NTNU – Trondheim
Norwegian University of
Science and Technology

Do Cash Crops and Species Compete for Scarce Water?

Milda Petersone

Master in Industrial Ecology
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Supervisor: Francesca Verones, EPT
Co-supervisor: Daniel Moran, EPT

Norwegian University of Science and Technology
Department of Energy and Process Engineering

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MASTER THESIS

for

Milda Petersone

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Do Cash Crops and Species Compete for Scarce Water?

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Background and objective

Amphibians are one of the vertebrate groups facing the highest extinction risks worldwide. Water scarcity, due to human competition for water, is of the key stressors to their ecosystems. More than two thirds of global water use is for agriculture. Previous studies have compiled consumption-based accounts of water use in order to track "embodied" water in goods (e.g. water used to make t-shirts) to final consumers. While some studies on water trade embedded in commodities have distinguished water produced using scarce vs. non-scarce resources, none have investigated the links between scarce water use, trade, and biodiversity. The aim of the master thesis is to test, empirically, whether there a relationship is observed between amphibian species under threat, as reported by the IUCN Red List of Threatened and Endangered Species, and water use for the production of export commodities (i.e. cash crops). This analysis will be conducted using spatially explicit correlation analysis in form of multi – dimensional scatterplots and correlation maps.

The following tasks are to be considered:

To investigate the relationship between scarce water use and A*mphibia* under threat we shall look retrospectively at extant data from prior years and test whether areas producing cash crops using scarce water overlap with areas providing habitat to many amphibians, or areas where amphibians are disproportionately threatened. Two hypotheses are proposed:

1. Areas exporting more scarce water due to cash crop production have lower amphibian species richness.
2. Areas exporting more scarce water due to cash crop production have higher overall amphibian species threat level.

The thesis shall test these hypotheses using the experiment design developed in this student's 2014 Master's Project report. Specific tasks include:

1. Perform cash crop anaysis and determine cash crops using statistical data about world agricultural production and trade from the UN FAO.
2. Perform spatially explicit correlation analysis in form of multi-dimensional scatterplots between scarce water exports and amphibian biodiversity threats.

3. Investigate spatial patterns of the relationship between scarce water exports and amphibian biodiversity threats by making maps.

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Within 14 days of receiving the written text on the master thesis, the candidate shall submit a research plan for his project to the department.

When the thesis is evaluated, emphasis is put on processing of the results, and that they are presented in tabular and/or graphic form in a clear manner, and that they are analyzed carefully.

The thesis should be formulated as a research report with summary both in English and Norwegian, conclusion, literature references, table of contents etc. During the preparation of the text, the candidate should make an effort to produce a well-structured and easily readable report. In order to ease the evaluation of the thesis, it is important that the cross-references are correct. In the making of the report, strong emphasis should be placed on both a thorough discussion of the results and an orderly presentation.

The candidate is requested to initiate and keep close contact with his/her academic supervisor(s) throughout the working period. The candidate must follow the rules and regulations of NTNU as well as passive directions given by the Department of Energy and Process Engineering.

Risk assessment of the candidate's work shall be carried out according to the department's procedures. The risk assessment must be documented and included as part of the final report. Events related to the candidate's work adversely affecting the health, safety or security, must be documented and included as part of the final report. If the documentation on risk assessment represents a large number of pages, the full version is to be submitted electronically to the supervisor and an excerpt is included in the report.

Pursuant to "Regulations concerning the supplementary provisions to the technology study program/Master of Science" at NTNU §20, the Department reserves the permission to utilize all the results and data for teaching and research purposes as well as in future publications.

The final report is to be submitted digitally in DAIM. An executive summary of the thesis including title, student's name, supervisor's name, year, department name, and NTNU's logo and name, shall be submitted to the department as a separate pdf file. Based on an agreement with the supervisor, the final report and other material and documents may be given to the supervisor in digital format.

☐ Work to be done in lab (Water power lab, Fluids engineering lab, Thermal engineering lab)
☐ Field work

Department of Energy and Process Engineering, 14. January 2014

Olav Bolland
Department Head

F. Verones
Francesca Verones
Academic Supervisor

Research Advisor: Daniel Moran

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Lastly, I would like to thank my family for their support and all my fellow classmates at Industrial Ecology for the time we spent together these two years.

Abstract

Water scarcity is a major environmental challenge of today. More than 2/3 of global water consumption is used in agriculture, part of which for export production or so called cash crops. Some argue that trade of water intensive crops can alleviate differences in water scarcity. However, trade can also put pressure on local water resources and ecosystems when crops are produced in water scarce regions. This study explores if cash crops and species compete for scarce water by investigating global correlation in year 2000 between scarce water consumption in cash crop production and species richness and vulnerability level of water dependent animals – amphibians. It was found that most scarce water intensive cash crops are produced in areas where low number of amphibian species live, suggesting no competition between cash crops and amphibian richness in the present agricultural areas. Moreover, in the present analysis it was found that most cash crops do not compete with vulnerable amphibians, which live in areas with minimal or no cash crop production. There are exceptions, however, where scarce water intensive cash crops, rich amphibian diversity and vulnerable amphibians coexist. Investigation of Western Ghats in India reveals that some cash crops like coffee and rice may sustain amphibians where their natural habitat is lost. This study can suggest potential hotspots for further local investigations looking at the relationship between water scarcity and biodiversity.

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Abbreviations

BW – Blue Water

CBD - Convention on Biological Diversity

EOO – Extent of Occurrence

EU – European Union

FAO – Food and Agriculture Organization of the United Nations

FAOSTAT - Food and Agriculture Organization of the United Nations, Statistics Division

IUCN - International Union for Conservation of Nature

LCIA – Life Cycle Impact Assessment

RED - Relevant for Environmental Deficiency

TL – Threat Level

UN – United Nations

VS – Vulnerability Score

WSI – Water Stress Index

WWF – World Wildlife Fund

1 Introduction

Due to the limited availability and uneven distribution of global freshwater resources, water scarcity is recognized as a coming major environmental concern (Postel 2000, Shiklomanov et al. 2003, Oki et al. 2006, Vörösmarty et al. 2010). According to Postel (2000) two of the main challenges linked to water scarcity are, firstly, maintaining food security with increasing water constraints in agriculture, and secondly, preventing a downward trend in the health of ecosystems. These sustainability challenges of increased water scarcity, food security and loss of biodiversity are daunting enough in isolation, and gets even more complex recognizing interconnection and feedback loops between them (Liu et al. 2015). In this study, only a small part of the complex water-food-biodiversity puzzle is investigated, namely the relationship between scarce water use in agriculture and biodiversity.

It is well known that aquatic and semiaquatic organisms such as amphibians are affected by surface and ground water depletion and reduced water availability (Lévêque et al. 2005, Balian et al. 2008). Therefore, it may be assumed, that water consumption in agriculture - the major water consumer globally - competes with these species, and that increased abstraction for agriculture will be likely associated with biodiversity threats. Water-dependent species are in general at a greater risk of extinction than land-based species and the primary reason for this trend is habitat change (Millenium Ecosystem Assessment 2005, WWF 2014). Habitat change is a complex phenomenon, consisting of a mix of direct impacts e.g. by land use and land cover change, and indirect impacts including eutrophication and competition with anthropogenic water abstraction (Millenium Ecosystem Assessment 2005). Due to this complexity, exact environmental impacts to particular species loss are mostly not known, however, it is believed that in most cases threatened species are affected by multiple drivers at the same time (Sodhi et al. 2008, Dirzo et al. 2014). To simplify this complex system, one may ask merely if water withdrawals and scarce water consumption in agriculture in particular can be used as a proxy for biodiversity threats.

While much of the water is used locally to satisfy domestic needs it has been estimated that up to one fifth of the total global water consumption in agriculture is used for production of cash crops or agricultural products traded between countries (Hoekstra et al. 2012). Moreover, it can be assumed that, the role of traded food commodities will only increase in the future as climate change will influence global food security (FAO 2015). It has been argued (Allan 1997, Chapagain et al. 2006, Yang et al. 2006) that trade in water-intensive crops can help alleviate differences in scarcity (i.e. when a humid region exports water-intensive crops to an arid region). At the same time, the opposite often occurs and the outflow of water embedded in water intensive commodities adds pressure on the local water resources and ecosystems. Adding to this, Lenzen et al. (2012) found that up to 1/3 of global species threats can be attached to traded commodities.

Against this background the following research question is posed: Do cash crops and species compete for scarce water? To investigate this, historic data from the year 2000 is examined in order to test for the existence of an overlap between areas producing export crops using scarce water, and areas experiencing amphibian biodiversity threats. The research question may be translated into two testable, falsifiable hypotheses:

1. Areas exporting more scarce water due to cash crop production have a lower amphibian species richness;
2. Areas exporting more scarce water due to cash crop production have higher overall amphibian species vulnerability level

In the next section a more detailed background of the water – food – biodiversity challenge and an introduction to the main concepts is given before proceeding with a presentation of the methods, results and discussion.

2 Background

2.1 Global biodiversity challenge

Biodiversity loss is a major environmental challenge. Over the past 50 years humanity has changed global ecosystems more than ever before in the human history (Hassan et al. 2005). This has led to a massive and largely irreversible biodiversity loss, so great that it has been called earth's "sixth extinction wave" (Barnosky et al. 2011, Ceballos et al. 2015, Régnier et al. 2015). The effects of this massive loss of species and populations of wildlife extend across nearly all taxonomic groups, yet some are more acutely affected than others (Cardillo et al. 2008). Amphibians, which include frogs, salamanders, newts and caecilians are limited by temperature, humidity and geographic barriers and therefore are particularly sensitive to changes in their ecosystems. Patterns of defaunation show that these are the vertebrates under the highest extinction risk with 41% of all amphibians currently considered threatened and 43% experiencing population declines (Stuart et al. 2004, Schipper et al. 2008).

Despite the awareness of biodiversity loss and many research efforts put into the problem, it has been challenging to measure the state of biodiversity and link particular drivers to its loss. The ground reason for this lies in the complexity of the biodiversity concept itself and its many aspects. The Convention on Biological Diversity (CBD), which is the authoritative international treaty on biodiversity conservation defines biological diversity as *'the variability among living organisms from all sources including, inter alia, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and among ecosystems'* (UN 1992). Biodiversity therefore is a multidimensional concept, and the challenge is how to measure such a broad phenomenon in ways that are representative and possible.

Even though most of the species have not been assessed globally, the expansion of research on biodiversity in the past years is bigger and more ambitious than ever. These developments are reflected by the increasing amount and availability of quantitative data with a global coverage like extinction risk of species from the IUCN database (IUCN 2012a) and such projects measuring global biodiversity as the Living Planet Index (WWF 2014) and the Map of Live (MOL 2015). These developments make the current study possible.

2.2 Drivers to amphibian loss

The stressors affecting amphibians are numerous and include pollution, habitat change, invasive species and pathogens, diseases and climate change (Dudgeon et al. 2006, Falkenmark et al. 2008, Smakhtin 2008, Sodhi et al. 2008, Vörösmarty et al. 2010).

Stuart et al. (2004) in their first global assessment of amphibians divided all rapidly declining species in three groups based on the cause of their decline. They found that in addition to habitat loss (considered the main cause of amphibian biodiversity threats according to the IUCN (2015)) and overexploitation, 'enigmatic decline' is a reason for many amphibian declines globally. With this, authors mean that decline takes place even in areas where suitable habitat remains and reasons for these declines are poorly understood. In addition to this study, many others (Lips et al. 2008, Rohr et al. 2008, Sodhi et al. 2008, Hof et al. 2011) point out the poor understanding of drivers of amphibian declines and even poorer insight into interconnections and synergies between the drivers, supporting the need of increased understanding of amphibian declines.

Habitat change, the principal driver of biodiversity declines, affects species both directly and indirectly. The main direct impact is land-use change. The best empirical study so far investigating the relationship between global land-use change and biodiversity loss has been done by Newbold et al. (2015) where authors have analysed local biodiversity data, comparing areas with no human impacts with similar areas modified by human use. The study clearly points out the links between agricultural land-use and biodiversity declines. According to the study, most impacts have occurred from land conversion to cropland and pasture causing species richness to decline by 8.1% on average globally. Most losses have happened in heavy grazed areas and areas that have experienced rapid agricultural growth to support the heavily growing population.

In addition to being the main driver of global land-use change, agriculture is the major water consumer globally causing indirect habitat changes due to extensive water withdrawals. According to Vörösmarty et al. (2010) 65% of global river discharge is under threat due to flow depletion from unsustainable water withdrawals (and therefore the aquatic habitats supported by this water are under threat as well). The exact link between biodiversity and intensity of water withdrawals due to agriculture is, however, not clear.

Even though amphibians are found in almost all habitat types, most species depend on freshwater and moist environments at some part of their lives to keep their skin moist and to reproduce (Balian et al. 2008). In general, amphibians breed and lay eggs in wetlands and other aquatic habitats and move to terrestrial areas to spend the winter (IUCN 2015). Therefore, amphibians are especially dependent on availability of fresh water. In addition, water scarcity tends to intensify the effects of other stressors to amphibians (Navarro-Ortega et al. 2014), e.g. by increasing concentration of pollution.

