, depending on the indicator. Still, multiple indicators show the trend of decreasing ecological quality from FIZ 1 to 4, including 'GUILDS', 'AS_DS' and 'AS_SDS' and from 1 to 3 including 'SPCOM', 'DEV_RG', 'EVAL_RG', 'EVAL_AS_DS', and 'AS'.

Looking at patterns in terms of variable importance between the indicators, the ES is the only indicator for which 'fish zone' doesn't account for the highest variable importance. This indicator is composed of the results of multiple biotic quality elements (according to the WFD), for rivers these are fish, benthic macroinvertebrates, phytobenthos and macrophytes. This means that not only information based on fish is incorporated in the index. Thus, other organisms may not correlate as much with the characteristics of 'fish zone'.

To summarize, both, natural variability and the distribution and patterns of stressors between fish zones may cause the strong response of biotic indicators to the predictor variable FIZ. The results also stress the assumption that differentiation along a longitudinal gradient makes sense as certain metrics are reactive in specific river zones as findings of Schinegger et al. (2013) propose.

**Limitations and outlook**

This study faces several limitations, but also implications for future investigations and improvements. Firstly, I am aware, that the aggregation of data (i.e. the re-coding/simplification of original stressor data) for the investigation of stressors and the descriptively observed response of biotic indicators leads to a loss of information. This was however necessary to conduct an analysis on the categories and quantities of stressors.

Available stressor data are described in categories of three to four intensity levels, based on a number of underlying variables. This partially leads to a low gradient of stressor intensity and often makes interpretation difficult. There are several variables available in the present database, which are not considered yet, but potentially relevant for further MARS analyses in Austria. Therefore I propose the consideration of a set of more precise/distinct stressors, such as the number of impoundments per water body, the total length of impoundments per water body and others for further investigations of the Austrian RBMP data. Especially for stressor connectivity disruption I suggest the calculation of variables which account for fragmentation of the riverine ecosystem or for a differentiation of passability of barriers by more detailed specifications (such as e.g. the number of barriers per segment/water body, individual segments contribution to the overall network connectivity or the delineation of segments based on the passability of barriers) as conducted in other studies (Unterberger, 2014; Van Looy et al., 2014).

Another important issue is that the low explanatory power of some models may also result from the assumption that one fish sample is representative for the whole water bodies' stressor status. This approach may not be suitable. In many cases, multiple fish samples were available per water body, however only one was selected. For modelling stressor-indicator relationships it may be advantageous to find a way to link multiple samples to an aggregated evaluation, which better represents the ecological status of a total water body. Here, an alternative method could be the implementation of a buffer approach as additional scale of analysis, as e.g. performed by Mielach (2010) and Schmutz et al. (2007). Moreover, an investigation about the location of the sampling area on a water body could give additional insights.

Another issue is the number of water bodies per stressor category. There are only five stressor categories occurring at least 20 times which poses a challenge for statistical analysis, as a minimum sample size is required. For example, a study by Stockwell and Peterson (2002) showing the effects of sample size on the accuracy of species distribution models suggests that for machine-learning methods, accuracy was near maximum at 50 data points. For finer surrogate models and logistic regression models, a sample size of about 100 data points was necessary for the same accuracy. My study does not fulfil these criteria for the majority of stressor categories, which limits statistical testing. Thus, statistical testing was not performed for stressor categories and stressor quantities. Instead, patterns were only observed visually. Some limits, especially related to data quantity may be resolved by extending the datasets and by using water bodies from comparable regions in entire Austria.

To summarize, this work will be continued within MARS; following a standardized methodology and objectives taking the present knowledge within the next steps of MARS into account. After improving BRT models, generalized linear models should be used to test and quantify these relationships, which were rather descriptively investigated here.

# 5. Conclusions

There are several relevant outcomes of this work, including strong implications for further analysis and research on the relationship of human stressors and fish based indicators at the river basin scale:

- A large amount of different stressor categories, i.e. single and multiple stressors currently occurs in the Austrian Drava and Mura River Basins.
- Most frequent single stressors identified for related water bodies are morphological alteration (M) and connectivity disruption (B).
- In terms of multiple stressors, morphological alteration combined with connectivity disruption (MB), connectivity disruption combined with residual flow (BR) and a combination of all three, i.e. morphological alteration, connectivity disruption and residual flow were most frequent in the Drava and Mura River basins.
- The identification of these single and multiple stressors may help to prioritize future restoration and management actions by informing practitioners and other scientists on the most frequently occurring stressor categories and quantities and their distribution and patterns within different fish zones.
- Fish based indicators and the ecological status reveal contrasting responses to the occurring, mainly hydromorphological stressors. This likely is caused by a limited methodological approach including narrow stressor gradients, aggregated stressor variables leading to dimension reduction/information loss and the linkage of one single fishing site to an entire water body.
- At the river basin scale, the variable 'fish zone' largely drives the response of biotic indicators. I assume that this is mainly due to the unequal distribution of stressors between fish zones and to a certain extent based on the fish zone itself which incorporates some natural variability.
- The thesis results confirm necessity of using multiple indicators for assessing the ecological integrity of rivers and streams.
- The RBMP data and the BRT approach bear high potential for further fruitful analysis: the updated RBMP data are generated through standardized methods with multiple variables that may still be considered, additional data from other river basins may be included and some BRTs show already promising explanatory power.

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# 7. Appendix

## a. *Concepts and studies conducted within the Drava River Basin*

*Table A1: Projects/studies conducted within the Drava River Basin with a focus on river restoration*

| Year | Project/study name | Description | Document/Source |
|---|---|---|---|
| 1993 | GEKs Kärnten und im speziellen GEK Obere Drau | River corridor management plans (Gewässerbetreuungskonzepte) in Carinthia. Including the GBK for Upper Drau and pilot restoration action "Kleblach-Lind" in 1993. Measures aiming at stabilization of river bed and improvement of ecological functioning. | Michor, K. et al. (1993): Gewässerbetreuungskonzept Obere Drau. Lienz-Sachsenburg, 1. Zusammenfassender Bericht. Im Auftrag des Bundesministeriums für Land- und Forstwirtschaft und des Amtes für Wasserwirtschaft Spittal/Drau |
| 1999-2003 | Auenverbund obere Drau | The Natura 2000 area contains a 68 km long river section and a total area including the surrounding riparian areas of 976 hectares. In the 1990ies the governmental department for water management commissioned a river care scheme and consequently first measures to extend the river bed were implemented. In this project those efforts have been pursued with the following measures: purchase of land for establishment of new habitats, removing river regulation and extending the river bed, restructuring tributary streams, removal of migration barriers in streams, establishment of new water bodies in the floodplains, establishment of additional floodplain forests, reimbursement of grazing rights in floodplain forests, contracts covering land use of floodplain forests, re-introduction of the German Tamarisk, re-introduction of the Lesser Bulrush, re-introduction of the Ukrainian Lamprey, re-introduction of the Spined Loach, promotion of the Common Tree frog, promotion of the White-clawed Crayfish, promotion of the Bitterling, promotion of the Pond mussels, provision of nesting sites for bats, provision of nesting sites for the Kingfisher, promotion of other fish species including Minnow, Stone Loach, Nase, Huchen and Grayling. Investment of about 6,3 million Euro (including 26% funding from the LIFE-Nature program by the EU). | Amt der Kärntner Landesregierung, Abt. 18 - Wasserwirtschaft (2004): Endbericht LIFE99 NAT/A/006055 LIFE-Projekt - Auenverbund Obere Drau, 1. April 99 - 31. Dezember 03 |
| 2006-2011 | Life Drau II Lebensader Obere Drau | Extensive river restoration project executed by the "Bundeswasserbauverwaltung Kärnten" and financially supported through the European LIFE-Nature fund. Cooperation of multiple stakeholders. 5 river kilometers were restored, 25 ha of surrounding areas were bought, multiple floodplain water bodies were created and measures for improved sediment regime were introduced. Monitoring on multiple biotic indicators was performed and shows positive development of biota and improvements for flood protection, fishery and leisure. | Unterlercher M. und Petutschnig W. (2011): F.2 Lebensader obere Drau - Monitoring Synthesebericht . Auftraggeber: Amt der Kärntner Landesregierung. LIFE06NAT/A/000127 - final report (2011): Covering the project activities from 01.09.2006 to 31.08.2011, Lebensader Obere Drau |
| 2011 | Master thesis | Master thesis with the objective to shed light on the pressures, hydromorphology, restoration measures, fish ecology - in particular fish species composition of the Austrian Drava River between Italy and Slovenia. The historical situation was compared with the current ecological status by investigating environmental and fish ecological parameters. Literature was analysed to answer the question of interest: can river restauration improve the situation? | Humpel, M. (2011). Diplomarbeit. Metaanalyse von eingriffen und deren Restaurationsmaßnahmen an der österreichischen Drau. Universität für Bodenkultur, Wien. |

