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Future drought propagation through the water-energy-food-ecosystem nexus – A Nordic perspective

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ABSTRACT

Droughts can affect a multitude of public and private sectors, with impacts developing slowly over time. While droughts are traditionally quantified in relation to the hydrological components of the water cycle that they affect, this manuscript demonstrates a novel approach to assess future drought conditions through the lens of the water-energy-food-ecosystem (WEFE) nexus concept. To this end, a set of standardized drought indices specifically designed to represent different nexus sectors across 50 catchments in Sweden was computed based on an ensemble of past and future climate model simulations. Different patterns in the response of the four nexus sectors water, energy, food and ecosystem services to future climate change emerged, with different response times and drought durations across the sectors. These results offer new insights into the propagation of drought through the WEFE nexus in cold climates. They further suggest that future drought projections can be better geared towards decision makers by basing them on standardized drought indices that were specifically tailored to represent particular nexus sectors.

1. Introduction

Despite affecting every continent, having vast socio-economic and environmental impacts, droughts often elude headlines. This is partially due to their slow onsets, long durations, and recovery times, which make it difficult to predict and quantify their impacts (Rajsekhar et al., 2015; Spinoni et al., 2015). Droughts are usually characterized by their severity, locality, duration, and timing. The term ‘drought’ is distinct from water scarcity in that drought is an episodic socio-climatologically induced water deficit caused by an anomaly in average conditions, whereas water scarcity is a long-term unsustainable disparity between water demand and supply (Pereira et al., 2006). While scarcity can be controlled for, drought impacts can only be mitigated via climate adaptation (Mukherjee et al., 2018; Van Loon et al., 2016; WMO and GWP, 2016).

Drought development is complex, as any change in water fluxes affects multiple feedback processes in the hydrologic cycle (Van Loon, 2015). Typically, drought propagation is conceptualized as a top-down (hierarchical) process, where anomalies in precipitation and temperature cascade down to soil moisture-, hydrologic-, and socio-economic drought, usually in a non-linear fashion and with significant lag (Mukherjee et al., 2018), and with inevitable negative implications as illustrated in Fig. 1.

Due to its creeping nature, drought processes, impacts, and even its definitions are varied and complex (Van Loon, 2015). While the underlying physical processes that govern the water cycle follow a fairly straightforward logic, the hydrometeorological system as a whole is stochastic, or random, in its nature - forcing us to rely on various statistical methods and parameterizations (model simplifications). These come with their own uncertainties that must be accounted for in climate-change impact assessments (Fowler et al., 2018; Garcia et al., 2017; Teutschbein and Seibert, 2012). Even then, assessing the impact of a

Abbreviations: WEFE nexus, water-energy-food-ecosystem nexus.

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drought is not a straightforward task, as one must establish which threshold defines a drought. Hence, different drought indices have been developed to reduce the complex problem of drought identification and quantification to single numbers.

A variety of indices have been proposed over the decades to simplify the problem (WMO and GWP, 2016). These must be chosen appropriately to match the hydrological regime and demands of local water management (Van Loon, 2015). Most of these indices quantify one aspect of the hydrological cycle (e.g., meteorological, soil moisture, or hydrological drought in Fig. 1), but there are also composite indices that span multiple sectors (see WMO and GWP (2016) for an exhaustive list). As these indices make varying assumptions about climate and catchment properties, they exhibit different regional and temporal patterns, and must be chosen accordingly (Hisdal et al., 2001). These indices can be classed as either 'standardized' or 'threshold' indices. Standardized indices are ideal for drought comparison between different regions as the droughts are quantified statistically and normalized, but they are not always useful for water management. Hence, in these cases, threshold indices are often used instead, as they rank drought severity based on an established threshold-level for hydrological variables (Van Loon, 2015). For the assessment of future drought severity, the chosen indices must also be robust and account for changing climates. They also should distinguish water scarcity from drought, which becomes a separate issue with growing populations and water demand (Mukherjee et al., 2018).

In our water-dependent society, droughts can affect a multitude of sectors both public and private, with impacts developing slowly over time (Mishra and Singh, 2010). Impacts can be both direct and indirect (Blauhut et al., 2016) when droughts affect key sectors of society such as agriculture, forestry, water supply, energy production, ecosystem services and human health (UNDRR, 2019). Their economic impacts are among the highest of natural hazards (Kim et al., 2015), but their intangible effects on human health and the environment are often underestimated (UNDRR, 2019). During droughts, competing water demands between these sectors can create potential conflicts, with their prominence often being correlated to the severity of the drought event (Hisdal and Tallaksen, 2003).

The described impacts and their related challenges are particularly important to be addressed in the context of climate change. The Earth's surface-, ocean-, and tropospheric temperatures have significantly increased over the last century, along with more frequent and intense precipitation and drought events, and these changes can be directly attributed to anthropogenic warming (Chiang et al., 2021; Hari et al., 2020; IPCC, 2014). As per the Clausius-Clapeyron relationship, every degree rise in temperature is associated with a 7 % increase in moisture-holding capacity of the atmosphere (Mukherjee et al., 2018). Thus, climate change has had a wide range of impacts on the hydrologic cycle globally, including for example changes to regional precipitation patterns, cloud cover, annual river streamflow, flood peak-duration shifts, flow-duration curves, magnitude and duration of lowflows, glacier and permafrost extent, or wildfires. These observed changes in hydrologic behavior also had consequences for drought frequency and severity. Since droughts can have a severe effect on various sectors such as