Therefore, as amphibians are highly threatened globally and are dependent on water, they have in this paper been selected in order to study the link between biodiversity threats and scarce water consumption in agriculture.

2.3 Water scarcity and agriculture

Water scarcity occurs when the demand for water is higher than the available resource. Even though it is estimated that currently less than 10% of the maximum available ground and surface freshwater resources are withdrawn by humans, due to high temporal and spatial variability, approximately 1/3 of the world's population and 65% of the habitats are under high levels of threat to water scarcity (Postel et al. 1996, Oki et al. 2006). Moreover, water scarcity is projected to continue to grow. This is due in part to expected increases in variability in hydrological cycles caused by climate change (Kenneth 2002), but also due to a expected continuation of increased water use in the agricultural sector (Shiklomanov et al. 2003, Pfister et al. 2011b), responsible for 80% of human water use.

Most of the ground and surface water used in agriculture is due to crop irrigation. Irrigation is applied to avoid water deficits that reduce crop production and is especially a large water consumer in semi-arid and arid zones exceeding 80% of the total water withdrawals (Fereres et al. 2007).

As irrigated crops have much higher yields, at least 40% of the total food production comes from irrigated agriculture while using only 16% of the total agricultural area. Therefore, it is considered important to expand irrigated agriculture to increase food security especially given the prognosis of increased food demand in the future (Dyson 1999). As a positive example here, we can mention India, which in the last several decades has attained food self-sufficiency from wheat and rice production in irrigated lands in the semi-arid plains of Punjab (Matson et al. 1997).

At the same time, irrigated agriculture is pointed out as highly inefficient and water resources wasteful (Postel et al. 1996). Overpumping of groundwater is a serious concern in many regions and irrigated agricultural lands in semi-arid and arid regions are degraded by salinization and waterlogging. Irrigation also affects the quality of downstream agricultural and natural systems. The problem is that irrigation return-flows usually carry more salt and minerals than surface and groundwater, and irrigation can deplete downstream systems by water withdrawals (Matson et al. 1997). This inevitably leads to pressures on surrounding and downstream ecosystems, and points out the importance to investigate food versus biodiversity trade-offs.

2.4 Water embedded in commodities and virtual water trade

The concepts of water footprint and virtual water trade have been used extensively in the last decade to account for how much water that is required for production of particular goods and how much of the embodied water in these goods (water consumed for production) are traded between regions (Allan 1996, Hoekstra 2003, Orlowsky et al. 2014). The concepts have played an important role in showing how interconnected water uses across the globe are, and linking global trade and water resources management, which traditionally has been conducted within administrative boundaries (Hoekstra 2009).

Majority of studies investigate virtual water trade of agricultural commodities as food production is responsible for more than 2/3 of the global water consumption (Shiklomanov et al. 2003, Pfister et al. 2011b). Traded agricultural commodities are called cash crops; however, historically this term has had slightly various meanings. In the past, the term 'cash crops' was associated with plantation crops purely grown for export such as tea, coffee, rubber, cocoa, tobacco and sugar cane. Currently, however, the term is more often used to distinguish marketed crops or cash crops from subsistence crops or food crops, which are consumed in the household where they are grown. In reality, it is often hard to differentiate between food and cash crops as most food crops are also marketed. This particularly is true for developed countries where almost all agricultural production is later sold (Achterbosch et al. 2014). In this study, cash crops are defined as all agricultural production traded between countries. Approach here refrain from the need to categorize cash vs. food crops by using 'export intensity' defining how much (in %) of the total production of particular crop in a year is exported.

International trade of agricultural commodities has experienced a rapid increase in the past decades. Much of this expansion can be attached to the intra-EU trade representing around 30% of the total trade of agricultural products in 2005. Generally, the largest share of agricultural exports originates in the developed countries and this share is increasing. International trade can provide food security in countries with insufficient domestic food resources. This is the case in many developing countries, which has led to increased imports in the last years (FAO 2005).

Similarly, many argue, that international trade of water intensive commodities as agricultural products can help to distribute uneven water resources and improve global water use efficiency (Allan 1997, Chapagain et al. 2006, Yang et al. 2006, Mekonnen et al. 2014). Virtual water trade is mentioned as one way of 'water smart' food production according to the FAO (WWAP 2012). This can be done when water rich regions export water intensive crops to water scarce regions, or countries with high crop productivity export to less productive countries. At the same time, others have found that the trade of water intensive commodities do not follow the patterns of water scarcity (Verma et al. 2009, Ansink 2010, Wichelns 2015). Virtual water trade flows are strongly influenced by other factors like available agricultural land or accessibility to markets. In this case water trade embedded in crops exacerbates water scarcity in already water scarce regions and adds pressure on local water resources and ecosystems.

3 Materials and methods

3.1 Research design

A conceptual research framework of the study is presented in figure 3.1. To answer the research question and test the hypothesis, the relation between scarce water consumption of exported crops and amphibian species threats is investigated for the year 2000. Both are highly dependent on their spatial location, therefore all input data (in coloured boxes) as well as results have spatial dimensions or location on the global map. Input data used here originally have three spatial resolutions: country, cell (5x5 arc minutes) and cell (3x3 arc minutes) resolution.

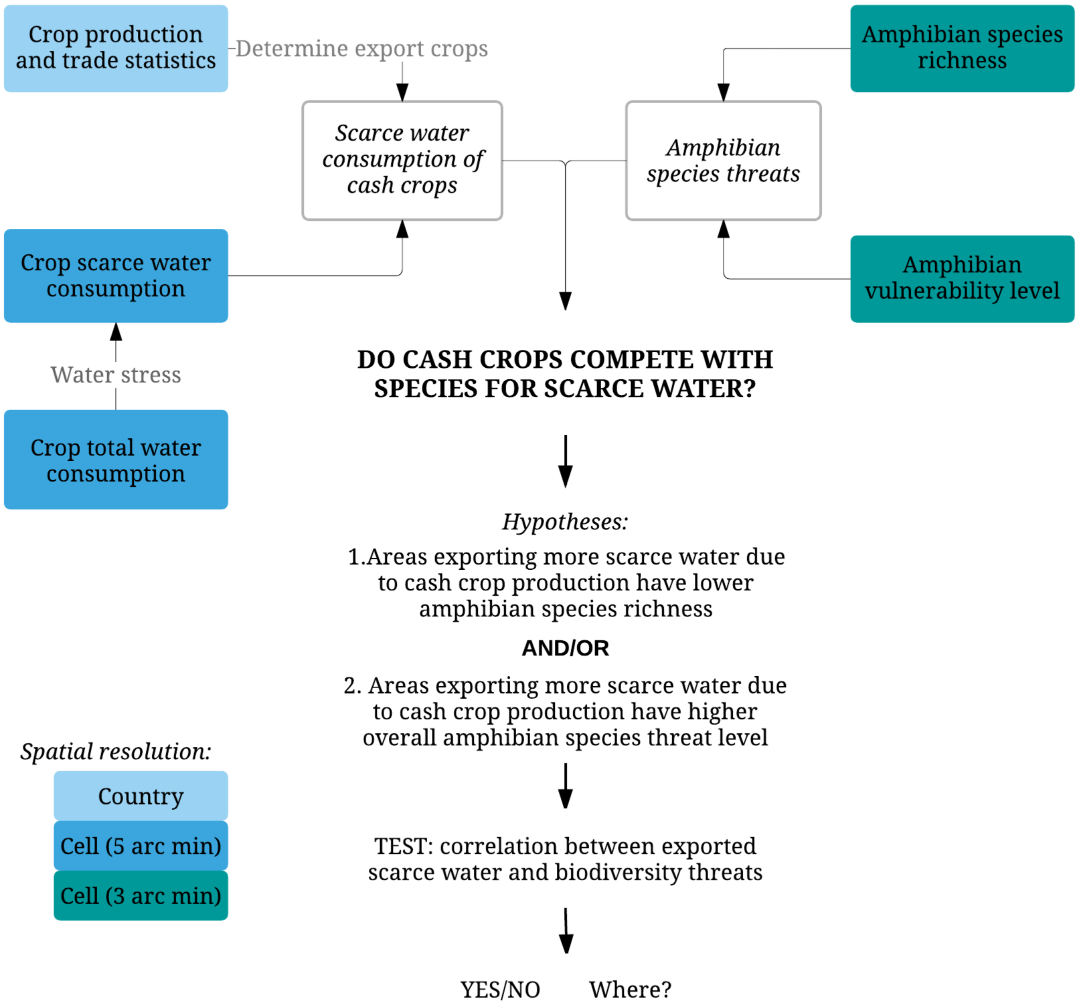


Figure 3.1. Conceptual research framework.

All input data and data transformations and calculations are described in more detail later in this chapter.

3.2 Data sources and maps

3.2.1 Crop production and trade statistics

Agricultural crop production and trade statistics was taken from Food and Agriculture Organization of the United Nations, Statistics Division (FAOSTAT) (FAO 2014). Data in EXCEL or CSV format can be directly downloaded from the homepage of the organization. All statistical data was taken for the year 2000, which is the reference year for the modelled crop water consumption. Initially, all 160 unprocessed crops according to the FAOSTAT crop classification and 185 countries and dependent territories were used. Each country's export intensity for each crop was determined by the ratio between production and export for each particular crop. As the classification of production and trade statistics in FAOSTAT is slightly different and trade data also includes livestock products, only those entities from trade statistics matching production classification was taken.

3.2.2 Blue and scarce water consumption of crops

Data about yearly blue and scarce water consumption of global agricultural crops were provided by Stephan Pfister from a study by Pfister and colleagues (2011a). Data has a global coverage for 160 different food, fibre and feed crops and has a high spatial resolution of 5 by 5 arc minutes.

Blue water (BW) concept denotes for the surface and ground water and in the case of agriculture particularly concerns irrigation water, as well as groundwater uptake by deep roots (Hoekstra 2009). Expected blue water consumption calculated by Pfister is based on the CROPWAT model (Smith et al. 2002) and is an arithmetic mean of the optimal irrigation water consumption and the deficit water consumption (for full calculations see (Pfister et al. 2011a)). It is assumed a conservative estimate of the water consumption. The unit in the spatial dataset provided is m^3 of blue water consumed (for each crop) per area on the global map of 5 arc min.

Water stress notion is commonly used to account for environmental impacts of water use and is defined as the ratio between total annual freshwater withdrawals and hydrological availability (Alcamo et al. 2000, Pfister et al. 2009). Pfister accounts for this by characterizing blue water volume with a spatially explicit Water Stress Index (WSI) ranging from 0 (no stress) to 1 (maximum stress) (Pfister et al. 2009). Originally made as a midpoint characterization factor for life cycle impact assessment (LCIA) 'water deprivation' category, it is widely used in water footprint studies of different products and regions, for example: (Feng et al. 2014, Huang et al. 2014, Joa et al. 2014, Ridoutt et al. 2014). To account for resulted scarce water, RED (Relevant for Environmental Deficiency) water concept is used, which represents a surrogate indicator of the amount of water deficient to human users and ecosystems. RED water data has the same resolution of 5 arc min and units of m^3 of RED water consumed per pixel. In this study the term scarce water or scarce water consumption is often used, which here means the same as RED water.

3.2.3 Amphibian species data

The measures chosen to represent the state of amphibian biodiversity are number of amphibian species and vulnerability of these species (the likeliness to become endangered or extinct, here vulnerability is not the VU category by IUCN). This data needs to be spatially explicit to be able to determine the relation with water scarcity, therefore it is needed to know the geographic extent of occurrence or range of individual species.

Verones et al. (2013) have spatially quantified freshwater species threats including amphibian species. In their study, they have made global maps with a 5 arc degrees (3 arc min) resolution of species richness and vulnerability using a vulnerability score. Both maps have been made based on IUCN red list data of threatened species (IUCN 2012a) and data about extent of occurrence of amphibians (IUCN 2012b). All currently existing amphibian species that contained spatial data were used, altogether 6021. For each species geographic range and information about the presence in the area, origin (native, reintroduced, introduced, vagrant or origin uncertain) and seasonal occurrence were used.

The species richness map was made by adding up individual species geographical extents of distribution and species presence categories 'extant', 'probably extant' and 'possibly extant'. The origin of species, or the difference whether species are native or introduced was not considered.