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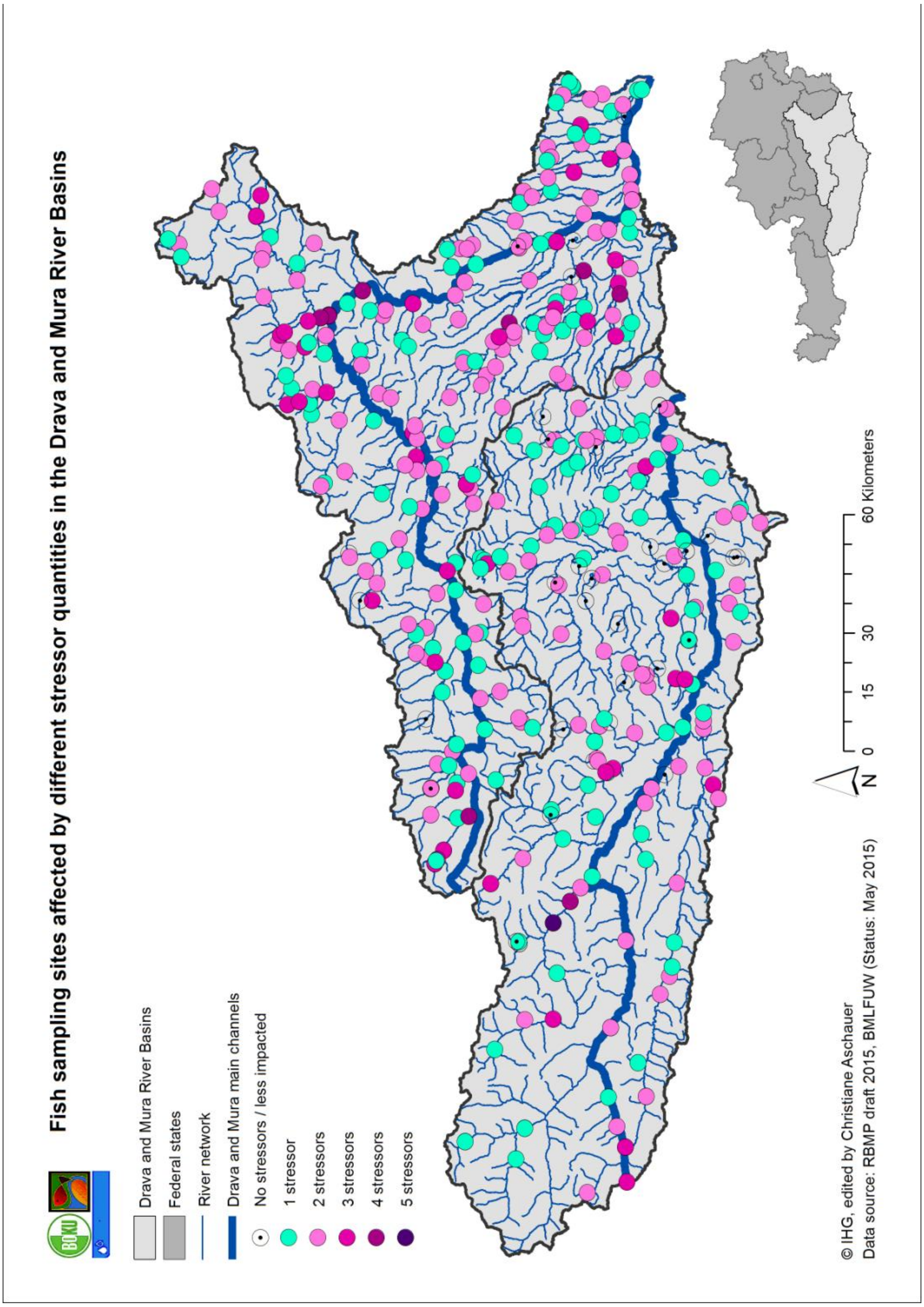
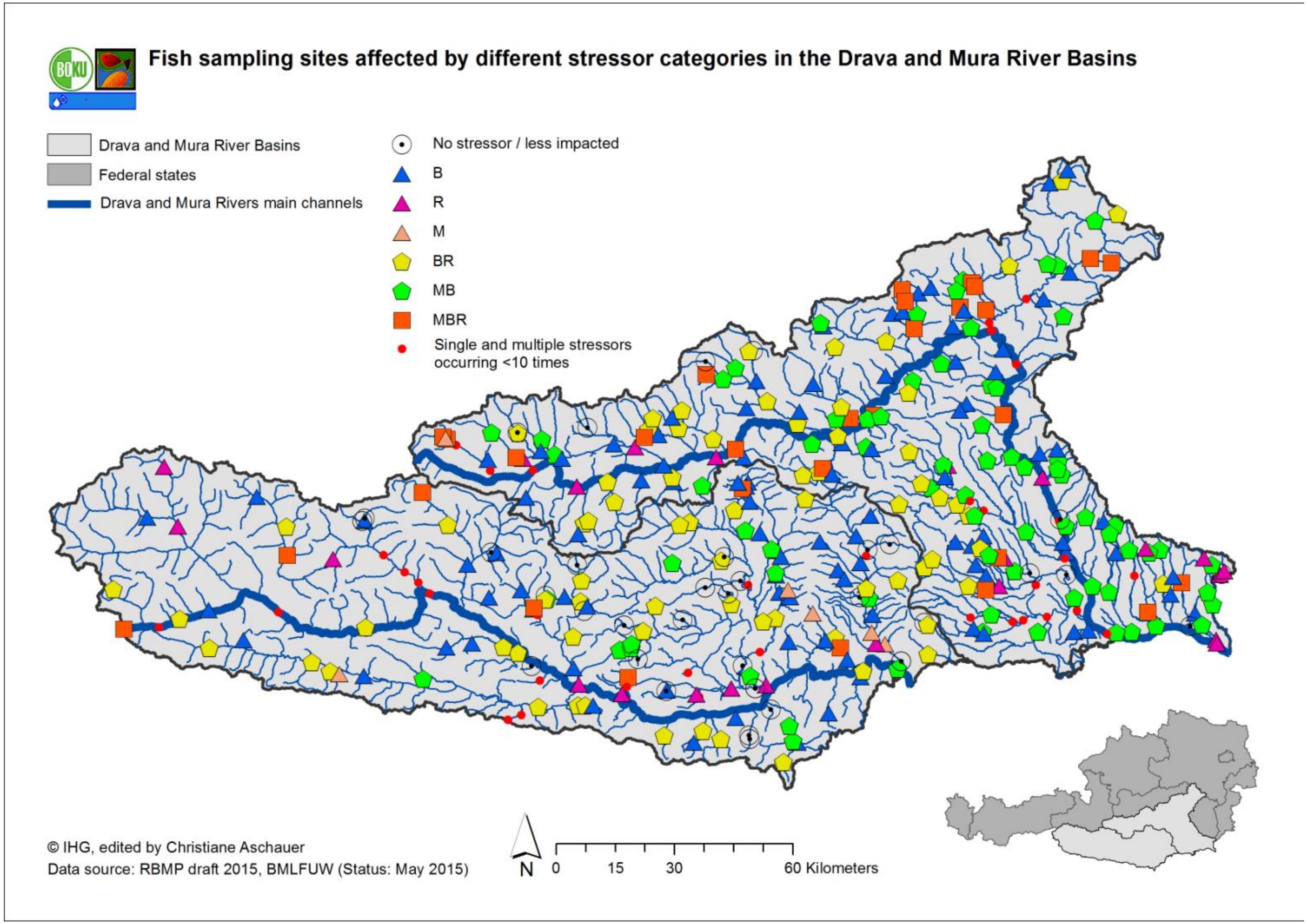
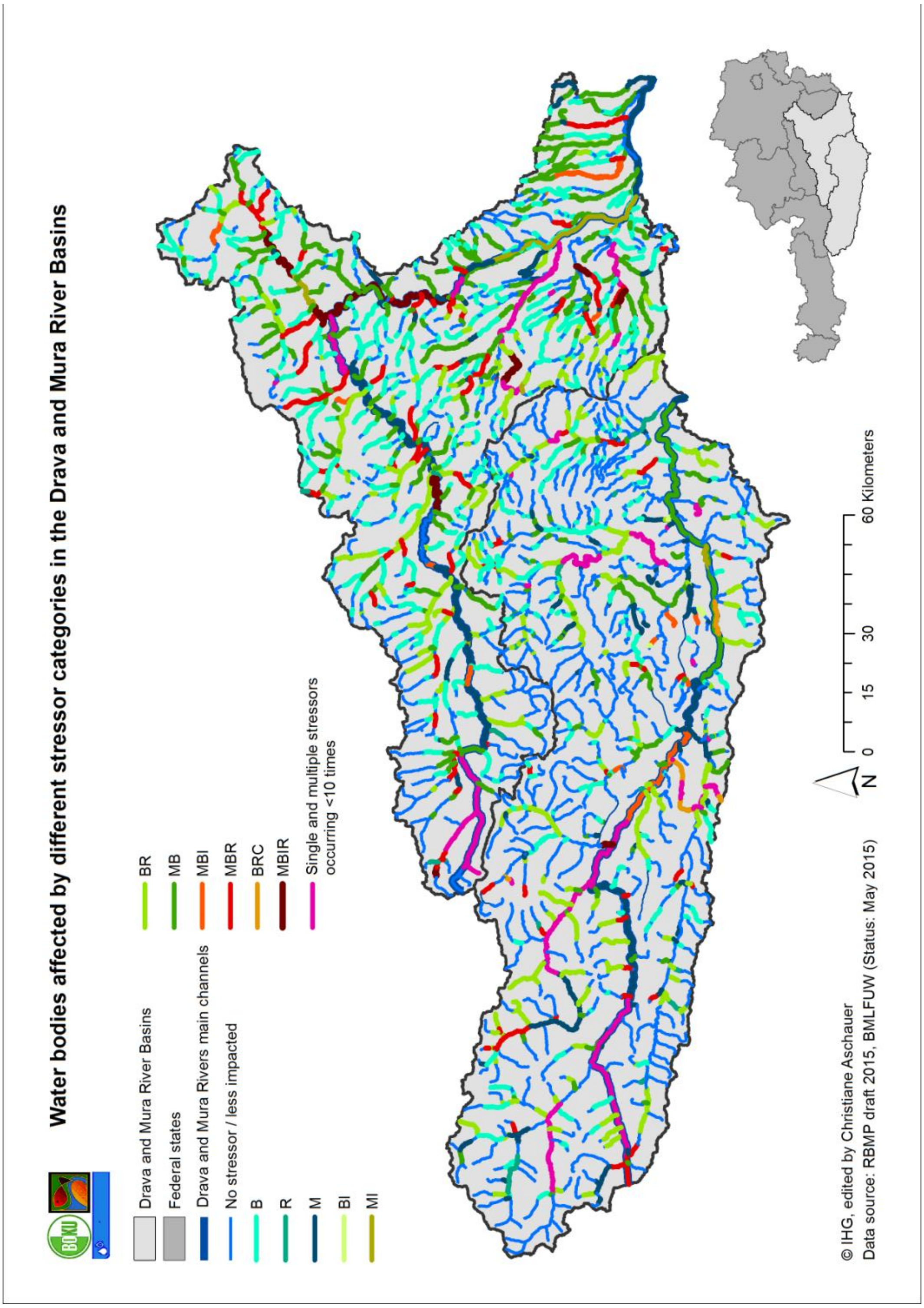
|---|---|---|---|
| 2011 | Verbund Studie: Flussgebiets-management für die Stauräume an der Drau | River catchment management plan for the impounded stretches of the Drava River: Data on operation and management of the impoundment chain were collected, structured, prepared and updated. The current status and problem areas were presented and analysed; proposals for management were drawn.<br>The plan shall be used as basis for strategic middle- and long-term decisions and detailed planning. Attention was set on the ecological analysis and the development of measures for the impoundment chain to propose possibilities for ecological improvements towards the aim of the WFD without changing hydropower operation. | Angermann, K., Eggger, G., Petutschig, J. (2007): Flussgebietsmanagement für die Stauräume and der Drau. Band 99 Schriftenreihe der Forschung im Verbund |
| 2012-2014 | SEE River Project | This South East Europe Transnational Cooperation Programme project aims to reach a common agreement on river corridor management by harmonizing development and conservation interests. Cooperation of multiple stakeholders from a wide range of fields of different countries and at different spatial scales (from local river areas to national authorities). Scale of interest is the river corridor where river and land management with pressure occur. Activities and findings include a toolkit with a model and guidance on how to reach future sustainable use of river corridors by harmonizing stakeholder interests. 6 river corridors were included: Drava, Bodrog, Neretva, Prut, Soča and Vjosa. Other key results include: Drava River Action Plan for integrative management, 5 multi-sectoral stakeholder agreements, 5 draft action plans for integrative management, directory of good practices, 10 capacity building seminars, 11 follow-up project proposals prepared, sustainability plan for future cooperation. | SEE River (2015): Final publication of the project 'Sustainable Integrated Management of International River Corridors in SEE Countries'.<br>www.see-river.net |
| 2014 | Gewässer-entwicklungs-konzept (GEK) Obere Drau | Gewässerentwicklungskonzept (GEK) implemented within the framework of the See River Project. Content: Resource analysis (Status of the river corridor regarding nature values, water related resources including quantity and quality, cultural values); Risk analysis (flood risks and status of flood defense, climate change, droughts, accidental pollution); Spatial analysis (spatial structure, identification of the Drava River Corridor); Institutional setup analysis (legal, institutional, organizational setup within the DRC per country); Project analysis (projects – past, ongoing, planned, foreseen development and conservation projects, including potential threats and benefits involved); Stakeholder analysis (identification of stakeholders, the existing and future goals and aspirations); Map of hotspots (to visualize the existing or potential conflict zones between river uses, nature values and development projects); Synergies and conflicts analysis (as identified among projects, stakeholders, conservation and development issues); Feasible measures (→ Toolkit) to dissolve conflicts; Progress indicators and benchmarks (to measure the distance of the present and foreseen status of the river corridor from the goals set in the Drava River Declaration). | Work package: WP4 – Application of the SEE River Toolkit on the Drava River Corridor<br>Action: 4.1. Preparation of the Drava River Framework – Analysis of the International Drava River Corridor: National river corridor analysis report of Austria and multiple reports |

*b. Additional maps*





Fish sampling sites affected by different stressor categories in the Drava and Mura River Basins
Drava and Mura River Basins
Federal states
Drava and Mura Rivers main channels
No stressor / less impacted
B
R
M
BR
MB
MBR
Single and multiple stressors occurring <10 times
© IHG, edited by Christiane Aschauer
Data source: RBMP draft 2015, BMLFUW (Status: May 2015)
N
0
15
30
60 Kilometers



Water bodies affected by different stressor categories in the Drava and Mura River Basins
Drava and Mura River Basins
Federal states
Drava and Mura Rivers main channels
No stressor / less impacted
B
R
M
BI
MI
BR
MB
MBI
MBR
BRC
MBIR
Single and multiple stressors occurring <10 times
0 15 30 60 Kilometers
N
© IHG, edited by Christiane Aschauer
Data source: RBMP draft 2015, BMLFUW (Status: May 2015)

## c. Boxplots of stressor-indicator relationships

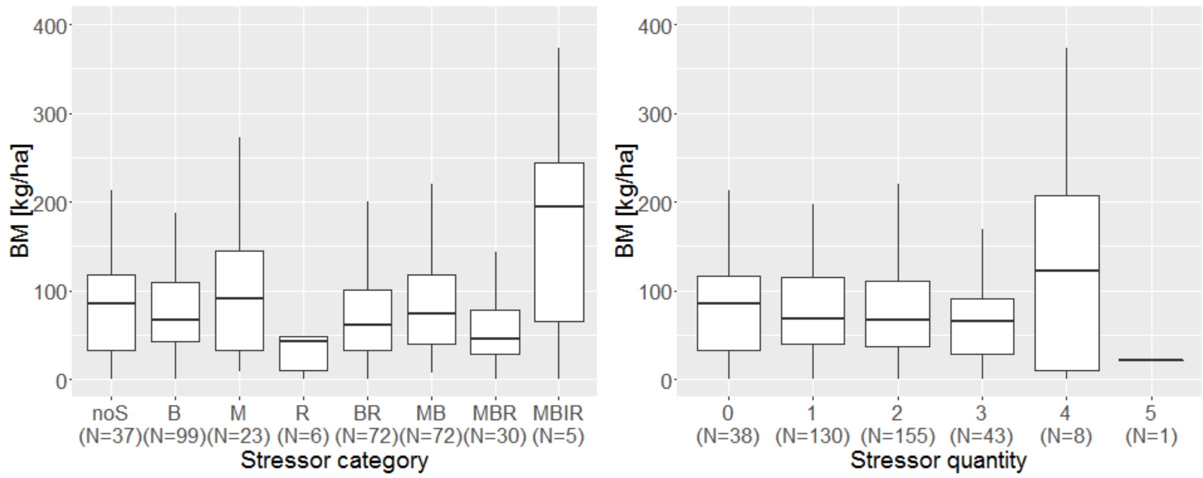



*Figure A1 a and b: Response of indicator 'biomass' (BM) to variables 'Stressor category' and 'Stressor quantity'.*