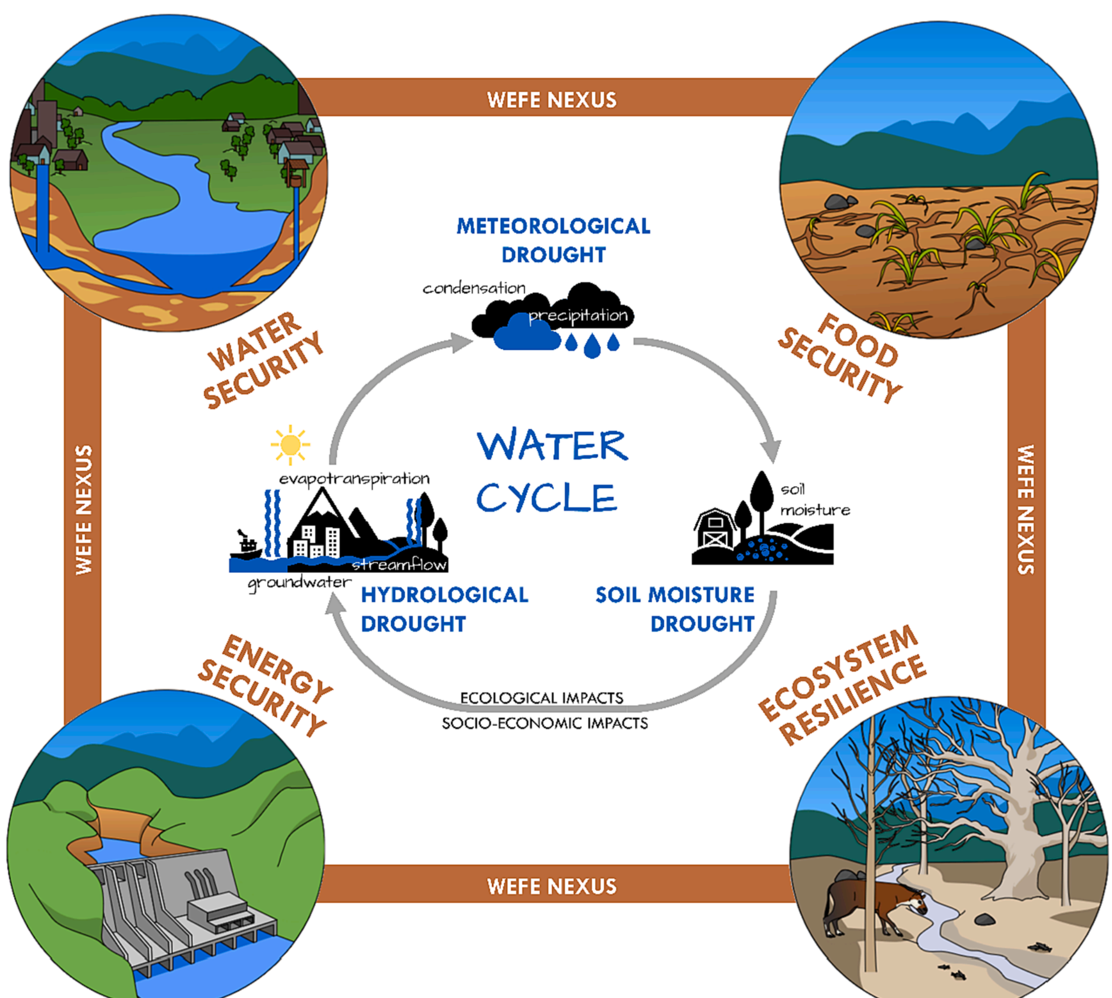

Fig. 1. Conceptual outline of drought development and propagation through the water cycle (center graphic) and its placement within the water-energy-food-ecosystem nexus framework (outer rectangle).

agriculture, forestry, water supply, sanitation, energy production, navigation, and ecosystems, it becomes a necessity to provide reliable projections of future change for mitigation and adaptation purposes (Bakke et al., 2020; Hakala et al., 2019; Staudinger et al., 2014; Zipper et al., 2019).be beb

In Europe, drought trends varied greatly depending on region, with northern Europe having exhibited mostly increasing trends in precipitation (Gudmundsson and Seneviratne, 2015). These changes in precipitation manifested themselves in streamflow shifts, i.e. causing less severe low flow conditions in most winter low-flow regimes across the northern parts of Norway, Sweden and Finland (Stahl, 2001; Stahl et al., 2010). In a more recent study by Teutschbein et al. (2022) over a 60-year period, an overall wetting trend across Sweden was confirmed. These patterns are consistent with findings of other studies in comparable climate zones: A tendency towards wetter conditions leading to less severe low flow conditions were also found for northern Canada (Asong et al., 2018; Yang et al., 2020), Finland (Korhonen and Kuusisto, 2010) and Norway (Wilson et al., 2010).

By the end of this century (2071–2100), increases in land surface temperatures are expected to exceed the 1.5–2 °C threshold. Meanwhile, annual (and summer) precipitation is expected to increase in northern Europe and decrease in southern Europe (IPCC, 2021). Both variables control the water cycle: precipitation as a direct component of the water cycle, and temperature as a proxy for energy availability, which plays a key role in estimating evapotranspiration as well as snow accumulation and melt, both of which exert influence on the amount and timing of streamflow. Because both mean temperatures and total precipitation are increasing in northern Europe, the exact future development of drought remains uncertain and unexplored, indicating a need for regional studies to explore this knowledge gap. The future development of droughts in

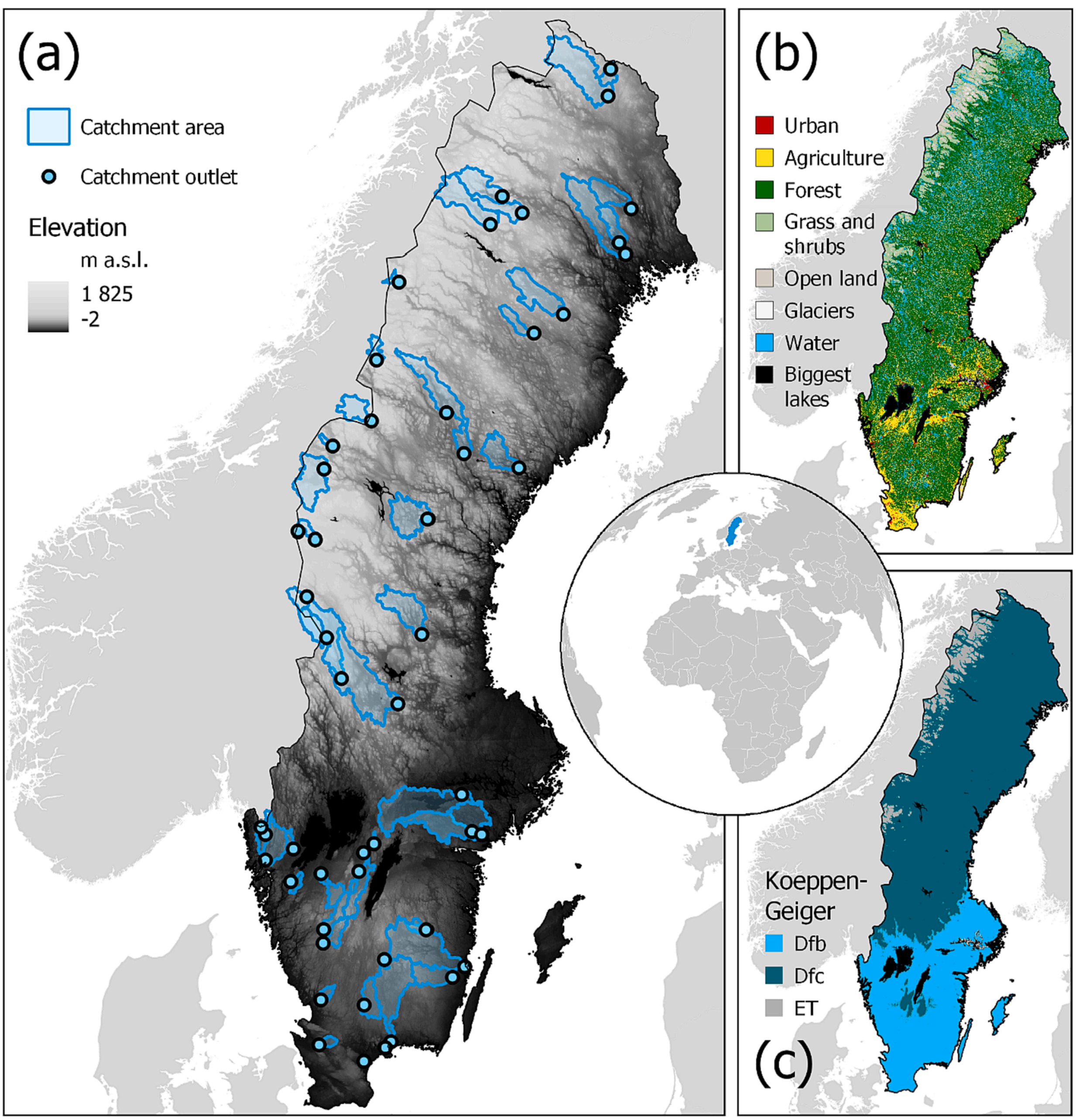

Fig. 2. Overview of (a) Sweden's topography obtained from Lantmäteriet, the Swedish Mapping, Cadastral and Land Registration Authority, together with the 50 chosen study catchments, (b) land cover classes according to the CORINE Land Cover CLC2018 dataset (Büttner, 2014), and (c) climate zones according to the Köppen-Geiger classification (Beck et al., 2018), including polar tundra climate (ET), subarctic boreal climate (Dfc), and warm-summer hemiboreal climate (Cfb).