For the amphibian vulnerability map a vulnerability score (VS) as indicator for global extinction risk was calculated. The VS for a pixel j is calculated:

$$VS_j = \frac{\sum_{i=1}^{n} \frac{TL_{i,j} * EOO_{i,j}}{\sum_{j=1}^{m} EOO_{i,j}}}{S_j}$$

VS is a function of the extent of occurrence (EOO) as a predictor for susceptibility to anthropogenic disturbance as species with small range are intrinsically rare, and threat level (TL) indicating already occurring threats. VS is calculated for each amphibian species i and each pixel j (3 x 3 arc min) as the area of the respective pixel where species occurs divided by the total EOO of the species and multiplied with $TL_{i,j}$. TL are taken from IUCN Red List of threatened species (IUCN 2012a) and represented as discrete values from 0.2 to 1 on a linear scale, where 0.2 – least concern, 0.4 – near threatened, 0.6 – vulnerable, 0.8 – endangered and 1 – critically endangered. Total VS_j per pixel is obtained by summing all values for all species i which occur in pixel j and dividing by the number of species present in pixel j (S_j) (Verones et al. 2013, Verones submitted)

3.3 Cash crop analysis

Cash crop analysis was done using FAOSTAT crop production and trade statistics described previously in the chapter. To determine each country's (index i) export intensity for each of the crops (index c), the ratio between yearly production and yearly export was calculated.

$$Export\ intensity_{i,c} = \frac{export\ quantity_{i,c}}{total\ production\ quantity_{i,c}}$$

Analysis was done for all countries with data in the FAOSTAT statistics and all crops, which were matching data about the crop water consumption.

In the trade and production statistics of FAOSTAT a country can be an exporter without producing the particular crop or export more crop quantity than it has produced in the particular year. This occurs, either because of export from the country's food reserves, or when the country is a middle trading partner re-exporting agricultural production with a foreign origin. In this study, in a case when a country's production was 0, but export was reported, export intensity was set to 0 %. In case of reported production quantity lower than the export quantity, all export intensities were set to 100%.

The final result of FAOSTAT cash crop analysis was a matrix (112 crops x 183 countries) showing the proportion of total crop production exported. This crop/country matrix was used as an input in the Matlab program to calculate global maps of water footprint embodied in cash crops. In Matlab altogether 112 datasets were made (for each crop with export intensity values above 100%) showing what was the export intensity for particular crop in each of the 183 countries in the year 2000. As cash crop analysis was done on a country level, exported water consumption reflects international trade of commodities in 2000.

3.4 Correlation analysis between scarce water exports and amphibian biodiversity threats

The aim of the correlation analysis is to investigate the strength and patterns of relationship between scarce water consumption of cash crops and amphibian species threats. This was done by:

(1) Graphic analysis using scatterplots to investigate overall global relationship;

(2) Correlation maps to investigate spatial patterns of the relationship

It is emphasised that the results of analysis here suggest relationships and correlation, not causes or explicit drivers. For this reason, specific historic data was chosen (year 2000) to empirically investigate whether there was a correlation between scarce exported water and biodiversity threats in the year 2000 (not whether scarce water exports are in general a cause of amphibian biodiversity threats).

The scarce and total water consumption of individual cash crops were calculated in the Matlab program using resulted matrix from FAOSTAT cash crop analysis and blue and red water consumption data from Stephan Pfister (Pfister et al. 2011a). All cash crop water consumption datasets were summed to get the total scarce and blue water consumption of all crops grown for export in year 2000. Resulted Matlab matrixes were used in graphic correlation analysis together with Matlab matrixes of amphibian species richness and amphibian vulnerability level. To make correlation maps total exported blue and scarce water datasets were georeferenced in Matlab (added coordinates so values could be put on the global map) to be later used in ArcGIS.

3.4.1 Graphic analysis

Graphic analysis was done on a cell level, meaning that each pixel on a correlation scatterplot denotes for a certain cell or place on the global map with an area of 5 x 5 arc minutes (approximately 100 km^2 on the equator). Each of the pixels shows multiple attribute values or variables such as exported water volume due to crop production distinguishing between blue water (surface and groundwater) and red water (deficit or scarce water), number of amphibian species and species vulnerability level. It was decided to use only 2 dimensional scatterplots for clearer understanding of trends and analysis.

Figure 3.2. conceptually shows trends in global correlation plots if both proposed hypothesis are approved. X-axes in the figures show water volume per area and Y-axes show variation of amphibian biodiversity measures in response to changes in consumptive water volume. In the graph to the left the number of species decreases when more scarce water is exported from the same area. Graph to the right shows how species vulnerability increases with increase in exported scarce water.

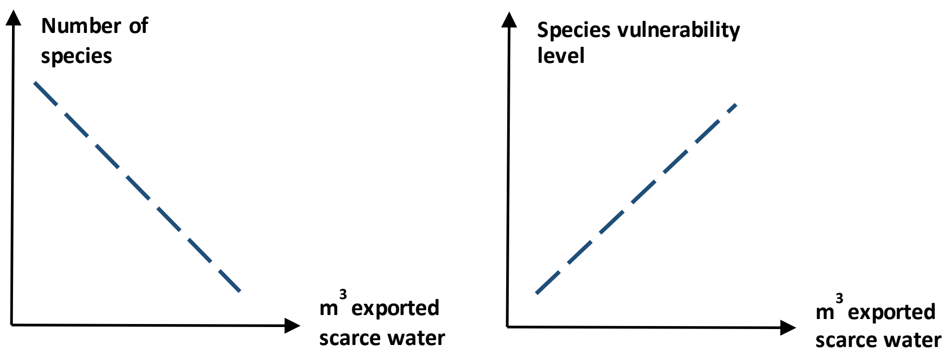


Figure 3.2 Trends in global correlation plots if proposed hypotheses are approved. Graph to the left shows hypothesis 1, graph to the left hypothesis 2.

In a correlation analysis of such a large scale, pixels on a correlation plot are so many that they will overlap. This overlap needs to be analysed to what the patterns of global correlation are. To see overlap of correlation points, density plots were made using Matlab.

3.4.2 Correlation maps

Similarly, as in a scatterplot, the relation between cash crop water consumption and the state of biodiversity can be shown also spatially using correlation maps. This way it is possible to get an insight of what the spatial patterns of the correlation are and where on the global map can we find 'hotspots'.

To make correlation maps 3 input datasets were used: (1) total scarce water consumption of cash crops, (2) amphibian species richness and (3) amphibian species vulnerability level. To be able to make correlation maps, resolution of amphibian biodiversity datasets were changed from 3 arc minutes to 5 arc minutes to match water consumption datasets. This inevitably leads to aggregation and small changes in the original data, which can be considered negligible considering the overall scale of the study.

Correlation maps were made in ArcGIS program using the georeferenced datasets mentioned above. It was decided to categorize data to best visualize the correlation between two different variables – set threshold levels (see table 3.1.).

Table 3.1 Chosen threshold levels for scarce water consumption data and amphibian vulnerability and species richness. Threshold levels were used to show correlation in maps between two different variables.

Variable	Threshold levels that were used in correlation maps
Scarce water consumption due to cash crop production	Below and above global average according to the dataset (7026 m^3 of RED water); Top 10% highest scarce water exporting areas (calculated in Matlab)
Amphibian species richness (number of amphibian species)	Below and over global average according to the dataset (14 species)
Amphibian species vulnerability level	All areas with vulnerability level over 0.0001 were set as vulnerable (this level is over average globally)

Based on the correlation map analysis a particular area (Western Ghats in India) was chosen to explore global results in a local context. It was essential that the chosen area has significant scarce water consumption due to cash crops and is important are for amphibian biodiversity/have threatened amphibians.

3.5 Limitations and assumptions

Before presenting and discussing results of the study, it is important to point out assumptions and limitations of data and methodology described earlier in the section. These are here drawn together to understand the implications on the analysis presented in the next section of the study.

3.5.1 Data quality

Data with a global coverage inevitably leads to uncertainties, as is also the case here.

Uncertainties of yearly blue and RED water consumption datasets attained from Stephan Pfister et al. (2011a) come both from the input data used (spatial datasets of crop distribution, yields and global irrigated area) and assumptions in the methods later applied to calculate these water footprints. Water consumption of crops can be calculated based on optimal-irrigation conditions (for best estimated yields) and deficit irrigation conditions (limited water availability). The difference between these two conditions can be regarded as a measure of uncertainty of annual crop water consumption, and as mentioned before in section 3.2.2, in this study arithmetic mean value of these two conditions was used. RED water consumption values could be overestimated in countries with large non-consumptive water use but good wastewater treatment. The reason for this is that water use and not consumption was used to define how scarce water is and degraded water is included in the water scarcity calculations (Pfister et al. 2011a). Despite these limitations, datasets represent finest currently available information on water consumption of agriculture on a global level.

FAOSTAT data represents the best available crop trade and production statistics with a global coverage. Uncertainties can arise, however, due to misclassification of commodities or weaker coverage of data reported by the national governments in form of annual FAO questionnaires. Statistics could also be influenced by time lag due to different exporting periods in different countries. To make the coverage as complete as possible sometimes FAOSTAT supplements national statistics with data from unofficial sources and makes corrections where reported data errors are obvious (FAO 2014).

The main limitation of amphibian species datasets is the number of amphibian species included in the dataset (6285), which in reality is much higher, especially in remote tropical areas. Similarly, it is often complicated to know exact range of species therefore leading uncertainties. These are well known limitations of global biodiversity data, however, the IUCN database provides most comprehensive data available today.

3.5.2 Methodological limitations

In this study only trade between countries is accounted for. In some large countries such as China inner-trade of agricultural commodities can be considerable, but it is not considered here. Data from year 2000 is used to investigate relationships between water use and the state of amphibian biodiversity. In reality, effects of water scarcity on ecosystems can sometimes be seen long time after the incident and therefore the use of trend data on biodiversity change and scarce water use would be more appropriate. Due to the limited availability of spatial data on crop water use, single year datasets were used and this limitation is recognized in the study.

It is assumed that the impact of water consumption is equally divided within the particular area where the crop is grown. Impacts outside 'overlapping' areas due to downstream effects of surface water withdrawals or extensive groundwater pumping are not considered.

4 Results and discussion

This section consists of three main parts: export analysis, global correlation and investigation of a particular territory – Western Ghats in India. Export analysis looks at how much water was embodied in cash crops in year 2000 both in total and spatially across the globe. Global correlation section tests two hypothesis proposed earlier looking at two widely used biodiversity measures – species richness and vulnerability level, to get insights if cash crops and amphibian species do compete for scarce water. This is done by overall correlation analysis and analysis of correlation maps to see spatial patterns across the globe. Finally, the last section looks at an exceptional territory globally, i.e. - Western Ghats in India. Firstly, it is generally interesting to explore global scale results in a local context. Secondly, it is interesting to investigate, how high amphibian species richness remain in areas with extremely high scarce water consumption and why are these species highly vulnerable.

4.1 Export analysis

Results of this study show that in the year 2000 6.56E+10 m^3 of scarce water was consumed globally for cash crop production. This is around 30% of the total surface and ground water (blue water) used in cash crop production meaning that close to every third liter of water used in crop production for export can be considered as scarce. At the same time this is only 8% of the total scarce water consumed due global crop production in the year 2000 suggesting that majority of scarce water used in agriculture is used for crops later consumed domestically.

Table 4.1 Results: global water consumption due to crop production.

	Water consumed, m^3
Total scarce water embodied in export crops	6.56E+10
Total blue water embodied in export crops	2.28E+11
Total scarce water consumption	8.74E+11
Total blue water consumption	1.77E+12

The only study to quantify scarce water flows in international trade on a global level has been done by Lenzen et al. (2013). The study uses different methods and assumtions to quantify virual water flows, and include animal grazing and industrial and domestic uses in the total water consumption (according to literature these uses should account altogether for 20% of the total global water consumtpion). Water consumption has been quantified using extended multi-regional input-output analysis with water consumption data taken from the Water Footprint accounts by Mekonnen and Hoekstra (2011), and water scarcity level distinguished on a country, not watershed level. Due to these differences, results in this study are generally higher with estimated total blue water consumption in year 2000 as 8E+12 m^3 with 4.8E+11 m^3 of scarce water being embedded in traded commodities. Due to methodological differences described above, comparison of total numbers with this study would be misleading. However, Lenzen et al. study gives a good indication of major scarce water exporting countries.

Figure 4.1. shows spatial distribution of total exported blue and scarce (red) water embodied in cash crops. Patterns of water consumption have large variations globally and these differences increase when considering water scarcity. This confirms that it is important to account for water scarcity in water footprint studies as this changes water trade patterns significantly. In the lower map (RED) of figure 4.1. certain areas appear as 'hotspots' of scarce water use for cash crops such as India and Pakistan, North-East China, central USA, Western and Southern Europe as well as certain areas in central Asia and Middle East. These results compare well with the results from the study by Lenzen et al. (2013) with top 10 scarce water exporting countries (from top down): India, Pakistan, China, USA, Syria, Thailand, Egypt, Australia, Morocco and Spain.

When interpreting results for particular areas two limitations need to be taken into account. Firstly, for some areas total exported blue and red water values can be overestimated. The reason for this is some uncertainty of location of irrigation systems and intensity of irrigation use. Secondly, in this study only trade between countries is considered, as consistent global trade data is availible only on a country level. In reality trade of agricultural production within large countries can be considerable. As an example, a recent study shows that in China coastal provinces with cities like Shanhgai and Beijing are relying on water intensive commodities produced in northern provinces such as Xinjiang and Inner Mongolia contributing to water scarcity in these provinces (Feng et al. 2014). At the same time, smaller and economically connected countries appear as major scarce water exporters, for instance France in the EU. According to FAO statistics (FAO 2014) France was among the top 4 largest exporters of wheat, maize and barley in year 2000 (by quantity). However, most of the production was sent to other EU countries.