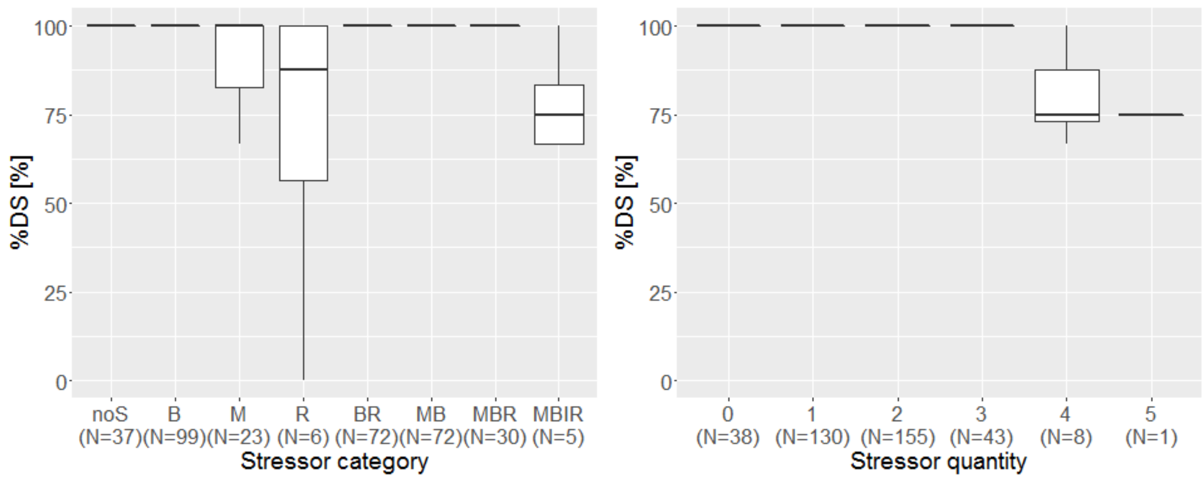



*Figure A2 a and b: Response of indicator 'Percentage dominant species' (%DS) to variables 'Stressor category' and 'Stressor quantity'.*

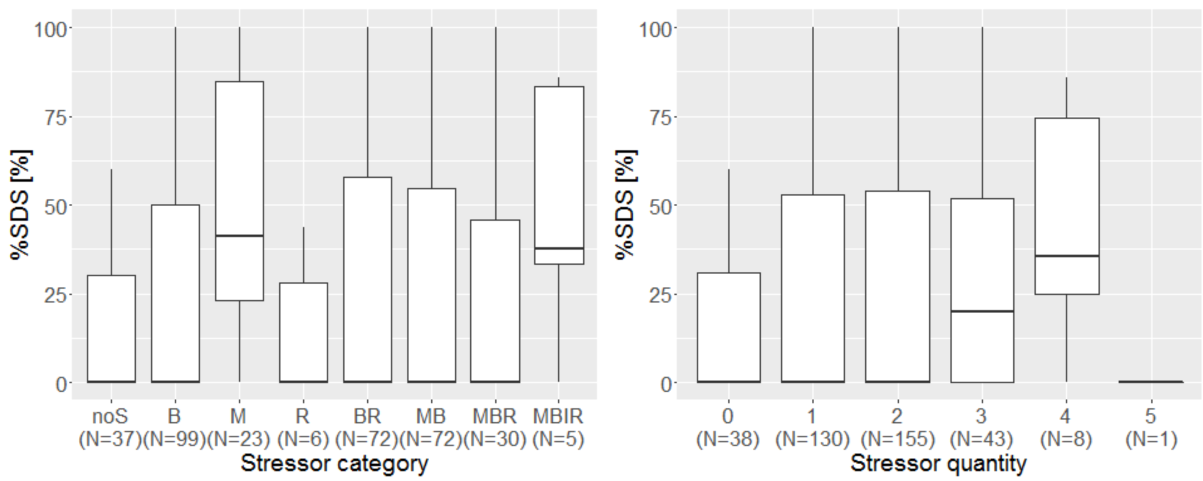



*Figure A3 a and b: Response of indicator 'Percentage subdominant species' (%SDS) to variables 'Stressor category' and 'Stressor quantity'.*

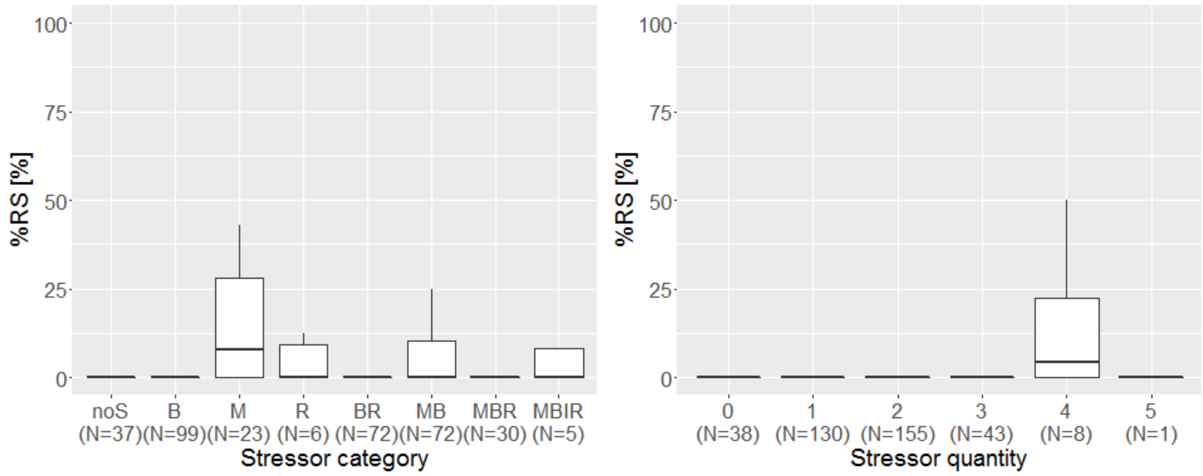



*Figure A4 a and b: Response of indicator 'Percentage rare species' (%RS) to variables 'Stressor category' and 'Stressor quantity'.*

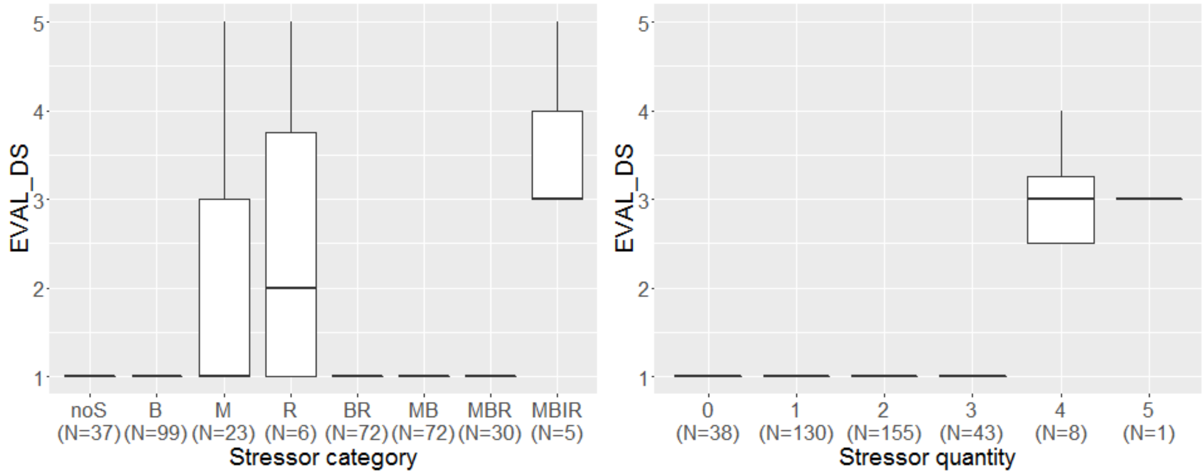



*Figure A5 a and b: Response of indicator 'Evaluation dominant species' (EVAL_DS) to variables 'Stressor category' and 'Stressor quantity'.*

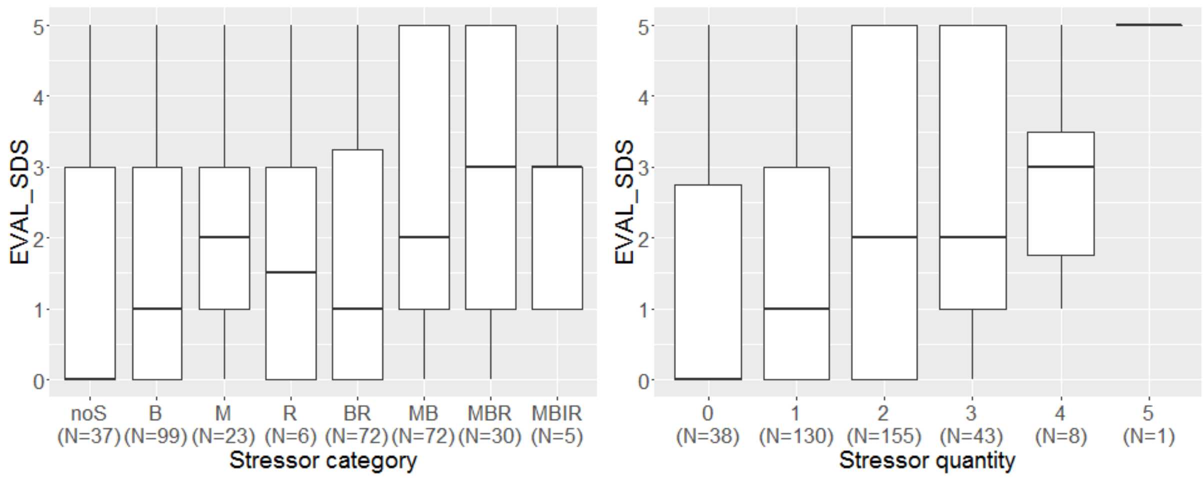



*Figure A6 a and b: Response of indicator 'Evaluation subdominant species' (EVAL_SDS) to variables 'Stressor category' and 'Stressor quantity'.*

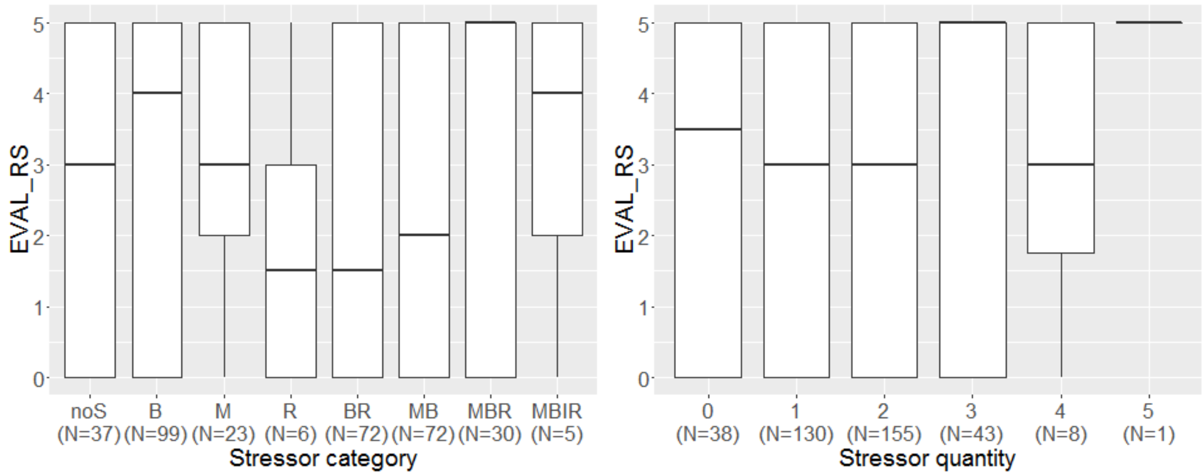



*Figure A7 a and b: Response of indicator 'Evaluation rare species' (EVAL_RS) to variables 'Stressor category' and 'Stressor quantity'.*

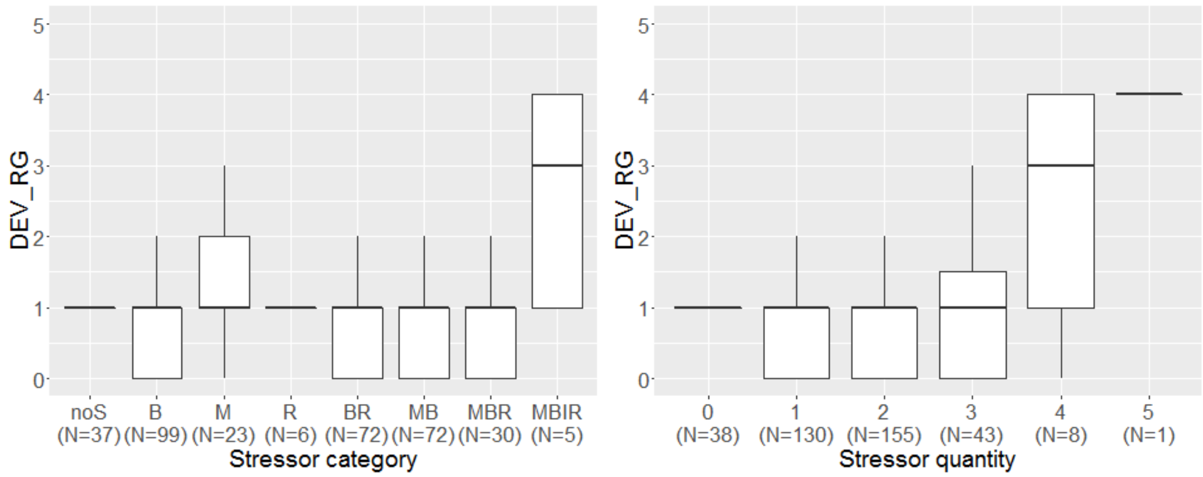



*Figure A8 a and b: Response of indicator 'Deviation reproductive guild' (DEV_RG) to variables 'Stressor category' and 'Stressor quantity'.*