Sweden has so far only been explored as part of large-scale pan-European studies (e.g., Spinoni et al. (2018) or Roudier et al. (2016)), which are often not robust as they typically only include a few large river basins in each country, and sometimes even point towards different directions.

Understanding how societies respond to droughts, or indeed climate change in general, is one of the major uncertainties in current climate projections (Van Loon et al., 2016). As such, it is prudent that we take time understanding how risk assessment and management work at all levels of society. In Sweden, knowledge about risk management and planning, as well as funding for preventative measures, is provided at the national level by institutes of hydrology, geotechnology, and urban planning, while actual management is delegated to municipalities at a local level. Municipalities are supervised and directed by regional county administrative boards who provide advice and data. Regional and local actors are thus responsible for data and implementing most of the climate mitigation and adaptation practices, while also judging their appropriateness (Storbjörk, 2007). Local actors, thus, play an important role in building infrastructure and resources to mitigate drought impacts. From this, we can deduce that more localized predictions of drought patterns are required to motivate these actors into action. At this level, the type of drought becomes important, as one area may primarily consist of forestry and other industries - requiring predictions on fire hazards, streamflow droughts, etc. - whereas another area may be more urbanized, requiring predictions that impact water supply and agriculture. For example, almost half of Sweden's electricity generation comes from hydropower (Swedish Energy Agency, 2022), which is generated mostly in northern Sweden. Meanwhile, urbanized areas such as Stockholm, Gothenburg or Malmö reside mostly southward and toward the coastlines (Fig. 2). Hence, different types of drought are important in different parts of the country and for different sectors.

In particular, the water, energy, and food sectors help fulfill many of society's demands for products and services, and they are increasingly recognized as being interconnected in a complex and mutually interacting system – hereafter referred to as the **W**ater-**E**nergy-**F**ood (WEF) "nexus". While challenges concerning natural resources management (including water resources management) have predominantly been managed by sectors (so-called silos) in the past (van den Heuvel et al., 2020), this silo-approach often failed to capture the complexity of the nexus. There is, in fact, growing evidence of plentiful interlinkages between the water, energy, and food sectors that should be considered (FAO, 2014). For instance, water supply uses energy, hydropower alters river flows and ecosystem functioning, and the production and distribution of fertilizer consumes energy while its application on farmland damages ecosystems. In cities, water and energy are intimately connected and heavily used. Furthermore, food production (agriculture) involves irrigation that consumes water and requires energy for pumping.

The 'nexus approach' is a rather novel way to address and analyze these complex interlinkages within the nexus with the aim to promote synergies and identify tradeoffs between sectors (Albrecht et al., 2018). While initially-two-sector nexus concepts (e.g., 'water-food' or 'water-energy') have been presented (Endo et al., 2017; Ringler et al., 2013), current state-of-the-art research also considers more complex nexus systems that include climate and land use change (van den Heuvel et al., 2020) or ecosystems (Hülsmann et al., 2019). The scientific community particularly agrees on the need for a better integration of the ecosystem perspective in the nexus concept (Bidoglio et al., 2019), since ecosystems deliver the resources and services needed to sustain human activity and, thus, are key players for reaching the Sustainable Development Goals (SDGs). Therefore, we here consider that **W**ater, **E**nergy, **F**ood and **E**cosystems form a complex **WEFE** nexus in Sweden with various interlinkages (Fig. 1).

In recent years, several WEF frameworks, models, techniques and tools proliferated to understand, identify or reproduce the intrinsic WEFE sector links (Purwanto, 2021). While numerous studies adopt the nexus as a conceptual framework (Albrecht et al., 2018) and provide sector-specific descriptions of water, energy, food, and ecosystems that aid in understanding the nexus (Dai et al., 2018), implementation and modeling studies that address multiple links and feedback mechanisms are extremely diverse, with the modeling itself heavily reliant on location, time, spatiotemporal scale and target group (Sušnik and Staddon, 2021). As a result of the diverse demands and requirements of nexus studies, several tools and techniques that attempt to quantify the representation and interactions between sectors emerged (Albrecht et al., 2018; Dai et al., 2018; Sušnik and Staddon, 2021), including (1) system dynamics modeling (SDM), (2) multi-region input–output modeling (MRIO), (3) agent-based modeling (ABM), (4) life-cycle assessment (LCA), and (5) integrated assessment modeling (IAM). Sušnik and Staddon (2021) argue that only SDM and IAM can coherently address the holistic nexus and its inter-sectoral dynamics, complexities and feedback loops.

Shifts in the WEFE nexus are driven by changes in hydroclimatic- (e.g., temperature, precipitation), environmental- (e.g., land cover), or socio-economic (e.g., population growth, economic development) conditions. Thus, hydrological extremes such as droughts and their alterations in a future climate are critical as they can severely impact a multitude of interlinkages within the WEFE nexus. Efficient resources management within the WEFE nexus, thus, requires robust assessments of past, and reliable projections of future drought impacts to help inform decision makers in communal, water-, energy-, food- and ecosystem-related sectors. However, studies that systematically and holistically assess drought impacts on the WEFE nexus, e.g., utilizing SDM or IAM, are extremely rare. A few examples include those conducted by Sridhar et al. (2021) and Kang et al. (2021) on the Mekong river in China, Zhao et al. (2021) on the Yakima River Basin in the United States, and Wicaksono et al. (2019) on a case study in the Republic of Korea.

Different types of drought in terms of duration, frequency, severity and intensity affect sectors differently. While, for example, hydro-power dams can persevere over short droughts of a few months, agricultural activities and municipal water supply may be heavily impacted. This is particularly the case in regions highly dependent on surface-water supply, which has a quicker response to drought than groundwater-dependent regions (Stagge et al., 2015). Additionally, short but intense droughts may be more conducive to fire hazards and heat waves, thus posing a bigger risk for public health, than prolonged, low intensity, droughts. For these purposes, some drought indices can be accumulated over different time scales to address the needs of different sectors. For monitoring and prediction, drought indices need to be general enough to be widely applicable but also specific enough to identify the type of drought relevant to the region and variable of interest (Staudinger et al., 2014). For this purpose, most threshold-level indices are insufficient as they are too specific and only applicable to a single catchment.

Thus, in this paper we identified a suite of standardized indices to describe different drought types (Fig. 1, center) that are deemed relevant for different WEFE nexus sectors (Fig. 1, outer rectangle). Instead of focusing entirely on the water cycle components, this paper puts the WEFE nexus at the heart of the analysis. It builds the foundation for assessing drought propagation across the WEFE nexus sectors, which is here represented by sectoral response times (i.e., the lag) to a precipitation deficit.

We hypothesize that different characteristics in the WEFE nexus lead to large differences in their future drought responses, frequency, severity and duration. By demonstrating how drought conditions change and are propagated through the nexus sectors in Sweden in a future climate, this paper serves as a foundation for integrated policy making (within and outside Sweden) to optimize synergies and trade-offs in the water-energy-food-ecosystem nexus.