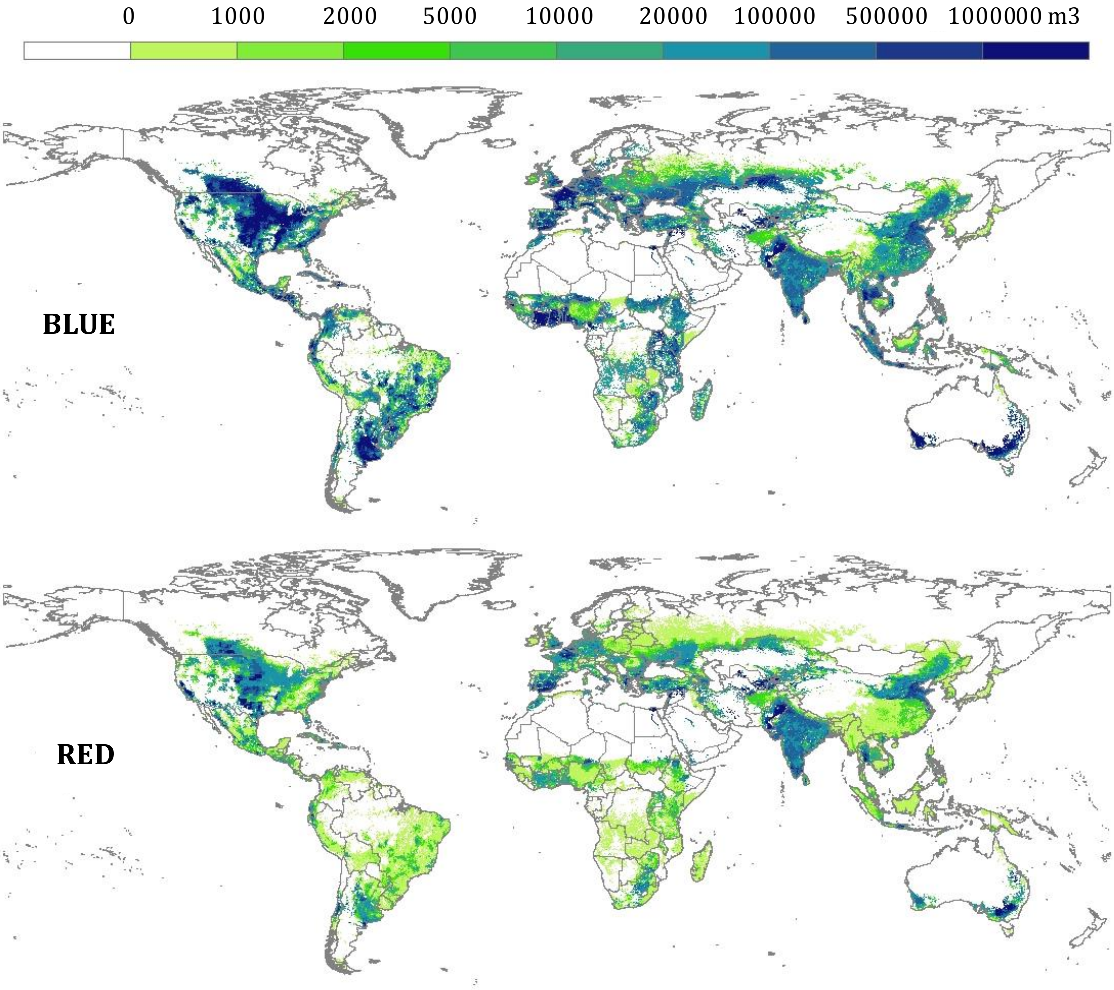


Figure 4.1 Total exported blue water (BLUE) and total exported scarce water (RED) in year 2000, m3. Map values calculated using crop production and export data from FAOSTAT and water consumption data from Pfister et al. (2011a)

In the RED water map we see that most countries in the tropics have low scarce water consumption. In much of these areas, rainfed agriculture dominates and often little or no irrigation is used. In addition, many developing countries are dependent on food imports (FAO 2005) and have low crop productivity (yields of irrigated crops can be up to 3 times higher).

Finally, results show that areas, which export most virtual water in form of cash crops, are often generally scarce. This suggest that global trade do not follow a 'rule' that water rich countries export water intensive crops to water scarce countries and in this way alleviate global differences in water scarcity. This also suggests that cash crop production may intensify water scarcity in already water scarce regions and therefore add pressure on amphibian habitats there.

4.2 Global correlation

4.2.1 Hypothesis 1: Areas exporting more scarce water due to cash crop production have lower amphibian species richness

The first hypothesis tries to partly answer the research question of the study: Do cash crops and species compete for scarce water? Amphibian species richness is used as one measure of biodiversity following an assumption that areas with higher scarce water consumption will have higher pressure on amphibian ecosystems and this will lead to less amphibian species[1].

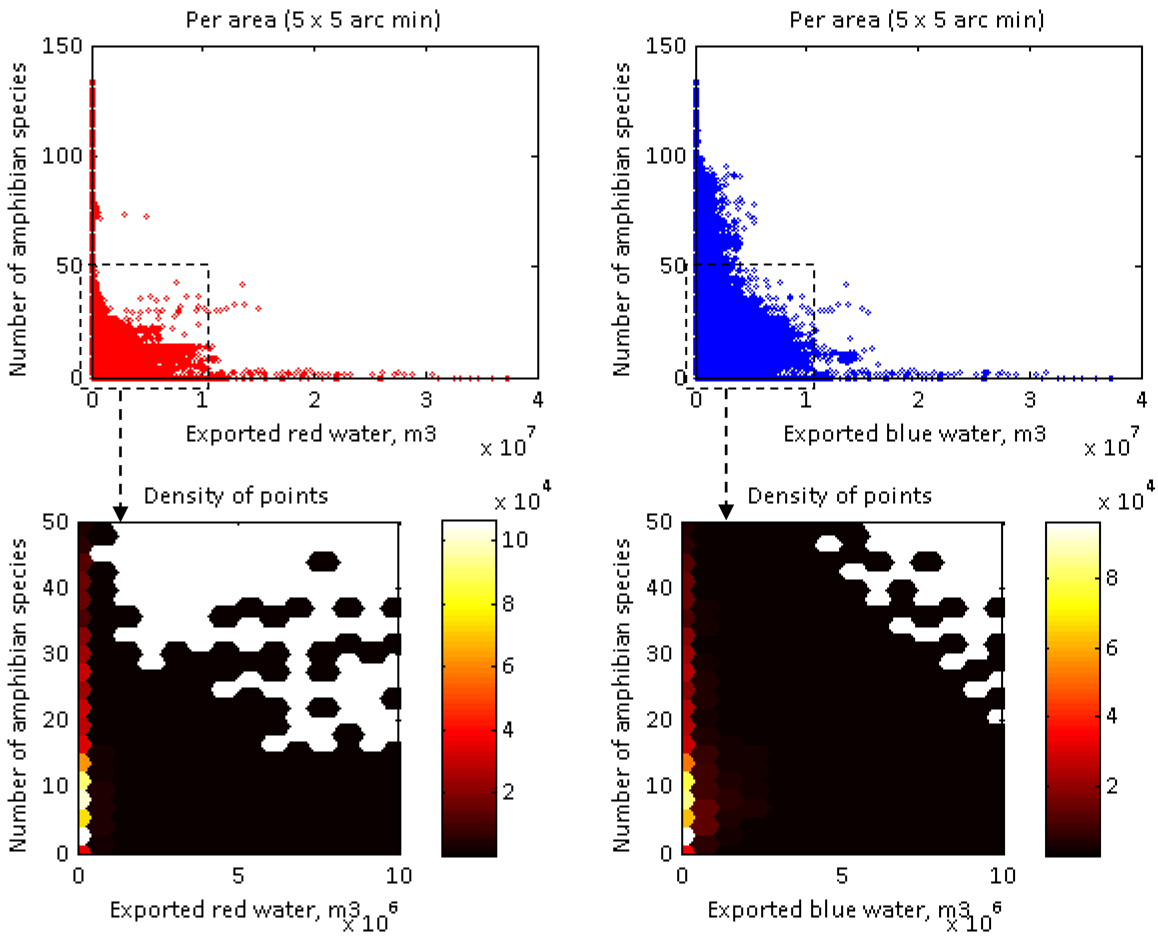


Figure 4.2. Global correlation between exported red (scarce) and blue water due to cash crop production and amphibian species richness. Each dot on the correlation plot shows an area on the global map. Density plots show overlap of correlation points, only values above 0 are displayed in the graphs.

[1] Water consumption data comes for year 2000 and it is assumed to be representative for a longer period as water consumption in agriculture is not a subject of fast change and is increasing with growing food production and irrigated land area.

Correlation results show (figure 4.2., top graph to the left) a weak trend indicating that areas with higher scarce water consumption have a lower number of amphibian species, and amphibian richness is gradually increasing with the decrease of scarce water consumption in cash crop production.

Meanwhile, there are large differences globally. An area with no scarce water consumption can have around 40 amphibian species present, which is a high number compared to the global average of 14 species. At the same time, another area can have the same number of species while producing cash crops, which annually consumes more than 10 million m3 of scarce water. This suggests the importance of other underlying factors on richness of amphibian species; such as climatic and environmental conditions, crop type and crop production system among others.

Moreover, results show that species richness is especially high in areas where there is no or very low scarce water consumption for cash crop production. There are no areas in the world with high scarce water consumption and exceptionally many amphibian species (>50). Whereas, in areas where very high amounts of scarce water is used (around 20 000 000 m^3 or more in year 2000) just some amphibian species live. In the figure 4.2., graph to the left we can read this trend as values extending on top/very close to the axes.

Lower graphs in the figure 4.2. show density of points in the correlation, important as here thousands of individual areas are investigated. We can see that in most areas with some agricultural activity, scarce water consumption is low. The number of amphibian species has more variety but rarely extends amphibian richness of 40 species.

Furthermore, it is interesting to investigate potential differences between correlation patterns of scarce and blue water. Figure 4.2. suggests that more amphibian species live in areas producing blue water intensive cash crops than areas that use the same amount of red water. From the correlation graphs this means that an area on the global map which produces cash crops consuming 1 000 000 m^3 of blue water annually can host up to 100 amphibian species but no more than 50 species if this water is scarce.

Correlation maps add the spatial dimension to the scarce water – amphibian correlation discussed here and show the spatial patterns of the correlation (for 'raw data' maps see Appendix 1). The map below (figure 4.3.) shows the top highest scarce water consuming areas globally (dark red colour) and areas with amphibian richness over the global average of 14 species (green). We can clearly see that most of these areas do not overlap. This means that in areas where scarce water intensive cash crops are produced amphibian species richness is generally low. Many of the high scarce water consuming areas are arid like Central Asia, Middle East and large part of Australia and naturally have lower amphibian richness than in wet tropical regions. This suggests that one of the reasons why there are lower amphibian richness in scarce water consuming areas (seen in the correlation graphs before) is that most of these areas are located in arid regions naturally having less amphibian species.