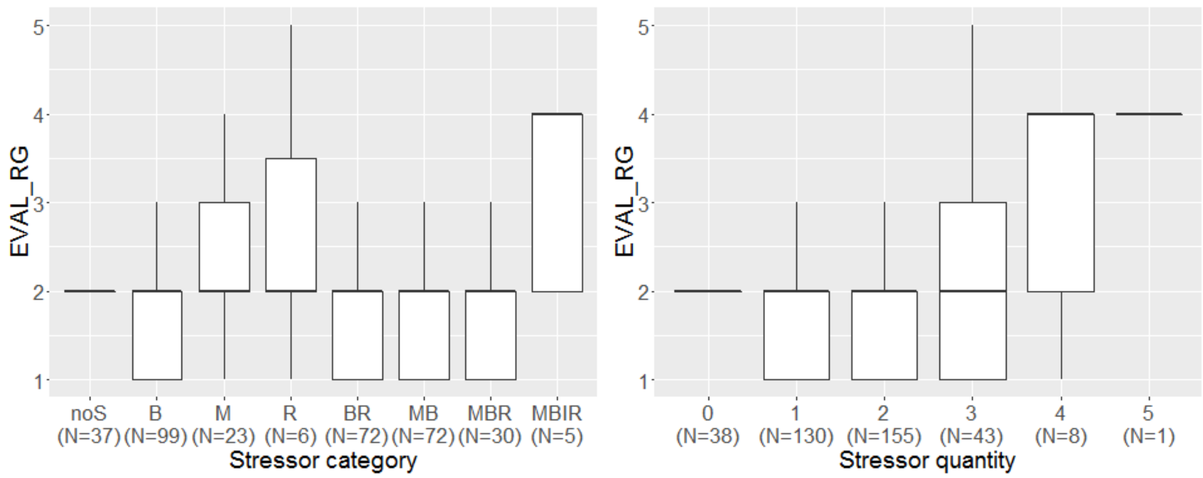



*Figure A9 a and b: Response of indicator 'Evaluation reproductive guild' (EVAL_RG) to variables 'Stressor category' and 'Stressor quantity'.*

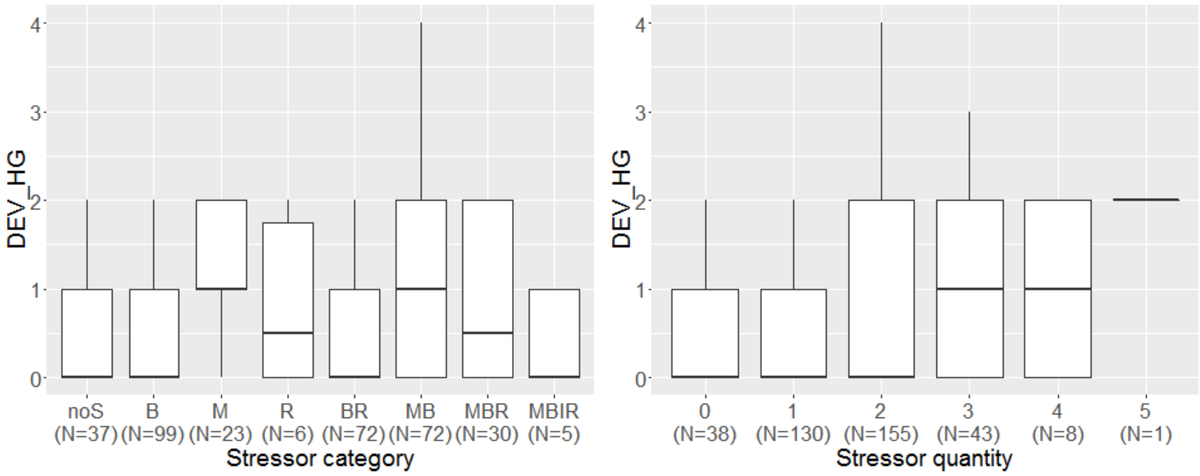



*Figure A10 a and b: Response of indicator 'Deviation habitat guild' (DEV_HG) to variables 'Stressor category' and 'Stressor quantity'.*

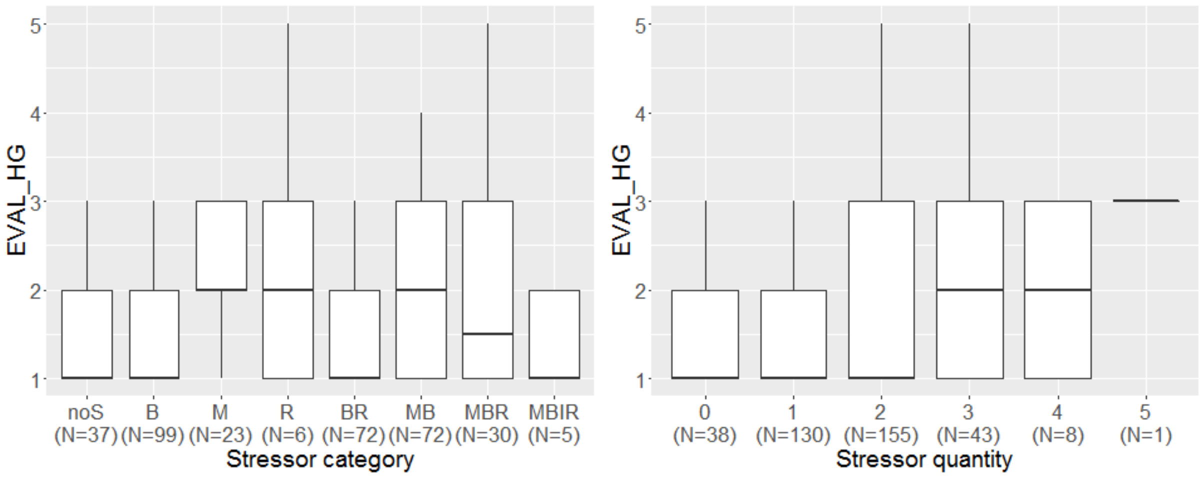



*Figure A11 a and b: Response of indicator 'Evaluation habitat guild' (EVAL_HG) to variables 'Stressor category' and 'Stressor quantity'.*

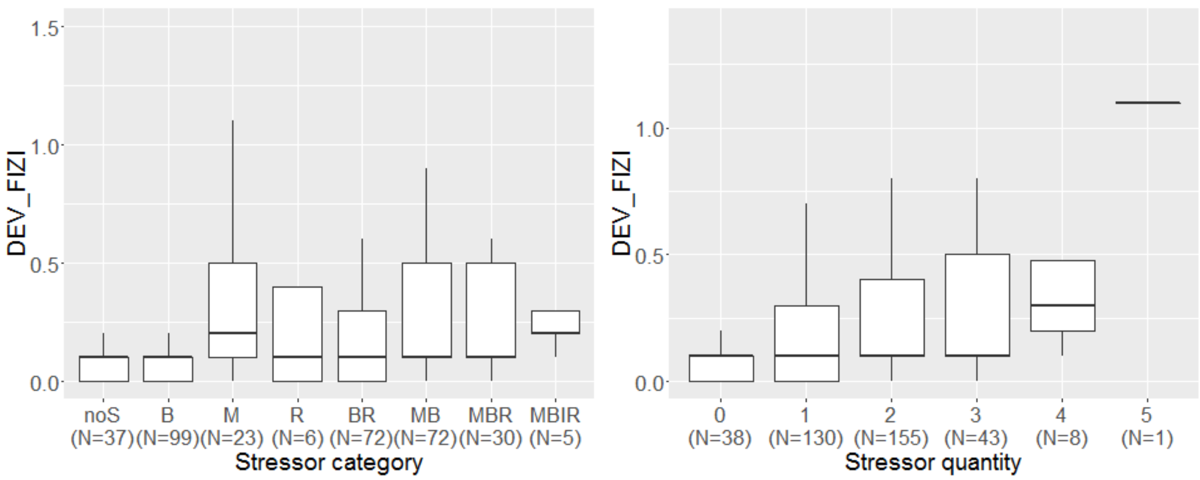



*Figure A12 a and b: Response of indicator 'Deviation fish zonation index' (DEV_FIZI) to variables 'Stressor category' and 'Stressor quantity'.*

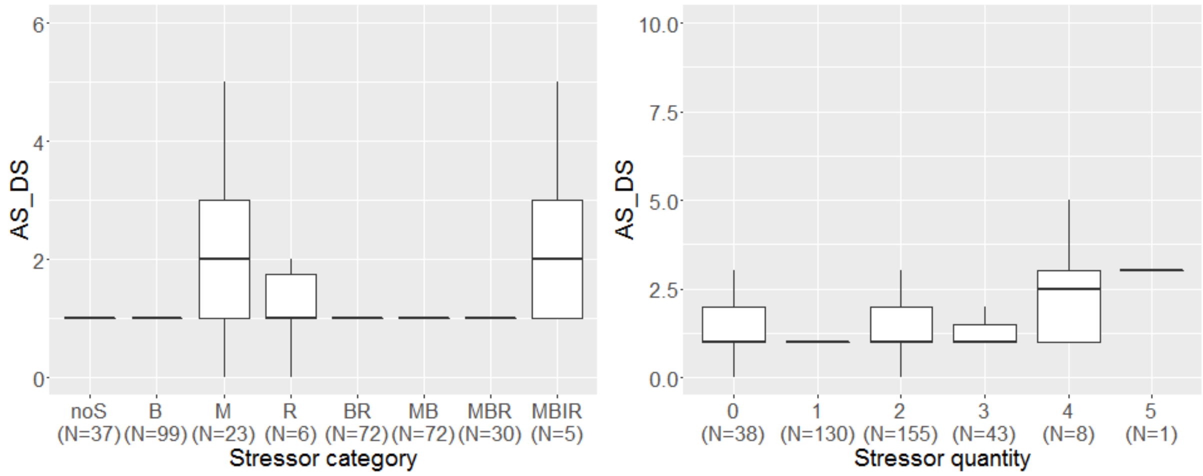



*Figure A13 a and b: Response of indicator 'Age structure dominant species' (AS_DS) to variables 'Stressor category' and 'Stressor quantity'.*

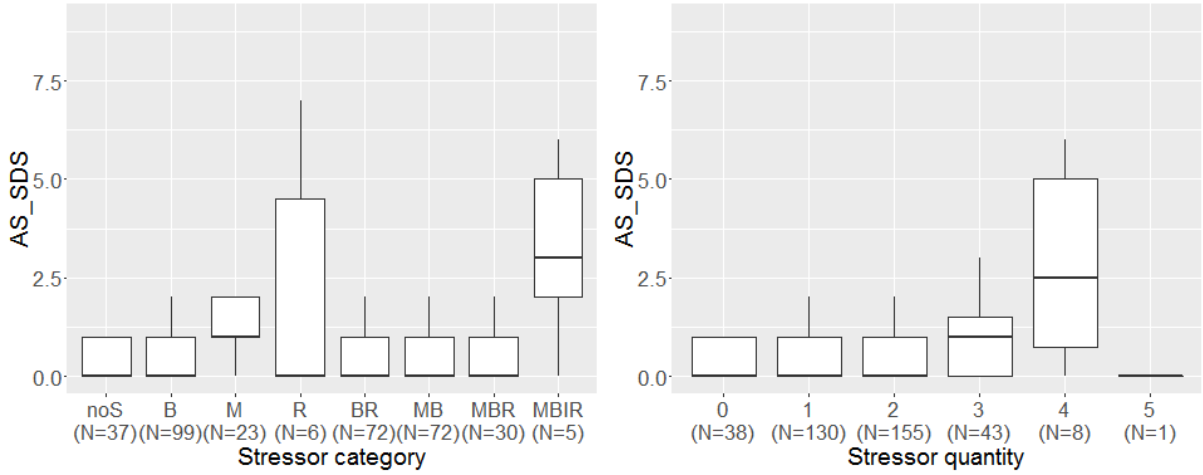



*Figure A14 a and b: Response of indicator 'Age structure subdominant species' (AS_SDS) to variables 'Stressor category' and 'Stressor quantity'.*

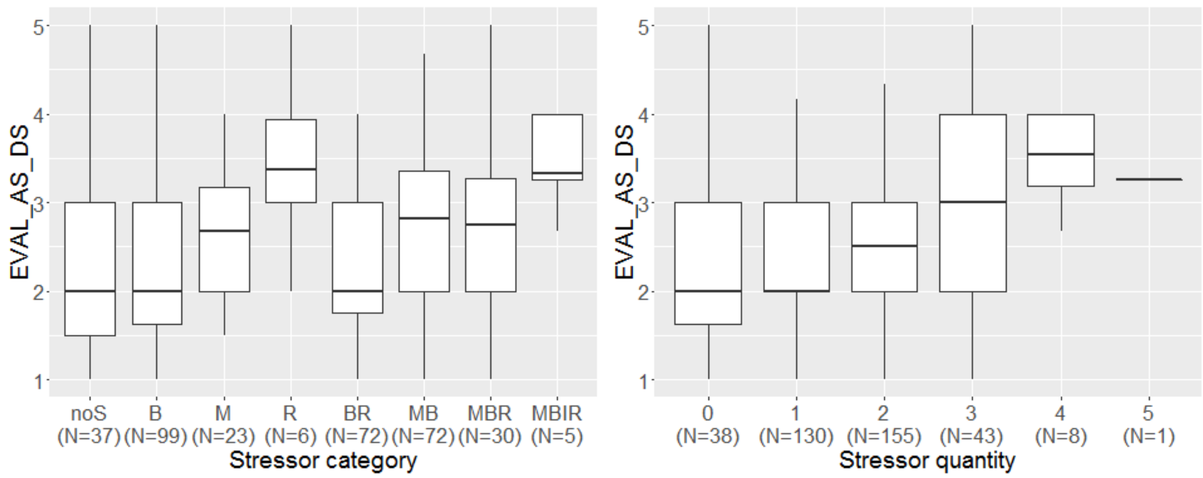



*Figure A15 a and b: Response of indicator 'Evaluation age structure dominant species' (EVAL_AS_DS) to variables 'Stressor category' and 'Stressor quantity'.*