2. Study area

A set of 50 high-latitude catchments in Sweden (Fig. 2a) was chosen, primarily selected based on data availability (i.e., requiring continuous streamflow measurements for the period January 1961 to December 2020 with gaps up to max. 14 days that were filled through linear interpolation), a low degree of reservoir regulation and low proportions of glaciers and urban areas (Table 1). Sweden, a country in Northern Europe, has an area of nearly 408,000 km^2 (SLU, 2015) and features elevation ranges of −2 to 2100 m.a.s.l. (Fig. 2a). Forest covers roughly 69 % of the land area, while 9 % of the area are made up by wetlands and water bodies, 8 % by shrubs and grass land, 8 % by agriculture (mostly in Southern Sweden), 3 % by human settlements (urban areas) and the remaining 3 % are open land and glaciers (Fig. 2b). Till is the dominant soil class, which covers about 75 % of the land area. According to the Köppen-Geiger classification (Beck et al., 2018), Sweden has a poleward gradient of a warm-summer hemiboreal (Dfb) climate zone in the southern regions, subarctic boreal (Dfc) climate with cool summers, very cold winter, persistent seasonal snow cover and soil frost during winters in central and northern Sweden, and tundra (ET) climate with monthly mean temperatures below 10 °C in the Scandinavian Mountains in northwestern Sweden (Fig. 2c). Most of what today is classified as Dfb and Dfc zones is projected to transition into Cfb and Dfb climates respectively by 2070–2100 (Beck et al., 2018).

During the period 1961–2020, annual mean temperature in Sweden was on average 2.6 °C, while the annual precipitation averaged 784 mm. During this period, annual temperature has been significantly rising at a rate of 0.037 °C per year (at 5 % significance level), which adds up to a total warming of + 2.2 °C from 1961 to 2020. At the same time, precipitation has been increasing at a significant rate of 2.4 mm per year, which corresponds to a total increase of 144 mm (or 20 %). For the same period, average annual streamflow showed considerable spatial variations with highest values ranging from 810 to 1300 mm/year in the Scandinavian Mountains in northwestern Sweden and lowest values of 168 to 300 mm/year in southeastern Sweden.

Table 1
Properties of the 50 selected study catchments.

Catchment Properties	Mean	Median	Min	-	Max
Geographic properties					
Latitude [°N, WGS84]	61.2	60.6	55.9	–	68.4
Area [km^2]	1 452	1 019	2	–	8 425
Mean elevation [m a.s.l.]	365	258	12	–	942
Land cover					
Agriculture [%]	10	2	0	–	99
Forest [%]	55	62	0	–	86
Glaciers [%]	0	0	0	–	2
Open land [%]	3	0	0	–	38
Shrubs and grassland [%]	16	11	0	–	77
Urban [%]	1	0	0	–	3
Water [%]	14	12	0	–	37
Bedrock and glaciers [%]	18	10	0	–	60
Soil Types					
Clay [%]	4	1	0	–	26
Glaciofluvial sediments [%]	3	2	0	–	13
Peat [%]	16	12	0	–	39
Sand-gravel [%]	7	2	0	–	88
Silt [%]	1	0	0	–	9
Till [%]	45	51	7	–	72
Hydroclimatic properties					
Mean annual temperature [°C]	3.2	2.7	−2.8	–	+7.9
Mean annual precipitation [mm year^{-1}]	800	761	544	–	1 196
Mean annual streamflow [mm year^{-1}]	480	377	169	–	1 303

3. Data

3.1. Observed (historic) data

Series of daily streamflow measurements were downloaded from a publicly accessible streamflow database (https://vattenwebb.smhi.se/) provided by the Swedish Meteorological and Hydrological Institute (SMHI). Only catchments with continuous daily streamflow records from January 1961 to December 2020 were included in this study. Furthermore, only catchments with low percentages of lakes, glaciers and urbanized areas, with a low degree of regulation, and without river bifurcations or backwater effects were considered. Geospatial data for the selected 50 streamflow stations was obtained from SMHI's SVAR database (Eklund, 2011). For each catchment, gridded daily mean temperature and daily precipitation were obtained from SMHI's PTHBV database (SMHI, 2005), which provides a spatially interpolated 4 km × 4 km national grid for the period 1961–2020 (Johansson, 2002). An area-weighted average of all grid cells partly or fully lying within each catchment's boundary were computed to obtain catchment-specific temperature and precipitation values.

3.2. Future data

3.2.1. Climatological data

Daily temperature and precipitation simulations for a reference control period (1961–2005) and a future scenario period (2006–2100) from ten different climate models (CMs) provided by the Coordinated Regional Climate Downscaling Experiment (CORDEX) initiative (Jacob et al., 2014) were used in this study (Table 2). The choice of CMs was limited to those that had both historic and future temperature and precipitation simulations available until the end of the century (2100), for all three-greenhouse gas concentration trajectories (i.e., RCP2.6, 4.5 and 8.5), and for the highest available resolution 0.11° (roughly 12.5 km). If simulations were available in several versions (e.g., v1 and v2), the most recent version (i.e., v2) was used. The gridded daily precipitation and temperature simulations were averaged over each catchment.

To ensure that the subsequent hydrological modelling provided robust and reliable future streamflow simulations (Ehret et al., 2012; Muerth et al., 2013; Teutschbein and Seibert, 2013, 2012, 2010), biases (i.e., systematic errors) in these climate model simulations were adjusted using the distribution-scaling method (Boe et al., 2007; Déqué et al., 2007; Ines and Hansen, 2006). To date, this is one of the most commonly used and most reliable as well as cost-efficient bias-adjustment methods (Teutschbein and Seibert, 2013; Tootoonchi et al., 2022a, Tootoonchi et al., 2022b), which corrects biases in daily CM-simulated temperature and precipitation on a monthly basis. Distribution scaling

Table 2
Selected climate model simulations for future projections.

	Institute	Global Climate Model (GCM)	Parameters	Regional Climate Model (RCM)	Version
1	CLMcom	ICHEC-EC-EARTH	r12i1p1	CCLM4-8–17	v1
2	CNRM	CNRM-CERFACS-CNRM-CM5	r1i1p1	ALADIN53	v1
3	CNRM	CNRM-CERFACS-CNRM-CM5	r1i1p1	ALADIN63	v2
4	DMI	ICHEC-EC-EARTH	r3i1p1	HIRHAM5	v2
5	GERICS	NCC-NorESM1-M	r1i1p1	REMO2015	v1
6	KNMI	ICHEC-EC-EARTH	r12i1p1	RACMO22E	v1
7	KNMI	CNRM-CERFACS-CNRM-CM5	r1i1p1	RACMO22E	v2
8	MPI-CSC	MPI-M−MPI−ESM−LR	r2i1p1	REMO2009	v1
9	MPI-CSC	MPI-M−MPI−ESM−LR	r1i1p1	REMO2009	v1
10	RMIB-UGent	CNRM-CERFACS-CNRM-CM5	r1i1p1	ALARO-0	v1

matches the theoretical cumulative distribution function (CDF) of CM-simulated data with the observed CDF. Typically, the Gamma distribution is used to represent precipitation on wet days, while the Gaussian distribution is commonly used for temperature. Preliminary evaluations confirmed the suitability of these two distribution families to represent CM output and were thus employed in this paper. Because CMs tend to simulate too many days with low precipitation (i.e., drizzle), a precipitation threshold of 0.1 mm per day was applied to avoid substantial distortions of the distributions. For a more detailed mathematical description of the procedure we refer the reader to Teutschbein and Seibert (2012).

3.2.2. Future streamflow

We utilized the conceptual rainfall-runoff model HBV-light (Seibert and Vis, 2012) to simulate daily streamflow in each of the study catchments. HBV-light is a lumped model that has been widely used for different basins and climates (Bergström and Lindström, 2015). A detailed description of the model structure and its routines is provided by Seibert and Vis (2012) as well as Seibert and Bergström (2022). The model takes observations of precipitation (P), air temperature (T), and potential evapotranspiration (PET) as input data and provides various runoff components (Q) of a catchment (or multiple sub-catchments) along with snow depth, and actual evapotranspiration (AET) as outputs. As we only had observed temperature and precipitation available, daily PET was calculated with the temperature-based Hamon equation (Hamon, 1968).