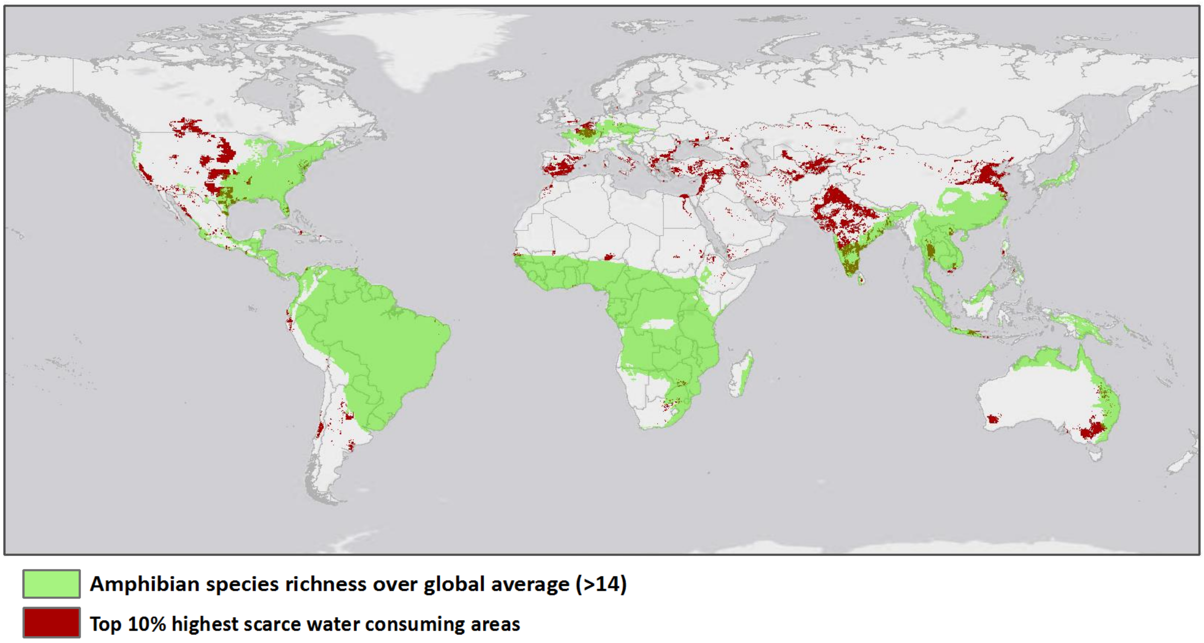
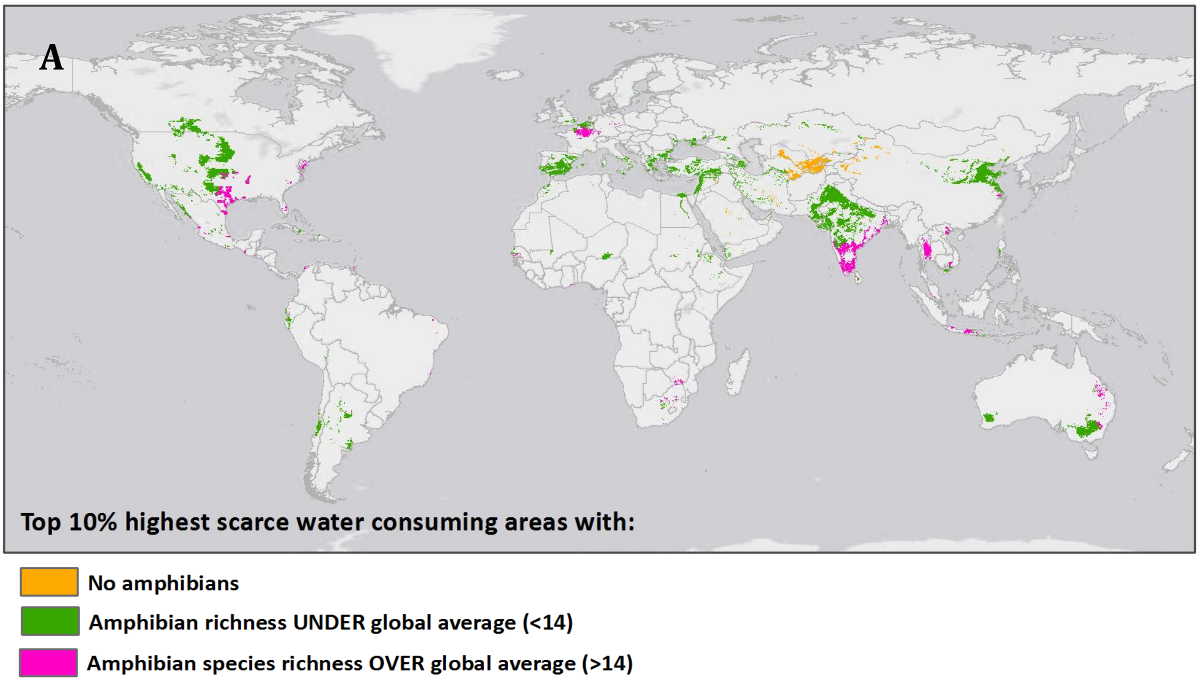


Figure 4.3. Areas producing cash crops leading to very high scarce water consumption (top 10% highest consuming areas) and areas with amphibian species richness over average.

From this, we can conclude that when considering purely species richness and no other biodiversity aspects as abundance or species threat level, scarce water intensive cash crops do not compete with amphibian biodiversity. Trade-offs to amphibians in areas producing water intensive cash crops in most cases will not be massive on a global scale if production is continued in the present agricultural areas. As there are not so many amphibian species present now, not many amphibians can be lost in the future due to scarce water consumption for cash crops.

In spite of this general trend, there are many variations globally. To illustrate this figure 4.4 shows areas with high scarce water consumption and the amphibian species richness in these areas. Maps show that areas growing cash crops with high scarce water consumption can have 1) no amphibians (areas in orange), 2) low amphibians species richness, here, species richness under average (areas in green) and 3) high amphibian species richness, here, species richness over global average (areas in pink). Difference between the two maps is threshold level chosen for scarce water consumption. The upper map (A) shows areas with 10% highest total scarce water consumption, whereas map below (B) covers larger area – all cash crop growing areas with scarce water consumption over global average level or over 7025 m^3 in year 2000.



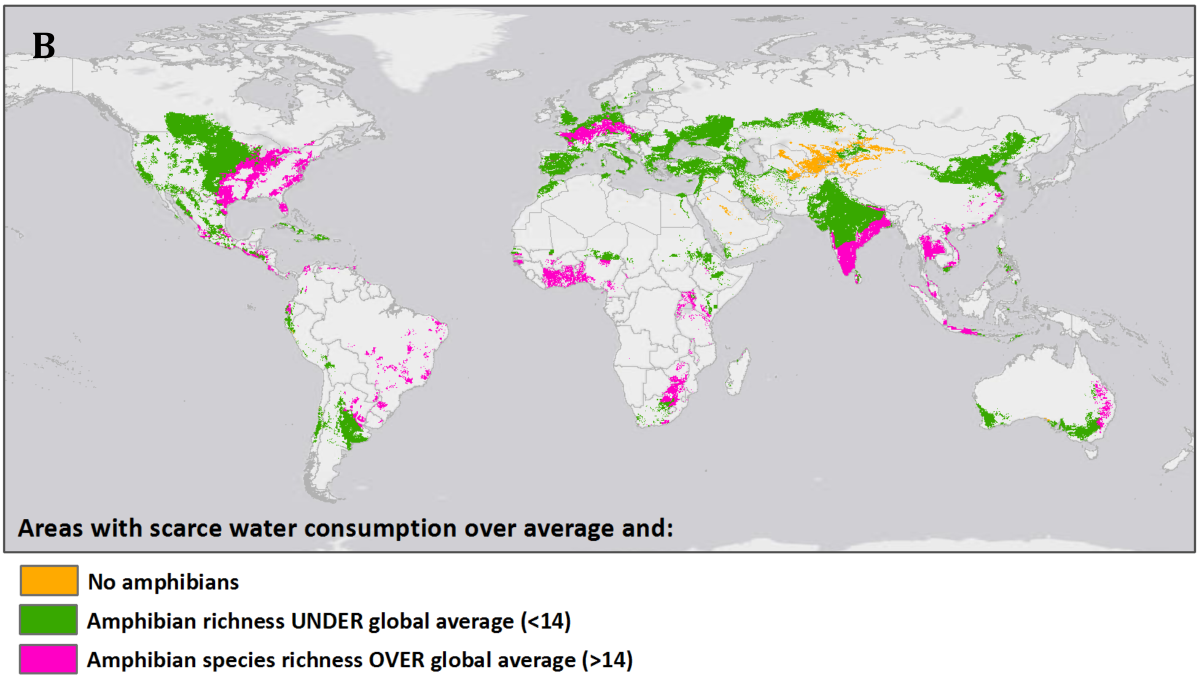


Figure 4.4. Areas with high scarce water consumption due to cash crop growing and amphibian species richness in these areas. A: areas with 10% highest total scarce water consumption, **B**: areas with scarce water consumption over the global average.

Central Asian countries Uzbekistan, Kyrgyzstan, Tajikistan and Turkmenistan are one of the most scarce water intensive cash crop producing areas globally (see areas in orange). In these countries up to 90% of all water withdrawals are used in agriculture, notably cotton production (WWAP 2012). Raw cotton is the most important agricultural export commodity earning from more than 40% of export income in Uzbekistan, to 7% in Kyrgyzstan in year 2000 (FAO 2014). At the same time we can see that cotton production do not compete with local amphibian biodiversity in this area simply as there are no amphibians. In this study it is not investigated whether amphibians have been lost in the past due to water abstraction. However, according to IUCN Red List none of the recorded 38 amphibian species extinctions are recorded in Central Asia (IUCN 2012a).

Maps show that with an increase in scarce water consumption, smaller proportion of areas have amphibian richness over average. In map B most areas in pink are classified as water abundant or having little or no physical water scarcity according to the UN (WWAP 2012). These include Southeast USA, Brazil, Eastern Australia, Western Europe and most pink areas in Africa. With increase in scarce water consumption (map A) most of these areas disappear.

In the map A some 'hotspots' come out where area sustain amphibian richness over global average and at the same time large amounts of scarce water is consumed to grow cash crops. Most of these areas are in South Asia, especially India. And one may ask whether many amphibian species can live in these areas because of crop systems that provide good habitat to many species and other favourable factors? Or are these diverse amphibian communities more threatened than in areas with lower pressures from scarce water consumption? These questions cannot be investigated looking at species richness alone. Therefore, discussion is continued with investigation of another biodiversity metric – vulnerability level of amphibians describing the potential risk of global extinction of species.

4.2.2 Hypothesis 2: Areas exporting more scarce water due to cash crop production have higher overall amphibian species vulnerability level

Vulnerability score reflects the overall likeliness of amphibian community in an area to become endangered or extinct. This measure is composed of data about extent of occurrence and threat level of individual amphibian species.

Even though we might expect that the vulnerability level of amphibians living in areas with high scarce water consumption will be higher, results suggest that globally this is not the case, therefore disproving the hypothesis 2.

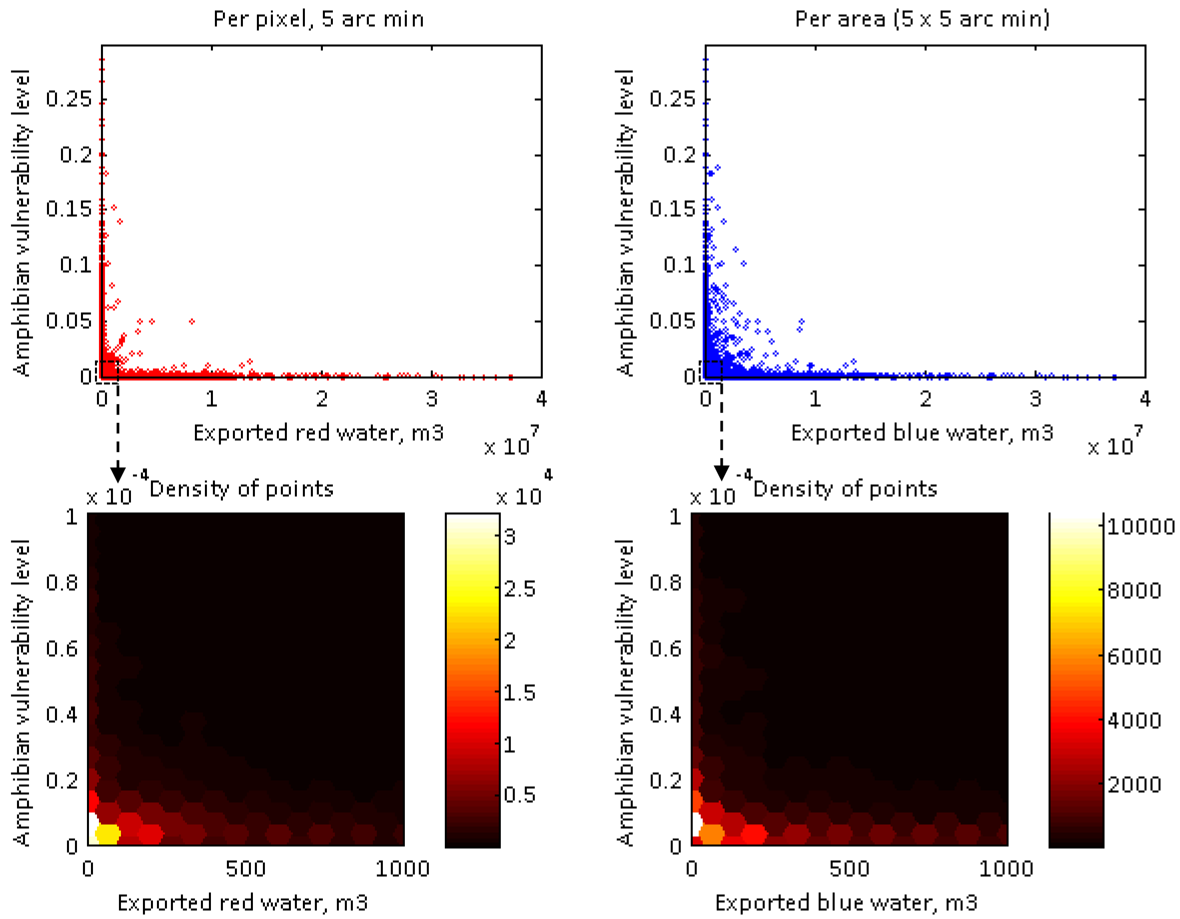


Figure 4.5. Global correlation between exported red (scarce) and blue water due to cash crop production and amphibian species richness. Each dot on the correlation plot shows an area on the global map. Density plots show overlap of correlation points.