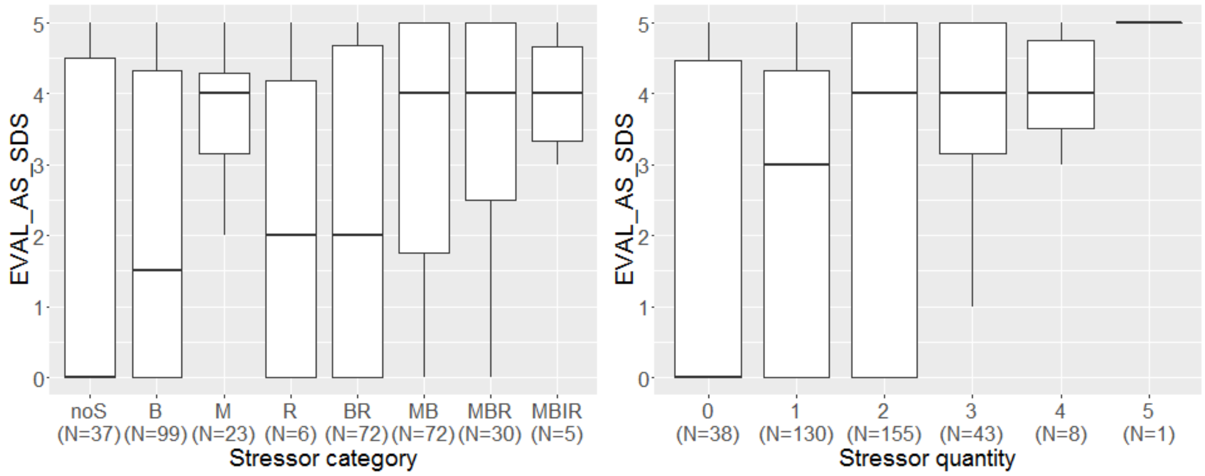



*Figure A16 a and b: Response of indicator 'Evaluation age structure subdominant species' (EVAL_AS_SDS) to variables 'Stressor category' and 'Stressor quantity'.*

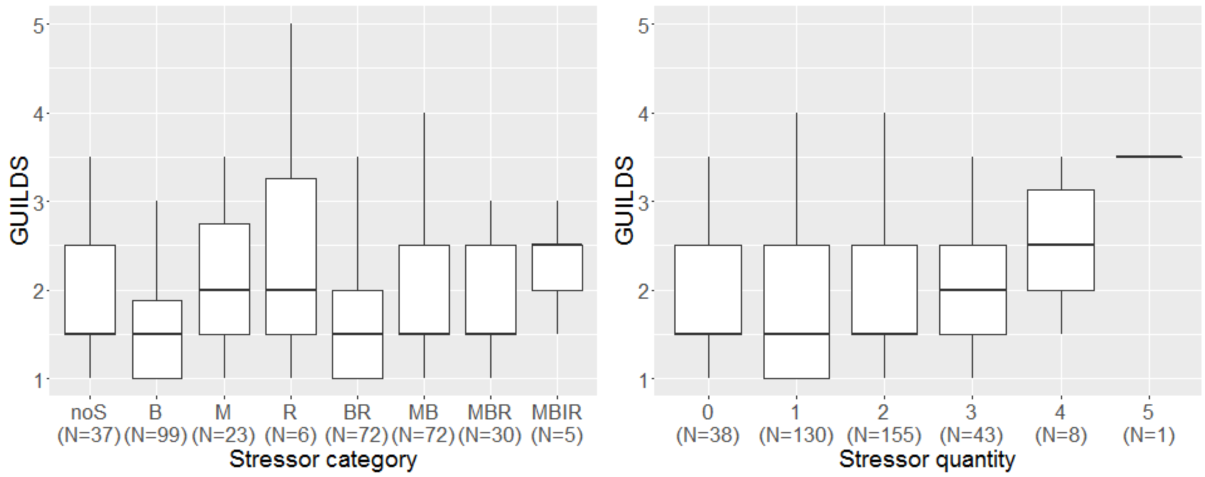



*Figure A17 a and b: Response of indicator 'Evaluation guilds' (GUILDS) to variables 'Stressor category' and 'Stressor quantity'.*

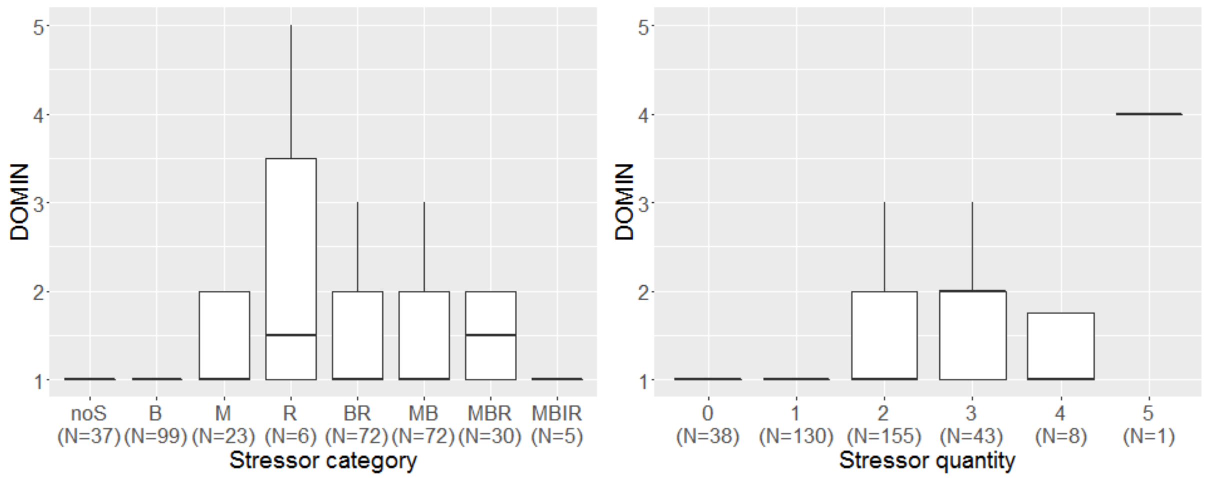



*Figure A18 a and b: Response of indicator 'Evaluation dominance' (DOMIN) to variables 'Stressor category' and 'Stressor quantity'.*

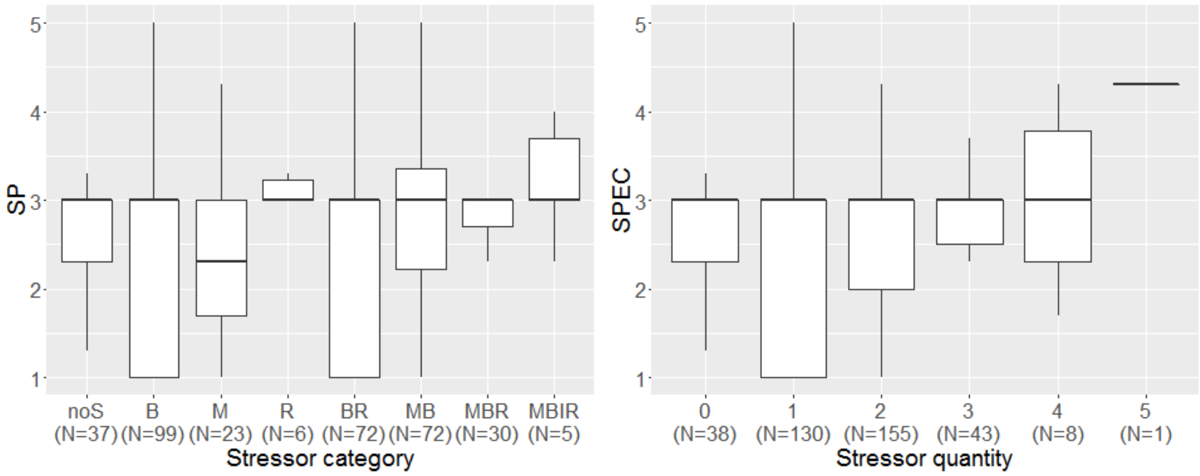



*Figure A19 a and b: Response of indicator 'Evaluation species' (SP) to variables 'Stressor category' and 'Stressor quantity'.*

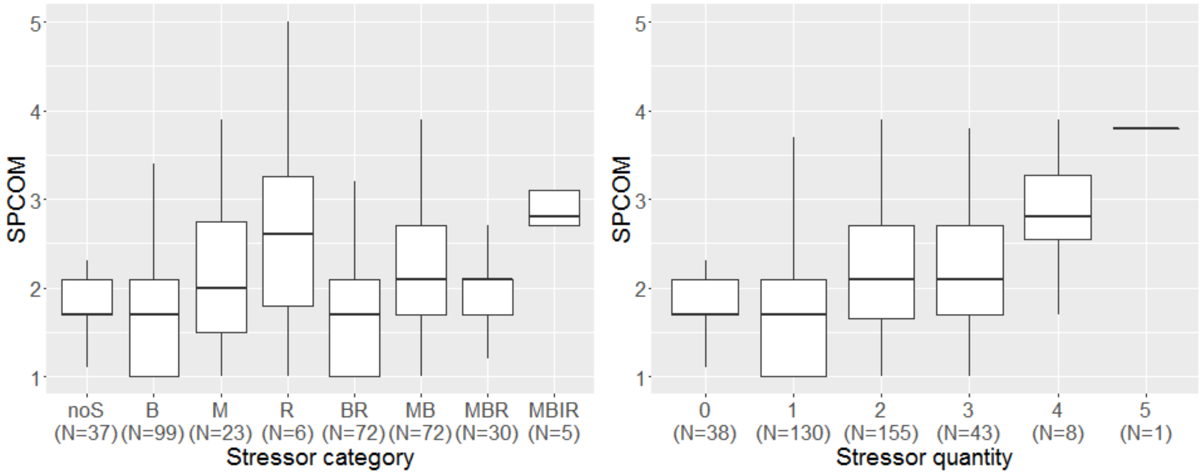



*Figure A20 a and b: Response of indicator 'Evaluation species composition' (SPCOM) to variables 'Stressor category' and 'Stressor quantity'.*

## d. *Full result of BRT models*

*Table A2: Results of BRT models for all indicators including general statistics, ranked variable importance (VIMP) and interactions.*