In each catchment, HBV light was calibrated to observed streamflow (1962–1991, with 1961–1962 serving as warm-up) by optimizing fifty randomly selected parameter sets using 5000 runs of the built-in GAP optimization algorithm (Seibert, 2000). The best parameter set for each catchment was selected according to a composite objective function that included the Nash-Sutcliffe efficiency (NSE), the logarithmic NSE (logNSE) and the volumetric efficiency (VE). The calibrated models for the 50 catchments were validated based on the observed streamflow from 1991 to 2020, and then used to simulate future daily streamflows in each catchment using the bias-adjusted precipitation and temperature simulations provided by the 10 CMs. The observed flow series was used only for calibration and validation of the hydrological HBV light model.

4. Methods

4.1. The WEFE Nexus Sectors: Water, Energy, Food and Ecosystem Services

The four nexus sectors water, energy, food and ecosystem services refer to the provision of essential resources required for the benefit of human well-being (Purwanto, 2021). The water sector mainly includes water supply and sanitation. In Sweden, water supply is mostly dependent on surface and groundwater resources (Teutschbein et al., 2022), thus this sector is sensitive to hydrological droughts (Fig. 1). The energy sector revolves around energy security that is based on renewable and non-renewable energy resources. According to the Swedish Energy Agency (2022), most energy in Sweden is supplied through biofuel (28 %) and nuclear power (27 %), followed by raw oil and petroleum products (20 %), hydropower (14 %) and wind power (6 %). About 24 % of the total energy production is transformed into electricity, which strongly depends on hydropower (45 %) and nuclear power (29 %). Thus, droughts influence the energy sector mainly through insufficient streamflow, which can limit hydropower production and hamper power plant cooling (van Vliet et al., 2013). The food sector comprises mainly crop and livestock farming. In a rainfed agricultural system (as is typically the case in Northern-European countries), arable land is most sensitive to meteorological (i.e., precipitation deficit) and soil moisture drought. The ecosystem services sector includes ecosystems such as forests, grasslands, agro-eco- and freshwater ecosystems and the goods and services they provide to support the well-being of humans. These services are essential to the provision of water, energy and food (Purwanto, 2021) and play an integral role in the WEFE nexus.

For this nexus (Fig. 3), no single drought index is appropriate for all sectors. Hence, it is good practice to include several, more targeted drought indices in climate change assessments. Because precipitation and temperature data are often the most widely available, many indices use these as input to quantify droughts. However, to account for climate change, suitable indices should also account for the effects of potential evapotranspiration (PET) (Marcos-Garcia et al., 2017; Mukherjee et al., 2018) and other hydrological variables that can impact the total water balance (Staudinger et al., 2014).

4.2. Standardized Drought Indices for the WEFE Nexus

The existing spectrum of drought indices can be categorized in multiple ways, which differ in their complexity and which are based on either natural boundaries, impact sectors, input data, calibration methods, or other characteristics (WMO and GWP, 2016). Based on natural boundaries, they can be divided into the typical drought categories: meteorological, soil moisture, and hydrological drought, along with composite or modelled indices and indices based on remote sensing data. However, in this paper we suggest a categorization based on the WEFE-nexus sectors that they represent. This new perspective implies that the drought indices are no longer used to merely judge the drought hazard and the propagation through the hydrological system, but instead the focus is shifted towards the impacted sectors—thus providing an essential foundation for studying drought propagation through the WEFE nexus lens and focusing on impact-based drought assessment and forecasting.

We carefully analyzed the exhaustive list of standardized indices provided by WMO and GWP (2016) and in a first step categorized them based on their suitability to represent WEFE nexus sectors as judged by the authors' expert knowledge and recommendations found in the literature. Please note that we only focused on standardized (as opposed to threshold-based) indices, as these are more suitable for the comparison across regions, sectors and time periods (future versus past). For each index, we also synthesized the data needs. In a second step, we identified all drought indices that could be easily computed based on the available data, which in our case were the measured hydroclimatic variables precipitation (P), temperature (T), and streamflow (Q), as well as potential evapotranspiration (PET) computed with the Hamon equation (Hamon, 1968) and various variables simulated by the HBV light model, including actual evapotranspiration (AET), snow-water equivalent (SWE), snow-melt rate (SM), soil-moisture content (SMC),

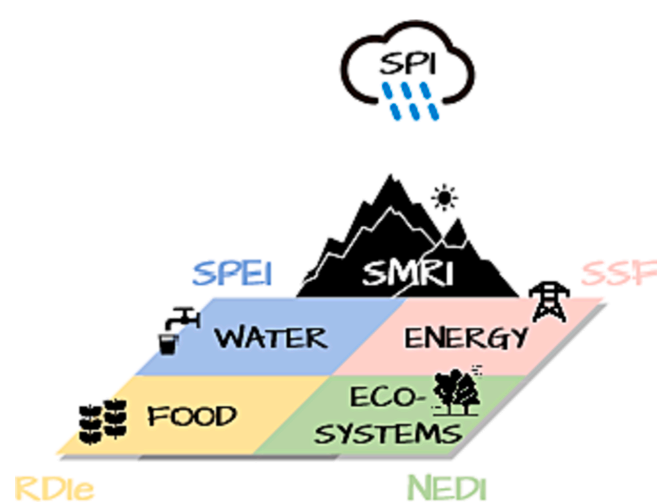

Fig. 3. Selected drought indices and their relation to the water-energy-food-ecosystem nexus concept.

groundwater recharge (GW), groundwater storage (RD), and effective precipitation (Pe) (as defined by Tigkas et al. (2016)).

Based on data availability, ease of computation, recommendations in the literature and their applicability and relevance for the Swedish and Northern-European WEFE nexus, one index each was chosen to represent one of the four WEFE nexus sectors (Fig. 3) as described further below.

Although not directly linked to a particular nexus sectors, we included the standardized precipitation index (SPI), introduced by McKee et al. (1993), for a comparison to describe future changes in the input of water. The SPI relies solely on precipitation and has been a popular index for drought intercomparison projects due to its wide applicability for different spatiotemporal scales. It has been endorsed by the World Meteorological Organization (WMO) and others as the standard way of quantifying meteorological drought (WMO and GWP, 2016). The SPI provides a dimensionless anomaly from normal situations, where positive SPI values indicate conditions above normal (i.e., wet conditions), while negative values represent below-normal conditions (i.e., drought conditions). Additionally, we also included the standardized snowmelt and rain index (SMRI), which was developed as a supplementary index to the SPI to account for the effects of snow accumulation and snowmelt in cold climates (Staudinger et al., 2014). Snow can both mitigate the severity of summer droughts while also intensifying winter droughts. The SMRI follows the same calculation procedure as the SPI, but is computed from the daily sum of snow melt and rain. To obtain the snowmelt, we utilized the snow routine in HBV-light, which only requires temperature and precipitation.

The multiscalar standardized precipitation evapotranspiration index (SPEI) (Vicente-Serrano et al., 2010) was selected to characterize droughts in the water sector. It is computed identically to the SPI, but instead standardizes the monthly difference in precipitation and potential evapotranspiration (PET), herein also referred to as the climatic water balance. As such, it is more robust with longer aggregation periods (e.g., 12 or more months) as it properly accounts for the water balance, making it also suitable for the characterization of hydrological droughts.

The standardized streamflow index (SSFI) follows the same way of calculations, but uses streamflow data (Vicente-Serrano et al., 2011), and is typically applied to quantify hydrological droughts (Vicente-Serrano et al., 2012). As such, it is here deemed suitable for the energy sector (i.e., availability of enough streamflow for hydropower production and power plant cooling).