According to the global correlation presented in graphs (figure 4.5., see top graph to the left), amphibian communities with vulnerable species reside in areas with very low intensity of scarce water use for cash crops or no production at all. Furthermore, areas with high red water exports have amphibian species with low vulnerability level (high values close to the axes).

The graph with density of points shows that even though the level of amphibian vulnerability in most areas is low (comes from the development of this biodiversity measure), with an increase of scarce water consumption vulnerability in most areas decreases. At the same time there are many variations globally represented by the vast dark area of the density plot.

So what could be the reasons for areas with high scarce water exports having amphibian species with a low vulnerability level? One answer could be that in areas with high intensity of agriculture, robust amphibian species with high tolerance of changes in water availability are left. In contrast, vulnerable amphibian species could be more sensitive to changes in their habitats and have disappeared from areas producing scarce water intensive cash crops (prior depletion). Even more, the small tolerance of vulnerable communities (high vulnerability scores close and on top of the axes in the top left graph, figure 4.5.) suggest that often it does not matter how scarce water intensive agriculture is. Land-use change from natural habitats to croplands which is a substantial cause for biodiversity loss in general (Newbold et al. 2015) could be the over lining reason for more robust amphibian species to remain and vulnerable ones to disappear from the area.

A comparison of red water and blue water correlation graphs shows that while vulnerable amphibians tend not live in areas with high scarce water consumption, there are more areas globally with high blue water consumption, such as over 1 million m^3 and vulnerable amphibians. There are also more variations of the relation blue water consumption – amphibian vulnerability meaning that vulnerable amphibians live in areas with no blue water consumption as well as in areas with low, and high blue water consumption for cash crops.

Correlation map showing amphibian vulnerability level vs. scare water consumption for cash crops can be seen in the figure 4.6. below (for 'raw data' maps see Appendix 2). It shows the main trend of relation between the two variables discussed earlier as well as exceptions. All coloured areas in the map are where vulnerable amphibian communities are located.

Distribution of vulnerable amphibians largely follow the location of areas with exceptional concentrations of endemic species and exceptional loss of habitat, or so called "biodiversity hotspots" (Mittermeier et al. 1998, Myers et al. 2000). As we can see, most of these areas have low scarce water consumption reflecting the major trend from the correlation graphs that most areas with vulnerable amphibians do not have scarce water intensive agriculture. At the same time, there are exceptions (areas in red and orange).

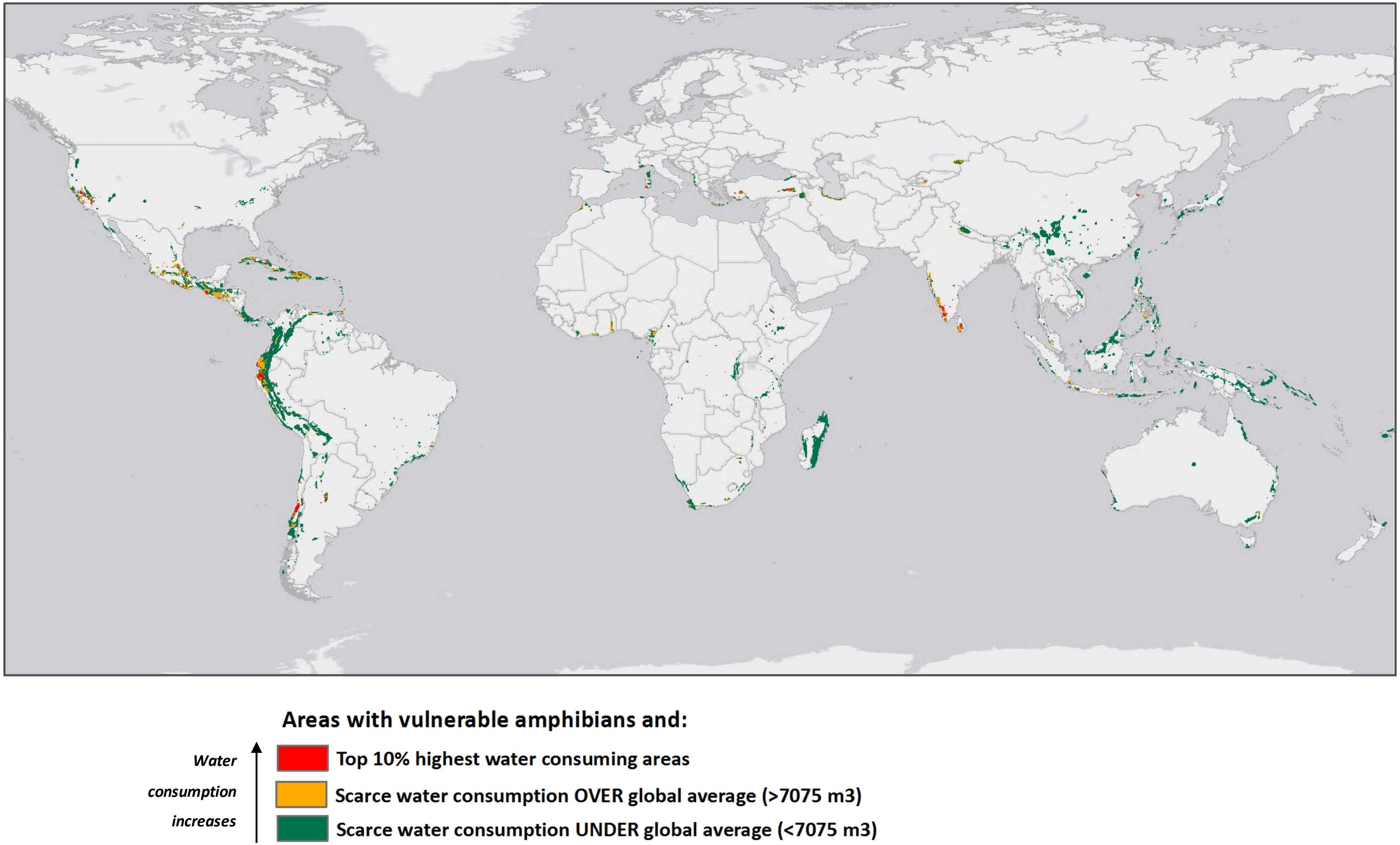


Figure 4.6. Areas globally with high amphibian vulnerability. Colour shows the level of scarce water consumption in these areas.

Areas in red and orange (figure 4.6.) are exception from other areas globally and follow the second hypothesis proposed. We can highlight 5 'biodiversity hotspots' with high scarce water consumption: Western Ghats and Sri Lanka in South Asia, Western Ecuador, Mesoamerica covering Central America and some areas in California Floristic Province and Caribbean.

In the previous section, areas having both high amphibian species richness and high scarce water consumption were identified (see figure 4.4.). It was asked, what is the vulnerability level of amphibians in these areas? When comparing correlation maps of species richness and vulnerability level, only one biodiversity hotspot comes out - Western Ghats and Sri Lanka. According to the results, this area in India and Sri Lanka, which has high amphibian diversity, was one of the top exporters of scarce water embodied in cash crops. These amphibians are also vulnerable.

What are the reasons for this exceptional relation between scarce water intensive agriculture and amphibians in this particular area? In the following section this will be investigated by looking at the Indian part of the 'hotspot', Western Ghats.

4.3 Investigating exceptions: Western Ghats, India

Western Ghats is a mountain range located along the Western coast of India extending from the Tapti river in the north until Tamil Nadu in the south (around 1490 km long and 48 – 210 km wide). It is recognized as one of the 25 biodiversity hotspots in the world (Myers et al. 2000, Molur et al. 2011). Approximate locations of the biodiversity hotspot can be well seen as the amphibian rich area on the West coast of India in the map B and coloured area with vulnerable amphibians in the map C (figure 4.7.). As found from the global correlation analysis, it is an exceptional territory globally for several reasons summarised as following:

(1) Western Ghats has exceptional amphibian species richness, and most amphibian communities in the area are vulnerable;

(2) India is one of the countries exporting most scarce water embodied in cash crops and one of most intensive scarce water consuming areas are within Western Ghats.

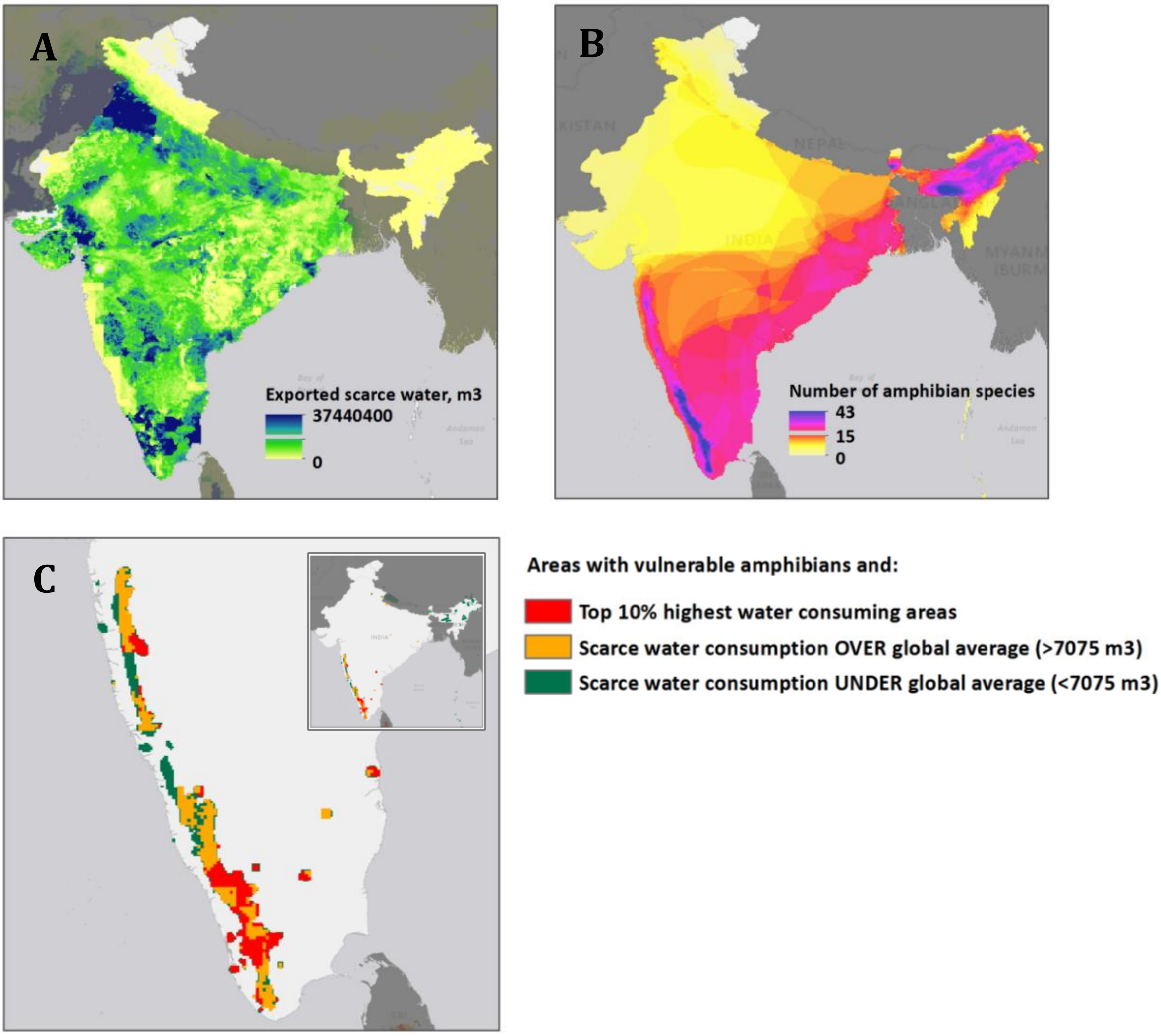


Figure 4.7. Scarce water export and amphibian biodiversity maps of India. A: total exported scarce water in India due to cash crops in year 2000. **B:** amphibian species richness in India, reproducing data from Verones et al. (2013), and **C**: areas in Southern part of India with high amphibian vulnerability (area along the W coast is the location of Western Ghats). Colours show the level of scarce water consumption in these areas.

Therefore, according to the results of this study, it is the largest area globally where 3 variables are present: high scarce water consumption, high amphibian species richness and high vulnerability level of amphibian species.

Figure 4.8. shows the correlation between scarce water exports and amphibian biodiversity variables in India. It is interesting to see areas having considerable species richness and vulnerable amphibians while consuming huge amounts of scarce water to grow cash crops. This does not follow the major trends of global correlation between these variables. Most of these 'exception' areas are in Western Ghats.