| | BRT MODEL 1 | | | | | | BRT MODEL 2 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | STAT | | VIMP | | Interactions | | STAT | | VIMP | | Interactions | |
| EVAL_SDS | N trees | 1550 | M | 65 | | | N trees | 1800 | FIZ | 46 | FIZxM | 3 |
| | mean tot dev | 2,23 | R | 18 | | | mean tot dev | 2,23 | M | 35 | | |
| | mean res dev | 2,02 | I | 11 | | | mean res dev | 1,92 | R | 12 | | |
| | estim cv dev | 2,10 | B | 4 | | | estim cv dev | 2,03 | I | 5 | | |
| | se | 0,05 | C | 2 | | | se | 0,07 | B | 2 | | |
| | training data corr | 0,34 | | | | | training data corr | 0,41 | C | 1 | | |
| | cv corr | 0,30 | | | | | cv corr | 0,35 | | | | |
| | se | 0,04 | | | | | se | 0,04 | | | | |
| | goodness of fit | 9,42 | | | | | goodness of fit | 13,66 | | | | |
| DEV_RG | N trees | 3500 | I | 55 | IxM | 1 | N trees | 4400 | FIZ | 67 | FIZxR | 2 |
| | mean tot dev | 1,10 | B | 17 | IxB | 1 | mean tot dev | 1,10 | I | 13 | FIZxM | 1 |
| | mean res dev | 0,93 | M | 15 | | | mean res dev | 0,72 | R | 10 | | |
| | estim cv dev | 0,99 | R | 11 | | | estim cv dev | 0,77 | M | 7 | | |
| | se | 0,07 | C | 1 | | | se | 0,06 | B | 2 | | |
| | training data corr | 0,05 | | | | | training data corr | 0,67 | C | 1 | | |
| | cv corr | 0,37 | | | | | cv corr | 0,61 | | | | |
| | se | 0,03 | | | | | se | 0,04 | | | | |
| | goodness of fit | 15,05 | | | | | goodness of fit | 34,49 | | | | |
| EVAL_RG | N trees | 3050 | I | 43 | | | N trees | 5600 | FIZ | 68 | FIZxR | 1 |
| | mean tot dev | 0,47 | R | 21 | | | mean tot dev | 0,47 | R | 12 | | |
| | mean res dev | 0,40 | B | 21 | | | mean res dev | 0,32 | I | 10 | | |
| | estim cv dev | 0,43 | M | 13 | | | estim cv dev | 0,35 | M | 8 | | |
| | se | 0,04 | C | 2 | | | se | 0,03 | B | 2 | | |
| | training data corr | 0,42 | | | | | training data corr | 0,58 | | | | |
| | cv corr | 0,33 | | | | | cv corr | 0,51 | | | | |
| | se | 0,05 | | | | | se | 0,04 | | | | |
| | goodness of fit | 16,10 | | | | | goodness of fit | 32,42 | | | | |
| AS_SDS | N trees | 4000 | I | 45 | BxM | 60 | N trees | 5200 | FIZ | 81 | FIZxM | 1 |
| | mean tot dev | 2,22 | B | 33 | IxM | 6 | mean tot dev | 2,22 | B | 8 | | |
| | mean res dev | 1,56 | M | 18 | | | mean res dev | 0,83 | I | 7 | | |
| | estim cv dev | 1,76 | R | 4 | | | estim cv dev | 0,94 | M | 2 | | |
| | se | 0,14 | | | | | se | 0,06 | R | 1 | | |
| | training data corr | 0,59 | | | | | training data corr | 0,84 | | | | |
| | cv corr | 0,42 | | | | | cv corr | 0,76 | | | | |
| | se | 0,09 | | | | | se | 0,04 | | | | |
| | goodness of fit | 29,65 | | | | | goodness of fit | 62,36 | | | | |
| AS_DS | N trees | 1200 | M | 37 | BxM | 10 | N trees | 1900 | FIZ | 82 | FIZxM | 6 |
| | mean tot dev | 0,93 | B | 27 | RxM | 3 | mean tot dev | 0,93 | M | 9 | FIZxR | 3 |
| | mean res dev | 0,61 | I | 24 | | | mean res dev | 0,22 | B | 5 | | |
| | estim cv dev | 0,70 | R | 12 | | | estim cv dev | 0,26 | I | 3 | | |
| | se | 0,08 | | | | | se | 0,04 | R | 2 | | |
| | training data corr | 0,55 | | | | | training data corr | 0,86 | | | | |
| | cv corr | 0,43 | | | | | cv corr | 0,84 | | | | |
| | se | 0,05 | | | | | se | 0,02 | | | | |
| | goodness of fit | 34,77 | | | | | goodness of fit | 76,86 | | | | |
| EVAL_AS_DS | N trees | 4200 | M | 39 | RxM | 4 | N trees | 3300 | FIZ | 54 | FIZxR | 2 |
| | mean tot dev | 1,04 | R | 33 | IxM | 1 | mean tot dev | 1,04 | R | 19 | FIZxM | 2 |
| | mean res dev | 0,90 | I | 12 | | | mean res dev | 0,87 | M | 18 | | |
| | estim cv dev | 0,97 | C | 10 | | | estim cv dev | 0,93 | C | 4 | | |
| | se | 0,06 | B | 7 | | | se | 0,06 | I | 4 | | |
| | training data corr | 0,37 | | | | | training data corr | 0,41 | B | 2 | | |
| | cv corr | 0,27 | | | | | cv corr | 0,34 | | | | |
| | se | 0,04 | | | | | se | 0,06 | | | | |
| | goodness of fit | 12,85 | | | | | goodness of fit | 16,14 | | | | |
| EVAL_AS_SDS | N trees | 2850 | M | 63 | IxM | 4 | N trees | 3150 | FIZ | 67 | FIZxM | 34 |
| | mean tot dev | 4,38 | I | 16 | RxM | 1 | mean tot dev | 4,38 | M | 20 | FIZxI | 4 |
| | mean res dev | 3,62 | R | 10 | | | mean res dev | 2,97 | R | 6 | | |
| | estim cv dev | 3,82 | B | 8 | | | estim cv dev | 3,18 | I | 4 | | |
| | se | 0,11 | C | 2 | | | se | 0,14 | B | 1 | | |
| | training data corr | 0,42 | | | | | training data corr | 0,57 | C | 1 | | |
| | cv corr | 0,39 | | | | | cv corr | 0,54 | | | | |
| | se | 0,04 | | | | | se | 0,03 | | | | |
| | goodness of fit | 17,36 | | | | | goodness of fit | 32,21 | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GUILDS | N trees | 3300 | M | 30 | RxM | 2 | N trees | 4350 | FIZ | 78 | FIZxR | 6 |
| | mean tot dev | 0,81 | R | 27 | | | mean tot dev | 0,81 | R | 11 | FIZxM | 1 |
| | mean res dev | 0,70 | I | 23 | | | mean res dev | 0,50 | M | 6 | | |
| | estim cv dev | 0,76 | B | 17 | | | estim cv dev | 0,55 | I | 4 | | |
| | se | 0,10 | C | 4 | | | se | 0,09 | B | 1 | | |
| | training data corr | 0,39 | | | | | training data corr | 0,62 | | | | |
| | cv corr | 0,29 | | | | | cv corr | 0,59 | | | | |
| | se | 0,06 | | | | | se | 0,04 | | | | |
| | goodness of fit | 14,02 | | | | | goodness of fit | 38,62 | | | | |
| SPCOM | N trees | 3050 | M | 35 | RxM | 2 | N trees | 3850 | FIZ | 71 | FIZxR | 2 |
| | mean tot dev | 0,86 | R | 33 | | | mean tot dev | 0,86 | R | 15 | FIZxM | 1 |
| | mean res dev | 0,74 | I | 19 | | | mean res dev | 0,62 | M | 9 | | |
| | estim cv dev | 0,79 | B | 9 | | | estim cv dev | 0,68 | I | 4 | | |
| | se | 0,11 | C | 3 | | | se | 0,09 | B | 2 | | |
| | training data corr | 0,39 | | | | | training data corr | 0,53 | | | | |
| | cv corr | 0,30 | | | | | cv corr | 0,46 | | | | |
| | se | 0,06 | | | | | se | 0,04 | | | | |
| | goodness of fit | 14,22 | | | | | goodness of fit | 27,39 | | | | |
| AS | N trees | 950 | M | 41 | RxM | 12 | N trees | 3750 | FIZ | 51 | FIZxM | 5 |
| | mean tot dev | 0,86 | R | 30 | I | 3 | mean tot dev | 0,86 | M | 22 | FIZxR | 2 |
| | mean res dev | 0,69 | I | 11 | | | mean res dev | 0,67 | R | 19 | | |
| | estim cv dev | 0,75 | C | 9 | | | estim cv dev | 0,72 | C | 5 | | |
| | se | 0,06 | B | 9 | | | se | 0,07 | I | 2 | | |
| | training data corr | 0,45 | | | | | training data corr | 0,47 | B | 1 | | |
| | cv corr | 0,37 | | | | | cv corr | 0,41 | | | | |
| | se | 0,04 | | | | | se | 0,05 | | | | |
| | goodness of fit | 20,26 | | | | | goodness of fit | 21,89 | | | | |
| FIA | N trees | 2600 | M | 40 | RxM | 2 | N trees | 2500 | FIZ | 61 | FIZxR | 4 |
| | mean tot dev | 1,25 | R | 26 | IxM | 1 | mean tot dev | 1,25 | R | 17 | FIZxM | 1 |
| | mean res dev | 1,11 | C | 13 | | | mean res dev | 1,02 | M | 14 | | |
| | estim cv dev | 1,18 | B | 11 | | | estim cv dev | 1,09 | C | 5 | | |
| | se | 0,09 | I | 10 | | | se | 0,09 | B | 2 | | |
| | training data corr | 0,34 | | | | | training data corr | 0,44 | I | 1 | | |
| | cv corr | 0,26 | | | | | cv corr | 0,38 | | | | |
| | se | 0,05 | | | | | se | 0,06 | | | | |
| | goodness of fit | 10,91 | | | | | goodness of fit | 18,14 | | | | |
| ES | N trees | 4250 | R | 39 | RxM | 1 | N trees | 5000 | R | 31 | | |
| | mean tot dev | 0,33 | M | 34 | | | mean tot dev | 0,33 | FIZ | 22 | | |
| | mean res dev | 0,23 | C | 19 | | | mean res dev | 0,21 | M | 22 | | |
| | estim cv dev | 0,25 | B | 6 | | | estim cv dev | 0,24 | C | 16 | | |
| | se | 0,03 | I | 2 | | | se | 0,02 | B | 7 | | |
| | training data corr | 0,53 | | | | | training data corr | 0,57 | I | 2 | | |
| | cv corr | 0,46 | | | | | cv corr | 0,49 | | | | |
| | se | 0,08 | | | | | se | 0,05 | | | | |
| | goodness of fit | 29,97 | | | | | goodness of fit | 34,86 | | | | |
| DEV_FIZI | N trees | 2500 | R | 47 | RxM | 5 | N trees | 3200 | FIZ | 75 | FRxR | 3 |
| | mean tot dev | 0,47 | M | 34 | | | mean tot dev | 0,47 | R | 14 | FRxM | 1 |
| | mean res dev | 0,43 | I | 13 | | | mean res dev | 0,40 | M | 7 | | |
| | estim cv dev | 0,46 | B | 4 | | | estim cv dev | 0,43 | I | 3 | | |
| | se | 0,14 | C | 2 | | | se | 0,13 | | | | |
| | training data corr | 0,35 | | | | | training data corr | 0,40 | | | | |
| | cv corr | 0,17 | | | | | cv corr | 0,41 | | | | |
| | se | 0,09 | | | | | se | 0,06 | | | | |
| | goodness of fit | 9,96 | | | | | goodness of fit | 15,25 | | | | |
| DEV_HG | N trees | 1600 | M | 63 | CxM | 1 | N trees | 3600 | FIZ | 90 | FIZxR | 3 |
| | mean tot dev | 1,28 | B | 13 | | | mean tot dev | 1,28 | M | 3 | FIZxM | 1 |
| | mean res dev | 1,16 | I | 12 | | | mean res dev | 0,39 | I | 3 | | |
| | estim cv dev | 1,21 | R | 10 | | | estim cv dev | 0,43 | R | 2 | | |
| | se | 0,04 | C | 1 | | | se | 0,07 | B | 2 | | |
| | training data corr | 0,33 | H | 1 | | | training data corr | 0,81 | | | | |
| | cv corr | 0,27 | | | | | cv corr | 0,80 | | | | |
| | se | 0,04 | | | | | se | 0,03 | | | | |
| | goodness of fit | 9,15 | | | | | goodness of fit | 69,80 | | | | |
| EVAL_HG | N trees | 2400 | M | 48 | RxM | 1 | N trees | 4650 | FIZ | 83 | FIZxR | 3 |
| | mean tot dev | 0,54 | R | 31 | | | mean tot dev | 0,54 | R | 9 | FIZxM | 1 |
| | mean res dev | 0,48 | B | 9 | | | mean res dev | 0,25 | M | 5 | | |
| | estim cv dev | 0,52 | I | 7 | | | estim cv dev | 0,05 | I | 2 | | |
| | se | 0,04 | C | 6 | | | se | 0,69 | B | 1 | | |
| | training data corr | 0,32 | | | | | training data corr | 0,05 | | | | |
| | cv corr | 0,21 | | | | | cv corr | 0,66 | | | | |
| | se | 0,04 | | | | | se | 0,05 | | | | |
| | goodness of fit | 10,07 | | | | | goodness of fit | 53,54 | | | | |

## e. Partial dependence plots of BRT models

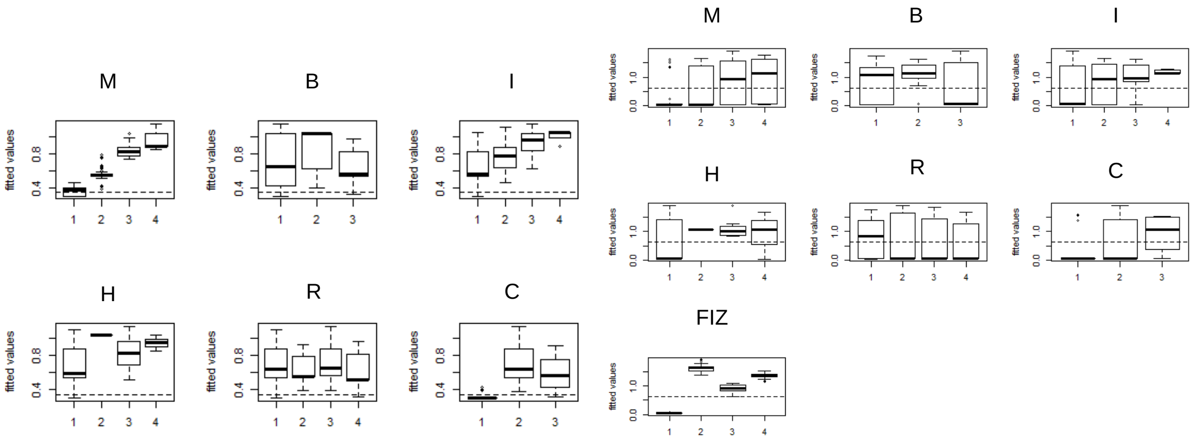



*Figure A21: Partial dependence plots showing the response of indicator 'Deviation habitat guild' (DEV_HG) to single stressors and fish zone for model 1 (left) and model 2 (right).*

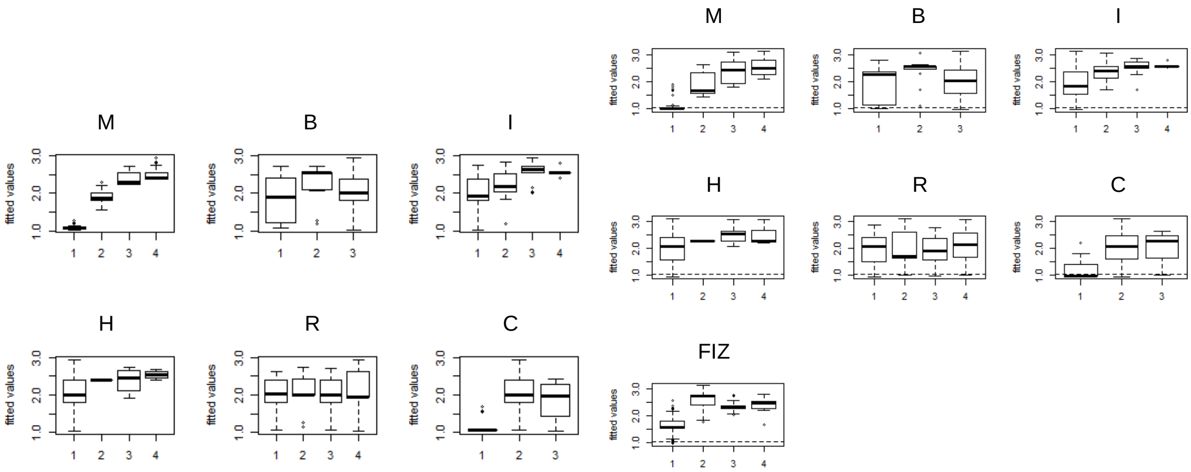



*Figure A22: Partial dependence plots showing the response of indicator 'Evaluation subdominant species' (EVAL_SDS) to single stressors and fish zone for model 1 (left) and model 2 (right).*