The modified reconnaissance drought index (RDIe) standardizes the effective precipitation (P_e) divided by the PET and, thus, more accurately represents the amount of precipitation that can be consumed by plants, as opposed to being lost to deep percolation (Tigkas et al., 2016). Thus, we here employ the RDIe to identify droughts in the food sector. The effective precipitation (i.e., the part of total precipitation that is not intercepted, does not runoff at the surface, and does not percolate to deeper soil layers) was in our study computed from HBV-light outputs. Both the SPEI and the RDIe require an estimation of PET, which was obtained using the Hamon equation (Hamon, 1968).

The normalized ecosystem drought index (NEDI) was specifically designed to reflect ecosystem responses to water stress (Chang et al., 2018). It is very similar to the SPEI in that it uses the difference between the cumulative monthly precipitation and PET as an indicator variable. However, unlike the SPEI, the NEDI subtracts the total monthly PET from the cumulative precipitation of the preceding month. This is done to account for the fact that the water from precipitation is often not immediately available for ecosystems, but has to go through a series of hydrological processes before reaching plant roots and providing nutrients for growth.

Please note that each drought index was computed for the entire period 1961–2100 to allow for a comparison of drying or wetting trends across time periods. The subsequent analysis of future droughts, however, only considered the future period 2071–2100.

4.3. Identification and Characterization of Droughts

Droughts are programmatically defined as in Spinoni et al. (2015), which follows run theory by Yevjevich (1967). A drought event is initiated when the drought index, e.g. SPI, reaches a value below −1 (i.e., becomes more severe than a mild drought). The drought then continues as long as the index stays below zero, at which point the drought ends. This definition determines the duration and frequency of drought. To assess the potential cost of droughts to different societal and ecological functions, drought severity was also computed as the sum of absolute values in deficits over the duration of that drought. Note the drought indices are based on monthly averages and drought events shorter than one month may not be resolved, unless they are more intense. Additionally, there was no pooling or exclusion of droughts.

4.4. Projected Changes in Future Droughts per Sector

Projected future (2071–2100) anomalies (ensemble mean of all climate models) from current conditions were estimated separately for each drought index and each RCP (i.e., 2.6, 4.5, and 8.5). All indices were computed for 1, 3, 6, 12, 24, and 48 months aggregation periods. In addition to overall projected changes, seasonal changes were also considered by separately evaluating drought conditions during the warmer spring/summer months and the colder autumn/winter months. To this end, we evaluated the 6-month indices for September (i.e., integrating the drought conditions of the warmer 6 months from April to September) and for March (i.e., representing drought conditions during the colder months from October to March).

4.5. Propagation across WEFE Nexus Sectors (Response Times)

Given the existing well-known complexity of the WEFE-nexus, there might be large differences in the drought response and resulting drought durations of different sectors. To analyze drought responses to precipitation deficits across all different WEFE nexus, we computed the cross-correlation between SPI and the four indices SPEI, SSFI, RDIe and NEDI, representing the water, energy, food and ecosystem service sectors, respectively. We used standard cross-correlation as a measure of similarity between the SPI series, and shifted (lagged) series of the four sector-specific indices as a function of the lag. Lags of 1 to 24 months were considered. We adopted the procedure by Bloomfield and Marchant (2013) originally outlined for groundwater response times, and used the lag time resulting in the highest cross-correlation between SPI and the sector-specific drought indices as proxy for the sector response times. Lag time is a common metric to characterize drought propagation (Zhang et al., 2022) and was here calculated for past conditions (1961–2005) as well as for future conditions (2071–2100) under RCP2.6, RCP4.5 and RCP8.5. A faster response of a sector is, hence, indicated by a shorter response time of the sector-specific index to the SPI.

5. Results

5.1. Projected Changes in Future Droughts per Sector

5.1.1. General drought trends

The chosen drought indices project different degrees of future changes in general drought behavior, which depend on the selected RCPs (Fig. 4). Anomalies projected for the lowest radiative forcing (RCP2.6) generally differ a bit from those projected for the more extreme radiative forcings RCP4.5 and 8.5, while the latter two are generally in line, but differ in their magnitude of change.

For RCP2.6, the SPI indicates a future wetting in central Sweden, which implies more precipitation input into the water balance, while a drying is projected for the far south-western catchments in the Dfb climate and the far north-eastern catchments along the Baltic Sea coast

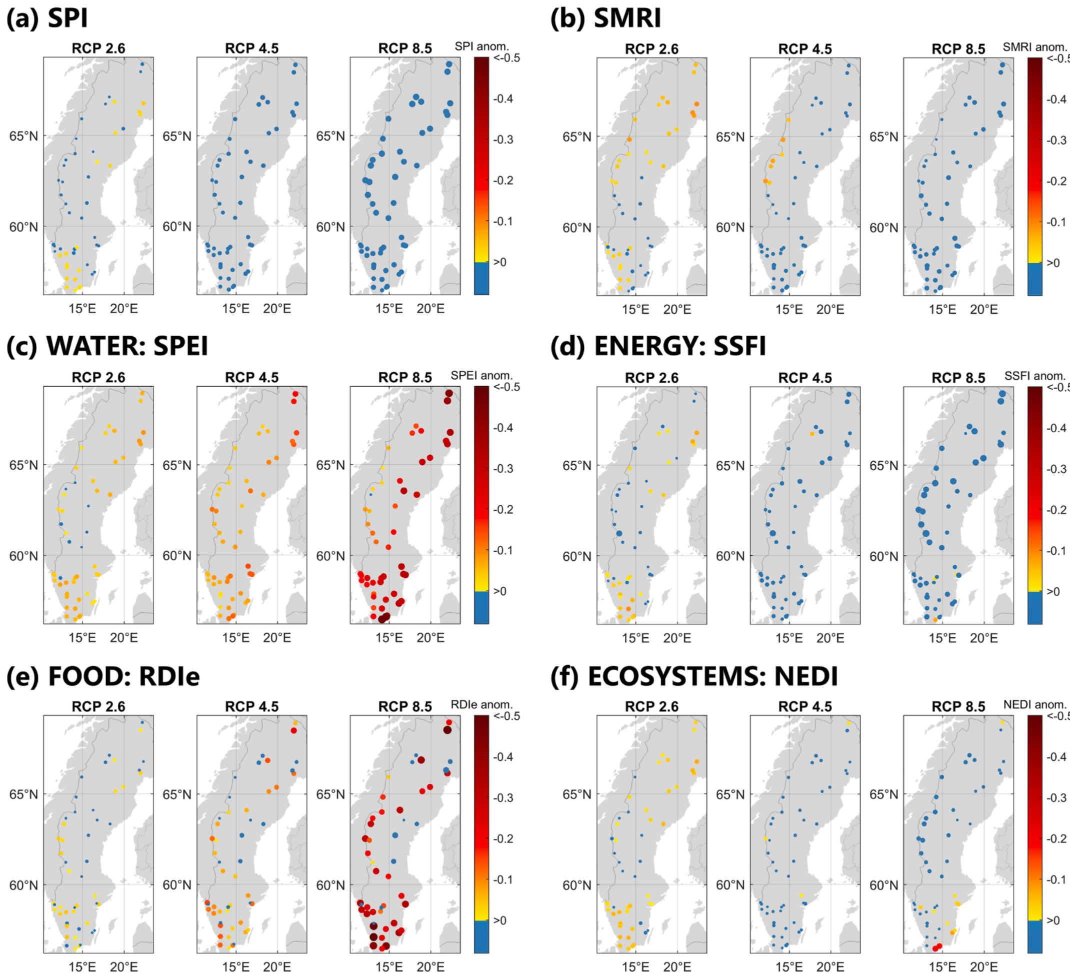

Fig. 4. Anomalies in average 12-month drought indices for the period 2071–2100 compared to 1961–2005 (averaged over all months). Yellow to red colors indicate a worsening of drought conditions (index becomes more negative), while blue colors indicate a wetting (index becomes more positive). Circle size is proportional to the projected change. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(Fig. 4a, left). For the other two RCPs, the precipitation is projected to increase across the entire country, with a stronger increase for RCP8.5 (Fig. 4a). These patterns are generally also visible with the SMRI (Fig. 4b), although here a more pronounced drying is seen in the northern regions compared to the SPI.