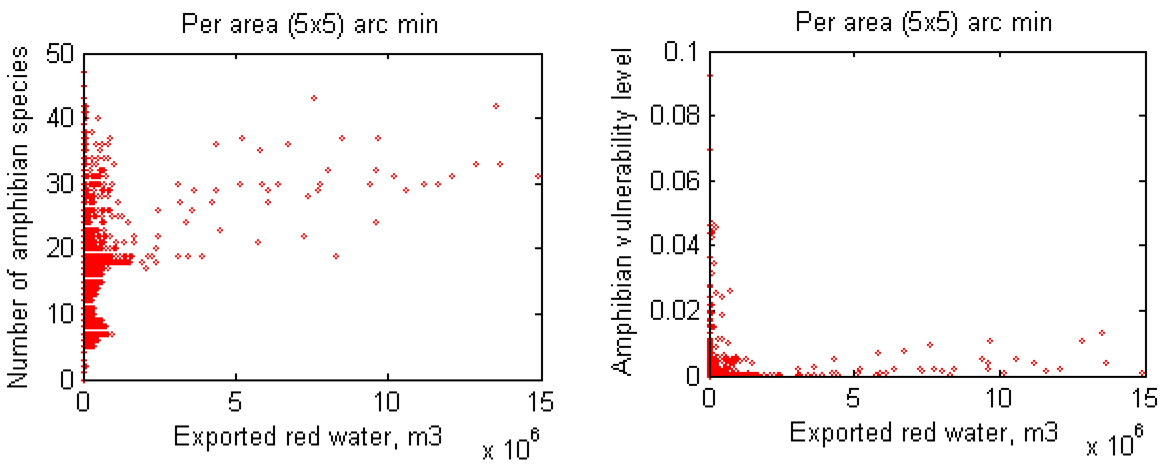


Figure 4.8. Correlation between exported red (scarce) water due to cash crop production and amphibian species richness (left graph) and amphibian vulnerability level (right graph) in India. Each dot on the correlation plot shows an area in India.

Western Ghats is one of the most fragmented and densely populated hotspots, and most of the natural forest vegetation has been cleared to make space for agriculture. At the same time, Western Ghats has at least 121 species of amphibians, 78% of them endemic (Ranjit Daniels 2003). The area is mountainous and receives heavy precipitation, however, only small quantities of water remains in headwater basins due to steep slopes. Agriculture in many valleys is supported by irrigation using surface waters from rivers as well as groundwater. Irrigation has increased crop yields in the area but has also caused disparity in water availability between irrigated and non-irrigated areas (Naik et al. 2003).

Results show that scarce water consumption due to cash crop growing is high in the Western Ghats area with extremely high scarce water footprint in the southern part. Various crops are grown but the three leaders are coffee, tea and rice. From these crops, most scarce water is consumed by coffee. One explanation of this is that coffee plants generally need large amounts of water. Usually, plantations gets enough water from precipitation (like in South America). In India, however, rainfall pattern is defined by the monsoon and 4 to 5 months coffee trees are under drought conditions and are irrigated to secure high yields. This leads to high consumption of surface and ground water. Secondly, according to the cash crop analysis, coffee was the most exported food commodity in India in year 2000 (55% of coffee beans were exported), followed by different spices as pepper and nutmeg and tea with export intensity of 24%. At the same time, large amounts of food crops in India are used to feed domestic population, and only

1% of rice was exported in year 2000 leading to low contribution of rice in the total scarce water footprint of Indian cash crops.

So how can so many amphibian species remain in Western Ghats in areas with scarce water intensive agriculture? Are these amphibian species vulnerable because of scarce water abstraction from their habitats in favour to agriculture? The answer to these questions are undoubtedly complex, but several studies provide relevant explanations.

Canopy cover is the most important factor determining amphibian richness and abundance in Western Ghats (Balaji et al. 2014). Forests are highly fragmented and shaded plantations of coffee gives refuge for forest biota and act as corridors sustaining connectivity between patches of forest (Anand et al. 2010). High amphibian diversity can be found also in tea plantations in Western Ghats (Ranjit Daniels 2003), and rice fields and irrigation channels have been recognized as important habitats for amphibians in areas where wetlands have been converted to agriculture (Duré et al. 2008, Maltchik et al. 2011). Vulnerability of amphibians in Western Ghats hotspot comes mostly from the small ranges of endemic amphibians. Patchy distribution of amphibian species could have evolved because of forest loss (Ranjit Daniels 1992), partly caused by expansion of coffee, known to be grown on previously forested areas (Donald 2004). Pollution could also potentially contribute to the threat level of amphibians, but the impact of pollution from agriculture in Western Ghats is still not clear. Abnormalities in frogs have been found in coffee and rice plantations in the Western Ghats (Gurushankara et al. 2007). At the same time, another study (Ranjit Daniels 2003) found high amphibian diversity without abnormalities in tea plantations known for heavy pesticide use.

When looking at all these aspects, we are able to conclude that some agricultural systems can play an important role in sustaining amphibians, including vulnerable amphibian communities. In highly fragmented and deforested Western Ghats coffee and tea plantations can give refuge to amphibians. It is also important to note here that amphibians are not always deprived from water when water flows are diverted from natural habitats to agriculture. The irrigated rice fields are a good example of valuable habitats to many amphibians. At the same time water abstraction in Western Ghats, source of many rivers in India, can potentially influence downstream regions with less precipitation as well as deplete groundwater resources. These effects are not considered in this study, but should be taken into account in the future research investigating the link between scarce water and amphibian biodiversity.

5 Conclusions and outlook

The aim of this study was to investigate a part of the complex water-food-biodiversity puzzle by answering the question: Do cash crops and species compete for scarce water? To do so the correlation between scarce water use in cash crop production and the state of amphibian biodiversity was examined.

There is an overall global tendency that scarce water intensive cash crops are produced in areas where low number of amphibian species live, and therefore cash crops if continuously grown in these areas will not compete with amphibian richness. Furthermore, possibly because of more advanced prior depletion, cash crops do not compete with vulnerable amphibians, which live in areas with minimal or no cash crop production at all.

However, there are exceptions globally where scarce water intensive cash crop production, rich amphibian diversity and vulnerable amphibians coexist. Cash crops may not only deprive amphibians from scarce water resources, but also in some areas play an important role in giving home to amphibians where their natural habitat is lost.

Although no causal links are established, this study can suggest potential hotspots for further local investigations looking at the relationship between water scarcity and biodiversity. For improving future analysis, downstream effects of water consumption should be accounted for and trend data used to see scare water consumption versus biodiversity changes over time.

References

Achterbosch, T., Berkum, S. and Meijerink, G. (2014). Cash crops and food security. Contributions to income, livelihood risk and agricultural innovation. Wageningen, April 2014, LEI Wageningen UR.

Alcamo, J., Henrichs, T. and Rösch, T. (2000). *World water in 2025: Global modeling and scenario analysis for the world commission on water for the 21st century*, Center for Environmental Systems Research, University of Kassel.

Allan, J. A. (1996). Water Use and Development in Arid Regions: Environment, Economic Development and Water Resource Politics and Policy. *Review of European Community & International Environmental Law* 5(2): 107-115.

Allan, J. A. (1997). *'Virtual water': a long term solution for water short Middle Eastern economies?*, School of Oriental and African Studies, University of London.

Anand, M. O., Krishnaswamy, J., Kumar, A., et al. (2010). Sustaining biodiversity conservation in human-modified landscapes in the Western Ghats: Remnant forests matter. *Biological Conservation* 143(10): 2363-2374.

Ansink, E. (2010). Refuting two claims about virtual water trade. *Ecological Economics* 69(10): 2027-2032.

Balaji, D., Sreekar, R. and Rao, S. (2014). Drivers of reptile and amphibian assemblages outside the protected areas of Western Ghats, India. *Journal for Nature Conservation* 22(4): 337-341.

Balian, E. V., Segers, H., Lévèque, C., et al. (2008). The Freshwater Animal Diversity Assessment: An overview of the results. *Hydrobiologia* 595(1): 627-637.

Barnosky, A. D., Matzke, N., Tomiya, S., et al. (2011). Has the Earth/'s sixth mass extinction already arrived? *Nature* 471(7336): 51-57.

Cardillo, M., Mace, G. M., Gittleman, J. L., et al. (2008). The predictability of extinction: biological and external correlates of decline in mammals. *Proceedings B of the Royal Society* 275(1641): 1441-1448.

Ceballos, G., Ehrlich, P. R., Barnosky, A. D., et al. (2015). Accelerated modern human–induced species losses: Entering the sixth mass extinction. *Science Advances* 1(5).

Chapagain, A., Hoekstra, A. and Savenije, H. (2006). Water saving through international trade of agricultural products. *Hydrology and Earth System Sciences* 10(3): 455-468.

Dirzo, R., Young, H. S., Galetti, M., et al. (2014). Defaunation in the Anthropocene. *Science* 345(6195): 401-406.

Donald, P. F. (2004). Biodiversity Impacts of Some Agricultural Commodity Production Systems. *Conservation Biology* 18(1): 17-38.

Dudgeon, D., Arthington, A. H., Gessner, M. O., et al. (2006). Freshwater biodiversity: importance, threats, status and conservation challenges. *Biological Reviews* 81(2): 163-182.

Duré, M. I., Kehr, A. I., Schaefer, E. F., et al. (2008). Diversity of amphibians in rice fields from northeastern Argentina. *Interciencia* 33(7): 523-527.

Dyson, T. (1999). World food trends and prospects to 2025. *Proceedings of the National Academy of Sciences of the United States of America* 96(11): 5929-5936.

Falkenmark, M. and Molden, D. (2008). Wake up to realities of river basin closure. *International Journal of Water Resources Development* 24(2): 201-215.

FAO (2005). The State of the Food Insecurity in the World 2005. Rome, Food Agriculture Organization of the United Nations (FAO).

FAO. (2014). FAOSTAT: Food and Agriculture Organization of the United Nations Statistics Division. Retrieved 6 November 2014, from http://faostat3.fao.org/home/E.

FAO (2015). Climate Change and Food Systems: Global assessments and implications for food security and trade, Food Agriculture Organization of the United Nations (FAO)**:** 357.

Feng, K., Hubacek, K., Pfister, S., et al. (2014). Virtual Scarce Water in China. *Environmental Science & Technology* 48(14): 7704-7713.

Fereres, E. and Soriano, M. A. (2007). Deficit irrigation for reducing agricultural water use. *Journal of Experimental Botany* 58(2): 147-159.

Gurushankara, H. P., Krishnamurthy, S. V. and Vasudev, V. (2007). Morphological abnormalities in natural populations of common frogs inhabiting agroecosystems of central Western Ghats. *Applied Herpetology* 4(1): 39-45.

Hassan, R., Scholes, R. and Ash, N. (2005). *Ecosystems and Human Well-being: Findings of the Condition and Trends Working Group of the Millennium Ecosystem Assessment*, Island Press.

Hoekstra, A. (2003). *Virtual water trade: Proceedings of the international expert meeting on virtual water trade*, IHE Delft, the Netherlands.

Hoekstra, A. Y. (2009). Human appropriation of natural capital: A comparison of ecological footprint and water footprint analysis. *Ecological Economics* 68(7): 1963-1974.

Hoekstra, A. Y. and Mekonnen, M. M. (2012). The water footprint of humanity. *Proceedings of the National Academy of Sciences* 109(9): 3232-3237.

Hof, C., Araujo, M. B., Jetz, W., et al. (2011). Additive threats from pathogens, climate and land-use change for global amphibian diversity. *Nature* 480(7378): 516-519.

Huang, J., Xu, C.-C., Ridoutt, B. G., et al. (2014). Water availability footprint of milk and milk products from large-scale dairy production systems in Northeast China. *Journal of Cleaner Production* 79(0): 91-97.

IUCN. (2012a). The IUCN Red List of Threatened Species. Version2012.2. Retrieved 25 October 2012, from www.iucnredlist.org.

IUCN. (2012b). Spatial data for amphibians from http://www.iucnredlist.org/technical-documents/spatial-data#amphibians.

IUCN. (2015). Amphibians. from http://www.iucnredlist.org/initiatives/amphibians.

Joa, B., Hottenroth, H., Jungmichel, N., et al. (2014). Introduction of a feasible performance indicator for corporate water accounting – a case study on the cotton textile chain. *Journal of Cleaner Production* 82(0): 143-153.

Kenneth, F. D., Major, D.C. (2002). *Climate change and water resources*. New York, USA, Edward Elgar.

Lenzen, M., Moran, D., Bhaduri, A., et al. (2013). International trade of scarce water. *Ecological Economics* 94(0): 78-85.

Lenzen, M., Moran, D., Kanemoto, K., et al. (2012). International trade drives biodiversity threats in developing nations. *Nature* 486(7401): 109-112.

Lévêque, C., Balian, E. V. and Martens, K. (2005). An assessment of animal species diversity in continental waters. *Hydrobiologia* 542(1): 39-67.

Lips, K. R., Diffendorfer, J., Mendelson, J. R., III, et al. (2008). Riding the Wave: Reconciling the Roles of Disease and Climate Change in Amphibian Declines. *PLoS Biol* 6(3): e72.