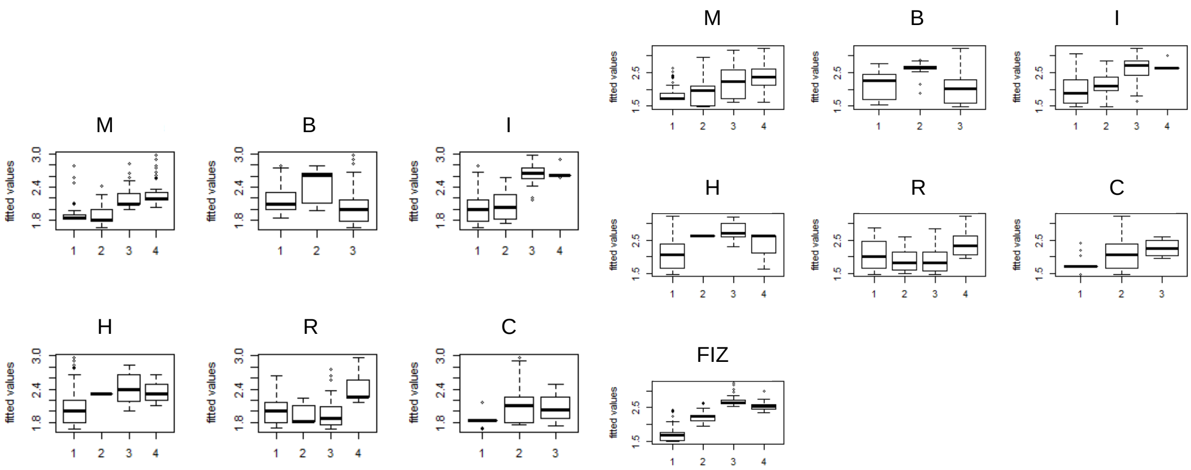



*Figure A23: Partial dependence plots showing the response of indicator 'Evaluation species composition' (SPCOM) to single stressors and fish zone for model 1 (left) and model 2 (right).*

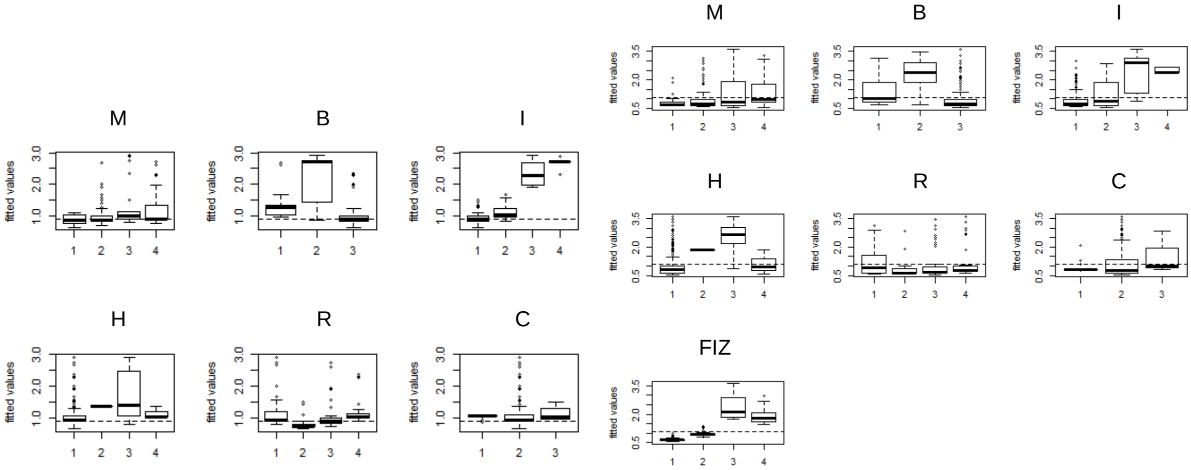



*Figure A24: Partial dependence plots showing the response of indicator 'Deviation reproductive guild' (DEV_RG) to single stressors and fish zone for model 1 (left) and model 2 (right).*

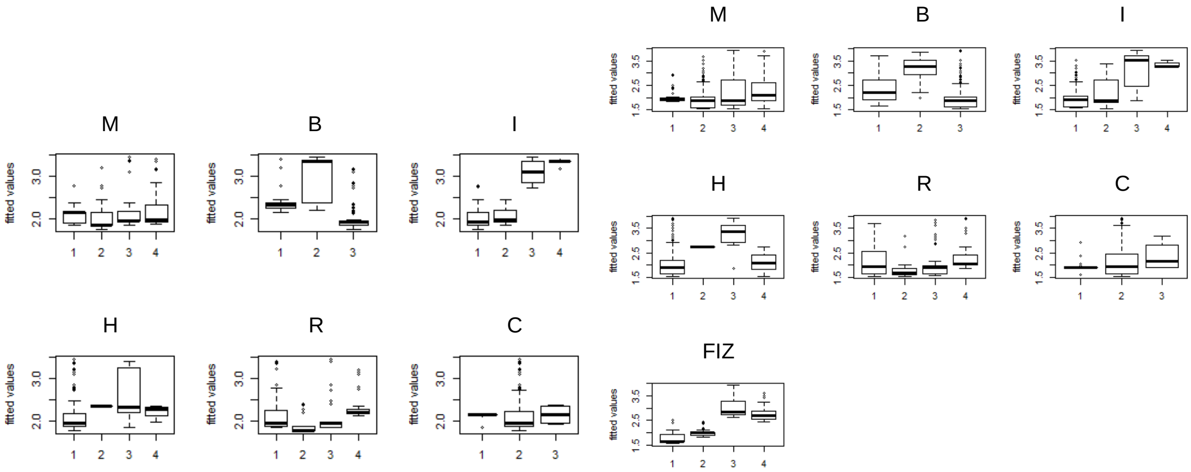



*Figure A25: Partial dependence plots showing the response of indicator 'Evaluation reproductive guild' (EVAL_RG) to single stressors and fish zone for model 1 (left) and model 2 (right).*

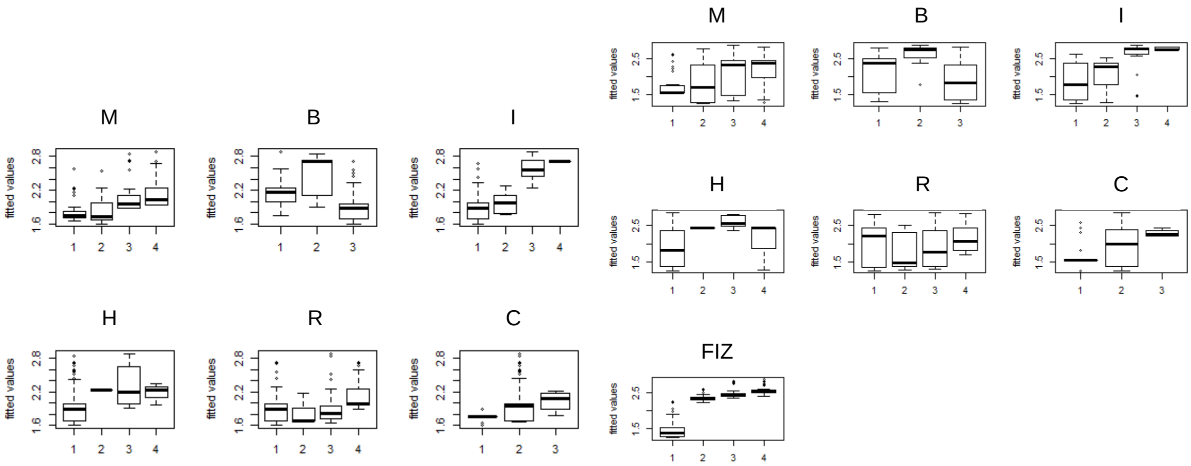



*Figure A26: Partial dependence plots showing the response of indicator 'Evaluation guilds' (GUILDS) to single stressors and fish zone for model 1 (left) and model 2 (right).*

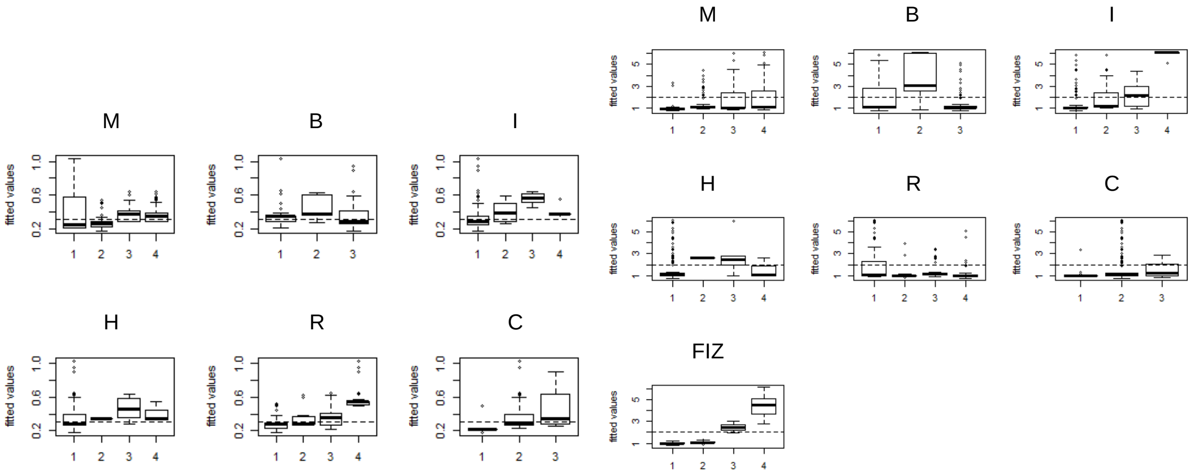



*Figure A27: Partial dependence plots showing the response of indicator 'Age structure dominant species' (AS_DS) to single stressors and fish zone for model 1 (left) and model 2 (right).*

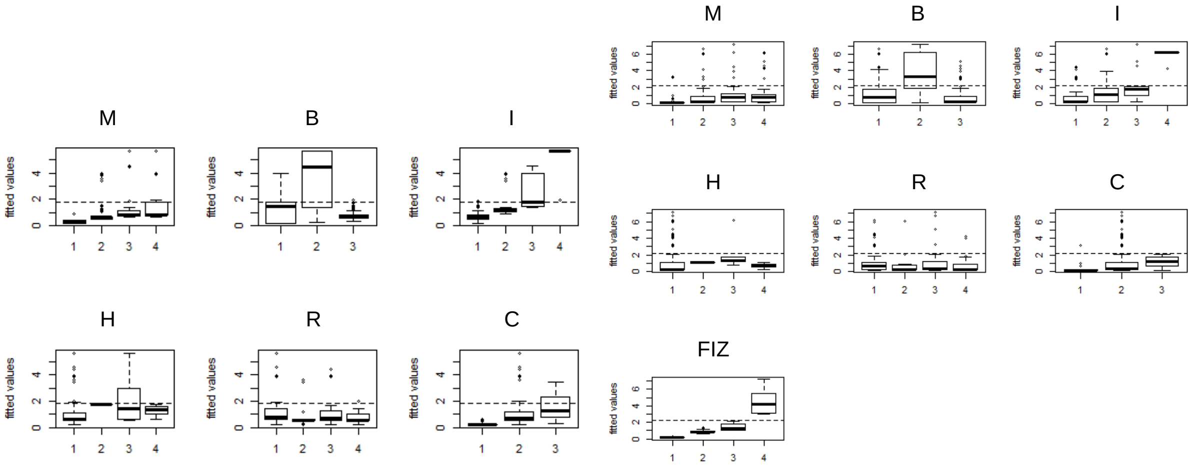



*Figure A28: Partial dependence plots showing the response of indicator 'Age structure subdominant species' (AS_SDS) to single stressors and fish zone for model 1 (left) and model 2 (right).*