The increasing water input is not reflected in the water sector as it is counteracted by increasing energy supply and, thus, increasing evaporation. Under RCP2.6, this implies a drying across the entire country, except for five catchments in central Sweden (Fig. 4c, left). For the stronger radiative forcings, the drying is more pronounced and affects all catchments (Fig. 4c). For the energy sector, 56 % of the catchments are projected to experience lower streamflow levels under RCP2.6, while 44 % (mainly located in central Sweden) are projected to become wetter. This wetting trend is seen for all catchments across the entire country under RCP4.5 and 8.5 (Fig. 4d).

For the food sector, the signal is not that clear (Fig. 4e): Under RCP2.6, most catchments in the south and only a few in central and northern Sweden are projected to become drier (Fig. 4e, left). Those catchments that are projected to become drier under RCP2.6, are projected to become even more dry under RCP4.5 and 8.5. The other catchments show different responses to a warming climate, some are projected to become drier, others to become wetter (Fig. 4e). For the ecosystem service sector (Fig. 4f), the simulations under RCP2.6 show similar conditions as for the water sector (i.e., a drying in the far South and North), but the patterns diverge for RCP4.5 and RCP8.5. Here, a wettening is projected instead, with only some drying catchments in the far south-eastern parts of the country under RCP8.5.

5.1.2. Seasonal drought changes

Despite an overall wetting trend in the meteorological conditions (Fig. 4a), clear seasonal differences emerged: For the warmer spring and summer months from April to September, which are characterized by higher vegetational and societal water demand, the SPI indicates that general water input through precipitation is increasing (Fig. 5a). This wetting trend is projected to be stronger for higher radiative forcings (strongest for RCP8.5).

For the lowest radiative forcing (RCP2.6), this wetting trend can also be seen with the SMRI in south-central catchments (Fig. 5b), and translates into all WEFE nexus sectors (Fig. 5c-f), except for a few catchments in southern regions. However, for the higher radiative forcings, the future projections in the nexus sectors diverge from the water input signal (i.e., from the SPI): The water sector consistently experiences a drying, which is particularly severe under RCP8.5 (Fig. 5c). The energy sector is projected to be affected by drier conditions especially in northern and western Sweden, while south-eastern regions are getting somewhat wetter (Fig. 5d). Both the food (Fig. 5e) and ecosystem service sectors (Fig. 5f) follow a similar pattern as the water sector with a drying across the entire country (with only very few exceptions in central Sweden), which is much stronger under RCP8.5. The strongest worsening of drought conditions (in the range of −0.4 to −0.6 standard deviations) is projected for the water (Fig. 5c) and food sectors (Fig. 5e).

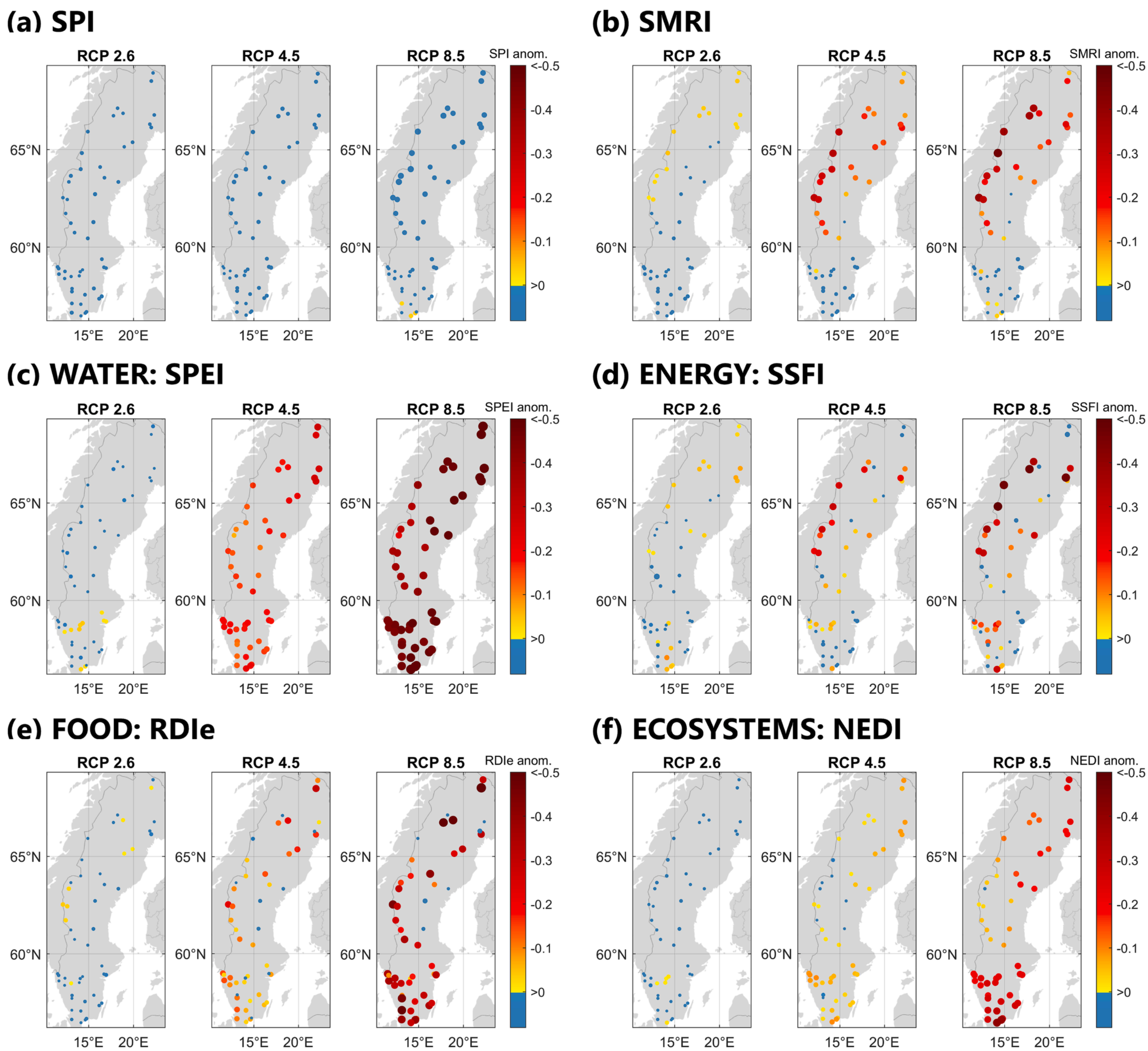

Fig. 5. Summer anomalies in average 6-month drought indices for the period 2071–2100 compared to 1961–2005 (averaged over all September months). September was chosen to represent the aggregated water deficits during the warmer spring and summer period from April to September. Yellow to red colors indicate a worsening of drought conditions (index becomes more negative), while blue colors indicate a wetting (index becomes more positive). Circle size is proportional to the projected change. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

For the colder autumn and winter months, the projected drying trends were weaker and the signals show somewhat different future developments (Fig. 6): For the lowest radiative forcing (RCP2.6), both the SPI (Fig. 6a) and the SMRI (Fig. 6b) indicate a drying trend with less precipitation across the entire country with a few exceptions in central Sweden (Fig. 6a). This pattern is, however, not reproduced with RCP4.5 and RCP8.5, which both show an increase in water input across the entire country. These future developments are generally projected for all four nexus sectors (Fig. 6c-f), in particular for the water (Fig. 6c) and ecosystem service sectors (Fig. 6f), which closely follow the patterns of SPI and SMRI. For RCP2.6, the energy (Fig. 6d) and food sectors (Fig. 6e) also demonstrate a drying in the southern regions under RCP2.6, but several regions in the north-western parts of Sweden feature a wetting (Fig. 6d,e) despite lower inputs (Fig. 6a,b). The food sector also sticks out as few catchments in the North-west, and some in the South are projected to undergo a substantial drying under RCP8.5 (Fig. 6f).