Liu, J., Mooney, H., Hull, V., et al. (2015). Systems integration for global sustainability. *Science* 347(6225).

Maltchik, L., Rolon, A. S., Stenert, C., et al. (2011). Can rice field channels contribute to biodiversity conservation in Southern Brazilian wetlands? *Rev Biol Trop* 59(4): 1895-1914.

Matson, P. A., Parton, W. J., Power, A. G., et al. (1997). Agricultural Intensification and Ecosystem Properties. *Science* 277(5325): 504-509.

Mekonnen, M. M. and Hoekstra, A. Y. (2014). Water conservation through trade: The case of Kenya. *Water International* 39(4): 451-468.

Millenium Ecosystem Assessment (2005). *Ecosystems and Human Well-being: Biodiveristy Synthesis*. Washington, DC, World Resources Institute.

Mittermeier, R. A., Myers, N., Tliomsen, J. B., et al. (1998). Biodiversity hotspots and major tropical wilderness areas: Approaches to setting conservation priorities. *Conservation Biology* 12(3): 516-520.

MOL. (2015). Map of Life. Putting biodiversity on the map. Retrieved 20 July 2015, from https://mol.org/.

Molur, S., Smith, K. G., Daniel, B. A., et al. (2011). The Status and Distribution of Freshwater Biodiversity in the Western Ghats, India. Cambridge, UK, Gland, Switzerland, IUCN and Coimbatore, India: Zoo Outreach Organisation.

Myers, N., Mittermeler, R. A., Mittermeler, C. G., et al. (2000). Biodiversity hotspots for conservation priorities. *Nature* 403(6772): 853-858.

Naik, P. K. and Awasthi, A. K. (2003). Groundwater resources assessment of the Koyna River basin, India. *Hydrogeology Journal* 11(5): 582-594.

Navarro-Ortega, A., Acuña, V., Bellin, A., et al. (2014). Managing the effects of multiple stressors on aquatic ecosystems under water scarcity. The GLOBAQUA project. *Science of The Total Environment*(0).

Newbold, T., Hudson, L. N., Hill, S. L. L., et al. (2015). Global effects of land use on local terrestrial biodiversity. *Nature* 520(7545): 45-50.

Oki, T. and Kanae, S. (2006). Global hydrological cycles and world water resources. *Science* 313(5790): 1068-1072.

Orlowsky, B., Hoekstra, A. Y., Gudmundsson, L., et al. (2014). Todays virtual water consumption and trade under future water scarcity. *Environmental Research Letters* 9(7).

Pfister, S., Bayer, P., Koehler, A., et al. (2011a). Environmental Impacts of Water Use in Global Crop Production: Hotspots and Trade-Offs with Land Use. *Environmental Science & Technology* 45(13): 5761-5768.

Pfister, S., Bayer, P., Koehler, A., et al. (2011b). Projected water consumption in future global agriculture: Scenarios and related impacts. *Science of The Total Environment* 409(20): 4206-4216.

Pfister, S., Koehler, A. and Hellweg, S. (2009). Assessing the Environmental Impacts of Freshwater Consumption in LCA. *Environmental Science & Technology* 43(11): 4098-4104.

Postel, S. L. (2000). Entering an era of water scarcity: The challenges ahead. *Ecological Applications* 10(4): 941-948.

Postel, S. L., Daily, G. C. and Ehrlich, P. R. (1996). Human Appropriation of Renewable Fresh Water. *Science* 271(5250): 785-788.

Ranjit Daniels, R. J. (1992). Geographical Distribution Patterns of Amphibians in the Western Ghats, India. *Journal of Biogeography* 19(5): 521-529.

Ranjit Daniels, R. J. (2003). Impact of tea cultivation on anurans in the Western Ghats. *Current Science* 85(10): 1415-1422.

Régnier, C., Achaz, G., Lambert, A., et al. (2015). Mass extinction in poorly known taxa. *Proceedings of the National Academy of Sciences* 112(25): 7761-7766.

Ridoutt, B. G., Page, G., Opie, K., et al. (2014). Carbon, water and land use footprints of beef cattle production systems in southern Australia. *Journal of Cleaner Production* 73(0): 24-30.

Rohr, J. R., Raffel, T. R., Romansic, J. M., et al. (2008). Evaluating the links between climate, disease spread, and amphibian declines. *Proceedings of the National Academy of Sciences* 105(45): 17436-17441.

Schipper, J. and al, e. (2008). The Status of the World's Land and Marine Mammals: Diversity, Threat, and Knowledge. *Science* 322(5899): 225-230.

Shiklomanov, I. A. and Rodda, J. C. (2003). *World water resources at the beginning of the twenty-first century*, Cambridge University Press Cambridge.

Smakhtin, V. (2008). Basin closure and environmental flow requirements. *International Journal of Water Resources Development* 24(2): 227-233.

Smith, M., Kivumbi, D. and Heng, L. (2002). Use of the FAO CROPWAT model in deficit irrigation studies. *Deficit irrigation practices*.

Sodhi, N. S., Bickford, D., Diesmos, A. C., et al. (2008). Measuring the meltdown: Drivers of global amphibian extinction and decline. *PLoS ONE* 3(2).

Stuart, S. N., Chanson, J. S., Cox, N. A., et al. (2004). Status and trends of amphibian declines and extinctions worldwide. *Science* 306(5702): 1783-1786.

UN (1992). Convention on Biological Diversity.

Verma, S., Kampman, D. A., van der Zaag, P., et al. (2009). Going against the flow: A critical analysis of inter-state virtual water trade in the context of India's National River Linking Program. *Physics and Chemistry of the Earth* 34(4-5): 261-269.

Verones, F., Pfister, S., van Zelm, R. and Hellweg, S. (submitted). Biodiversity impacts from water consumption on a global scale for use in life cycle assessment.

Verones, F., Saner, D., Pfister, S., et al. (2013). Effects of consumptive water use on biodiversity in wetlands of international importance. *Environmental Science and Technology* 47(21): 12248-12257.

Vörösmarty, C. J., McIntyre, P. B., Gessner, M. O., et al. (2010). Global threats to human water security and river biodiversity. *Nature* 467(7315): 555-561.

Wichelns, D. (2015). Virtual water and water footprints do not provide helpful insight regarding international trade or water scarcity. *Ecological Indicators* 52: 277-283.

WWAP (2012). The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk. Paris, UNESCO.

WWF (2014). Living Planet Report 2014. WWF International. Gland, Switzerland.

Yang, H., Wang, L., Abbaspour, K. C., et al. (2006). Virtual water trade: an assessment of water use efficiency in the international food trade. *Hydrology and Earth System Sciences* 10(3): 443-454.

APPENDIX 1

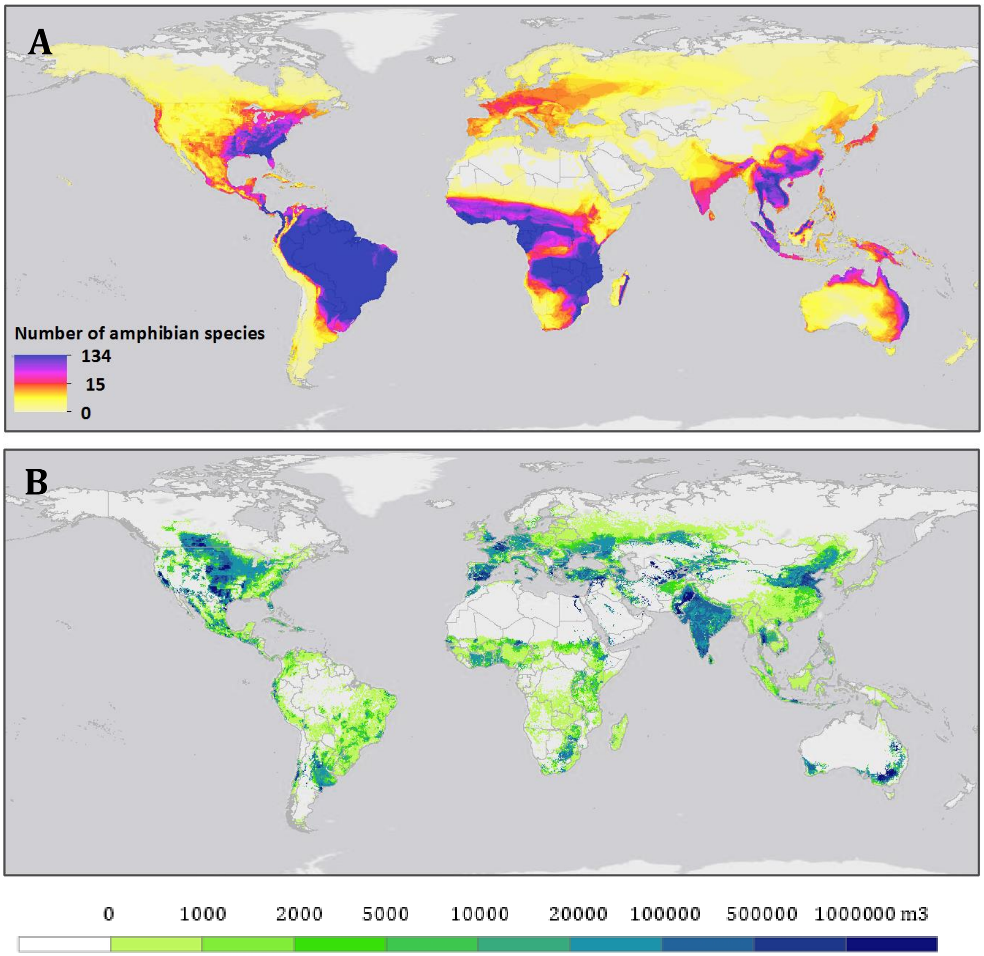


Figure A.1 A: Amphibian species richness based on data from Verones et al. (2013) and B: exported red (scarce) water across the globe in year 2000.

APPENDIX 2

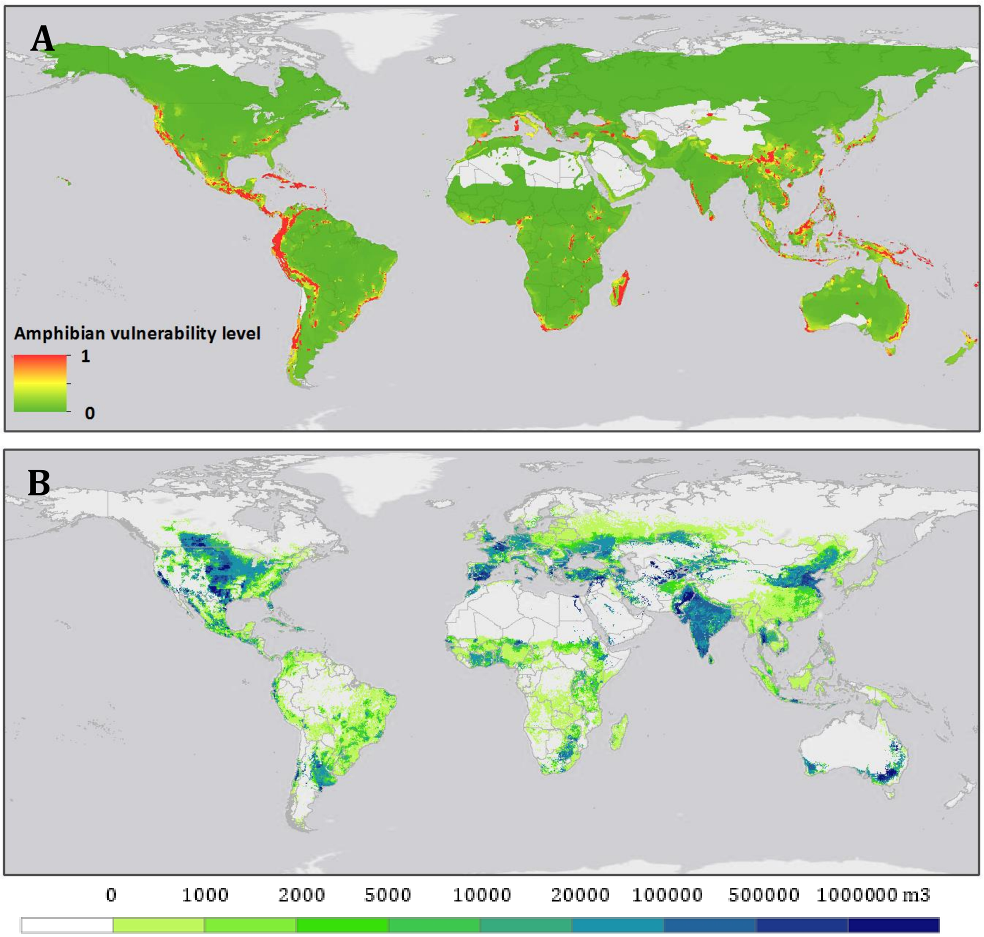


Figure A.2. A: Amphibian vulnerability level based on data from Verones et al. (2013) and B: exported red (scarce) water across the globe in year 2000.