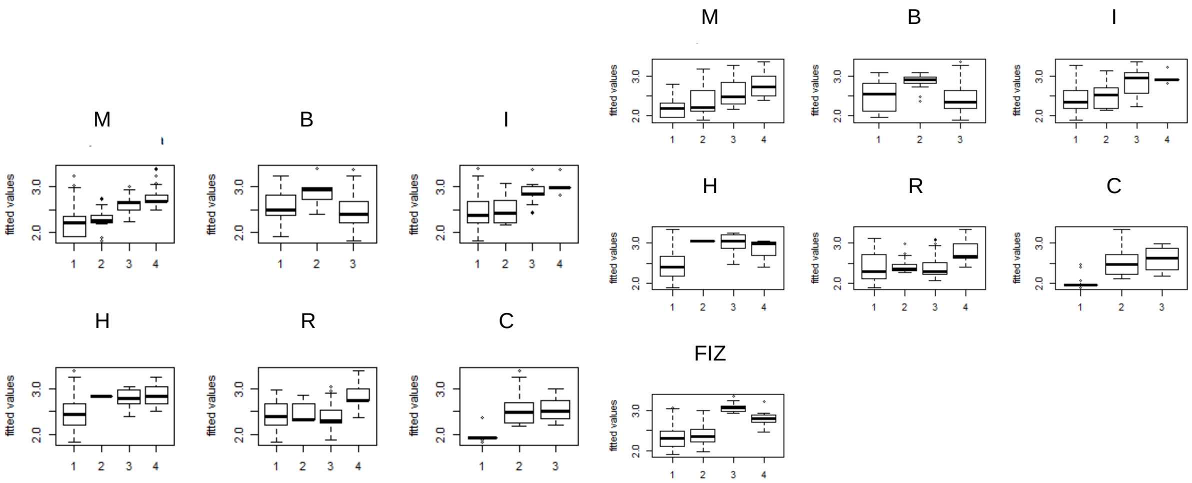



*Figure A29: Partial dependence plots showing the response of indicator 'Evaluation age structure dominant species' (EVAL_AS_DS) to single stressors and fish zone for model 1 (left) and model 2 (right).*

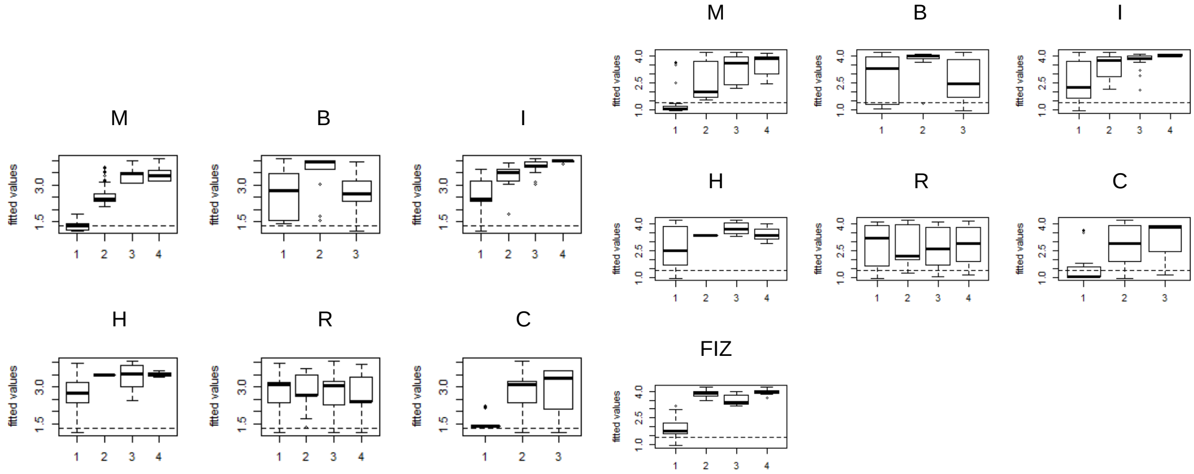



*Figure A30: Partial dependence plots showing the response of indicator 'Evaluation age structure subdominant species' (EVAL_AS_SDS) to single stressors and fish zone for model 1 (left) and model 2 (right).*

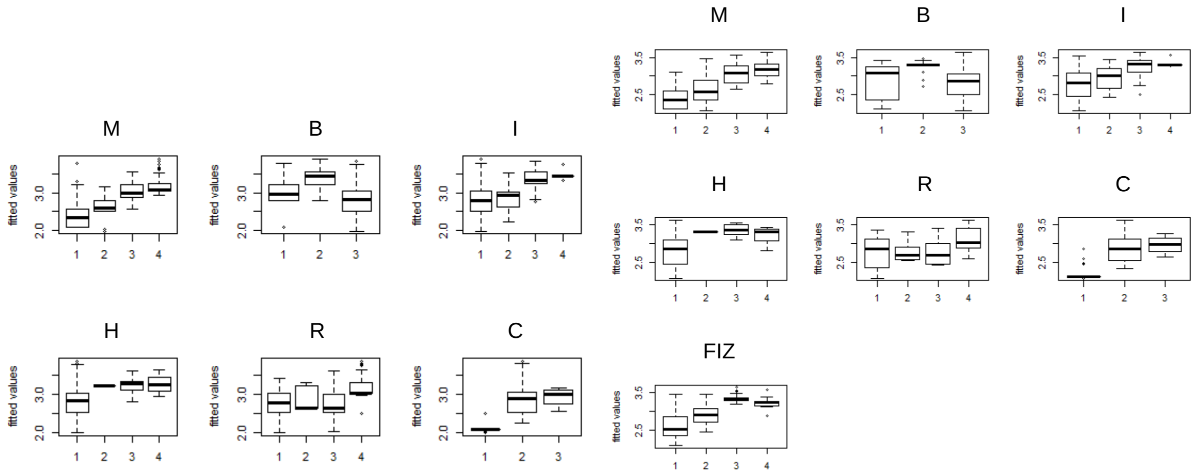



*Figure A31: Partial dependence plots showing the response of indicator 'Evaluation age structure' (AS) to single stressors and fish zone for model 1 (left) and model 2 (right).*

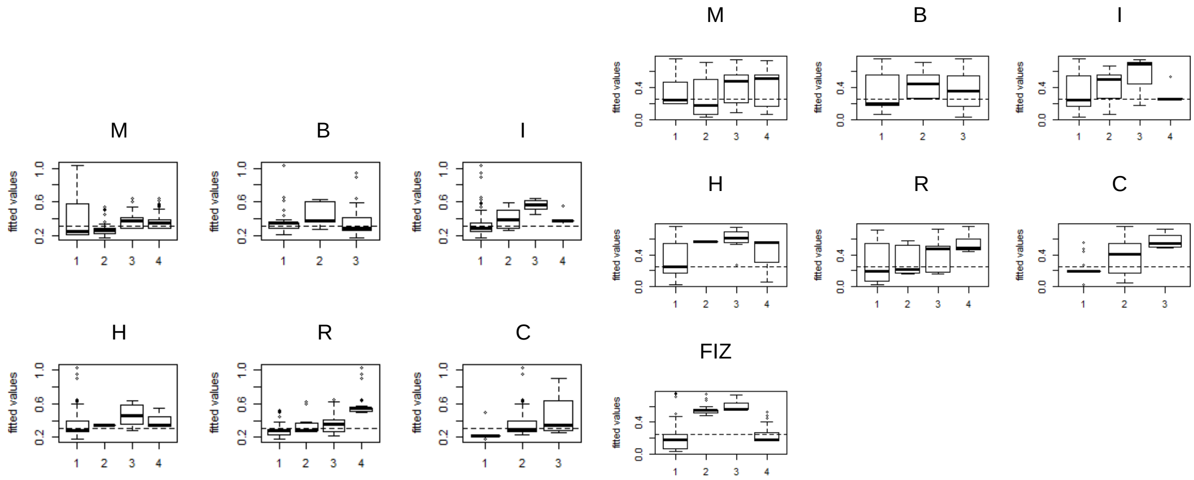



*Figure A32: Partial dependence plots showing the response of indicator 'Deviation fish zonation index' (DEV_FIZI) to single stressors and fish zone for model 1 (left) and model 2 (right).*

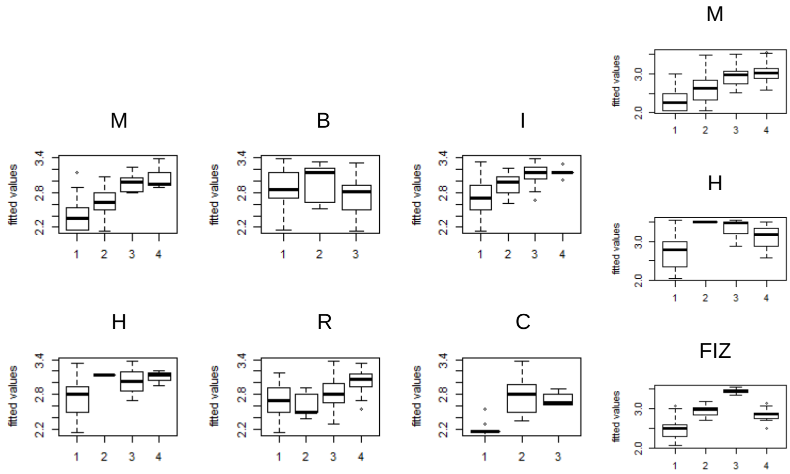



*Figure A33: Partial dependence plots showing the response of indicator 'Fish Index Austria' (FIA) to single stressors and fish zone for model 1 (left) and model 2 (right).*

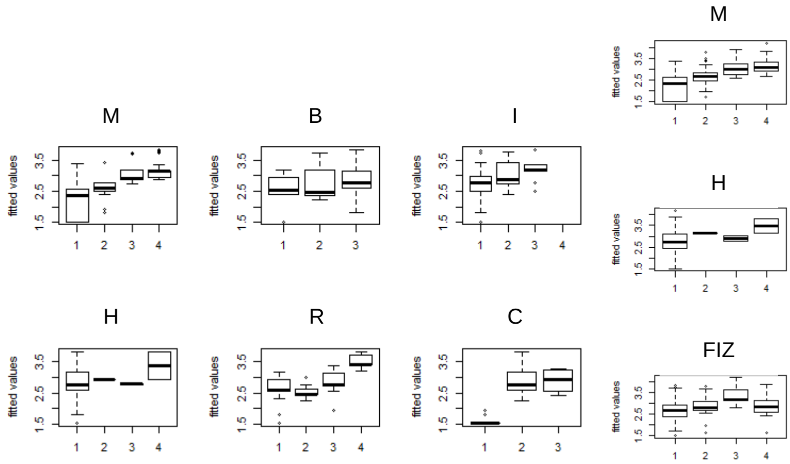



*Figure A34: Partial dependence plots showing the response of indicator 'ecological status' (ES) to single stressors and fish zone for model 1 (left) and model 2 (right).*

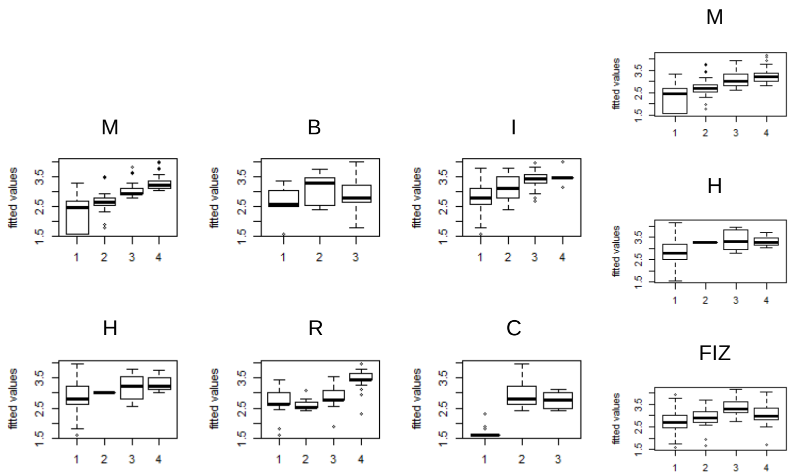



*Figure A35: Partial dependence plots showing the response of indicator 'biological status' (BS) to single stressors and fish zone for model 1 (left) and model 2 (right).*

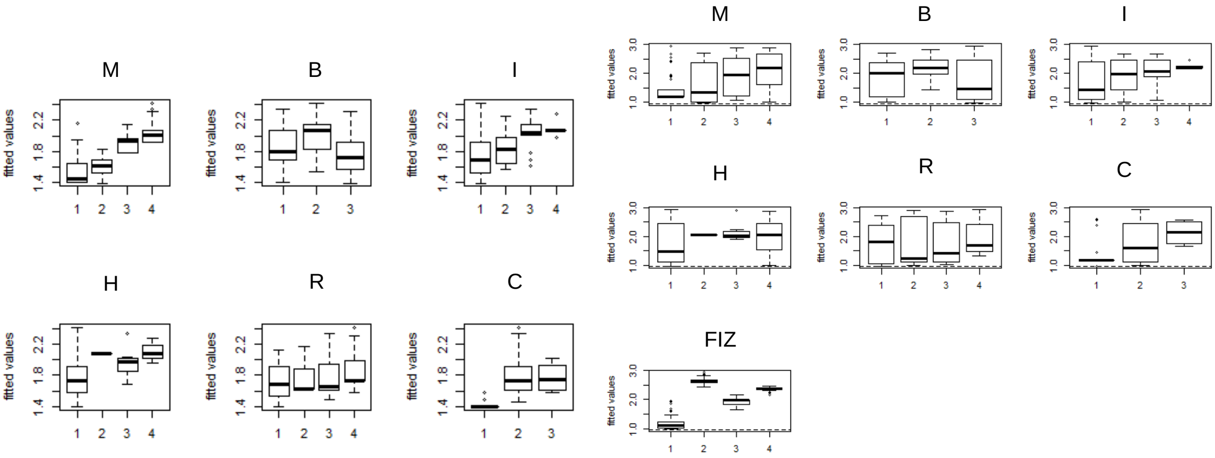



*Figure A36: Partial dependence plots showing the response of indicator 'Evaluation habitat guild' (EVAL_HG) to single stressors and fish zone for model 1 (left) and model 2 (right).*