5.1.3. Projected changes in drought characteristics

The projected changes in drought frequency, duration and severity over the 21st century are not consistent across all 50 catchments, and are also incoherent across the four nexus sectors and across the RCPs (Fig. 7). For the water sector (Fig. 7a-c), a clear majority of catchments (82 % – 98 %) is projected to have a higher drought frequency in the future (Fig. 7a), ranging from a median of 0.3 more drought events per decade (max 1.0) under RCP2.6 to 0.9 more drought events per decade (max 1.9) under RCP8.5. At the same time, under RCP2.6, only 40 % of the catchments are projected to experience longer drought durations in the future (Fig. 7b), while under stronger forcing, most catchments (i.e. 72–78 %) are projected to suffer from longer droughts, on average 0.75 months longer (max 3.2 months) under RCP4.5 and 0.4 months longer

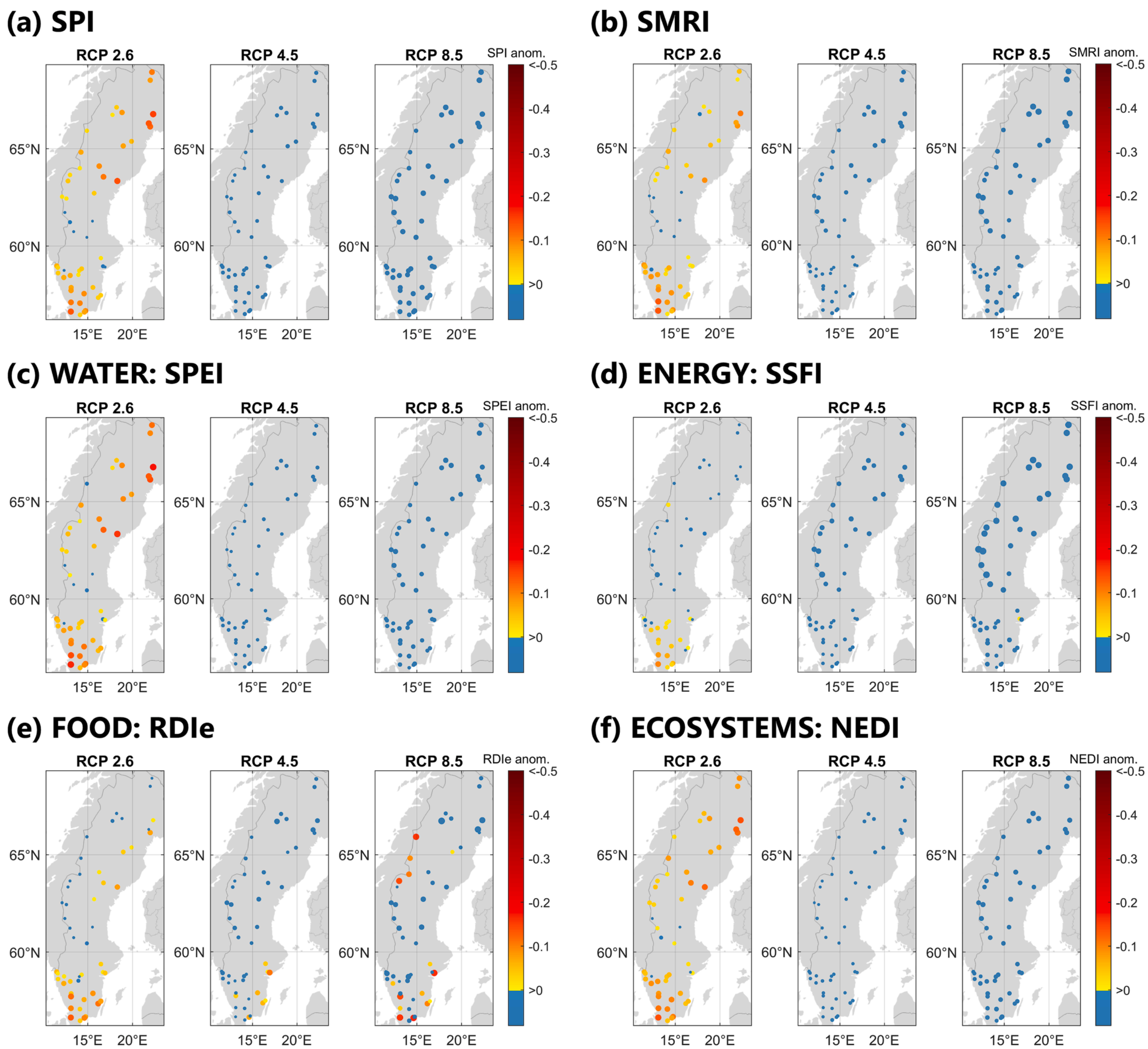

Fig. 6. Winter anomalies in average 6-month drought indices for the period 2071–2100 compared to 1961–2005 (averaged over all March months). March was chosen to represent the aggregated water deficits during the colder autumn and winter period from October to March. Yellow to red colors indicate a worsening of drought conditions (index becomes more negative), while blue colors indicate a wetting (index becomes more positive). Circle size is proportional to the projected change. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(max 2.5) under RCP8.5. These trends are also reflected in the projected severity (Fig. 7c), which gets worse for the majority of catchments under RCP4.5 and RCP8.5.

The energy sector (Fig. 7d-f) shows the opposite signal: The majority of catchments is projected to have fewer drought events (Fig. 7d) of shorter duration (Fig. 7e) and lower severity (Fig. 7f) in a future climate. The signal is consistent across all three forcings, but represents different levels of changes, with RCP2.6 showing the smallest and RCP8.5 the largest anomalies in a future climate.

Both the food (Fig. 7g-i) and ecosystem services sectors (Fig. 7j-l) show similar future projections as the water sector, with a clear increase in drought frequency, a prolongation of drought events and more severe droughts, especially under RCP4.5.

5.2. Drought Propagation Across the Nexus Sectors

The computation of sectoral response times to the precipitation deficits (as indicated by the SPI) revealed differences in the timing of droughts among the four WEFE nexus sectors (Fig. 8a). While both the water (SPEI) and ecosystem service sectors (NEDI) showed a relatively quick response within the same month of the precipitation deficit signal under past conditions, the food sector (RDIe) had the second quickest response (on average 0.1 months), followed by the energy sector (SSFI) with 1.6 months (Fig. 8a). For the energy sector, response times are projected to decrease to 1.5, 1.4 or 1.2 months in a future climate (depending on the RCP), while only small and inconsistent changes are projected for the food and ecosystems sector.

Similarly, the duration of drought events in each sector also varied in the past (Fig. 8b): The energy sector featured the longest drought

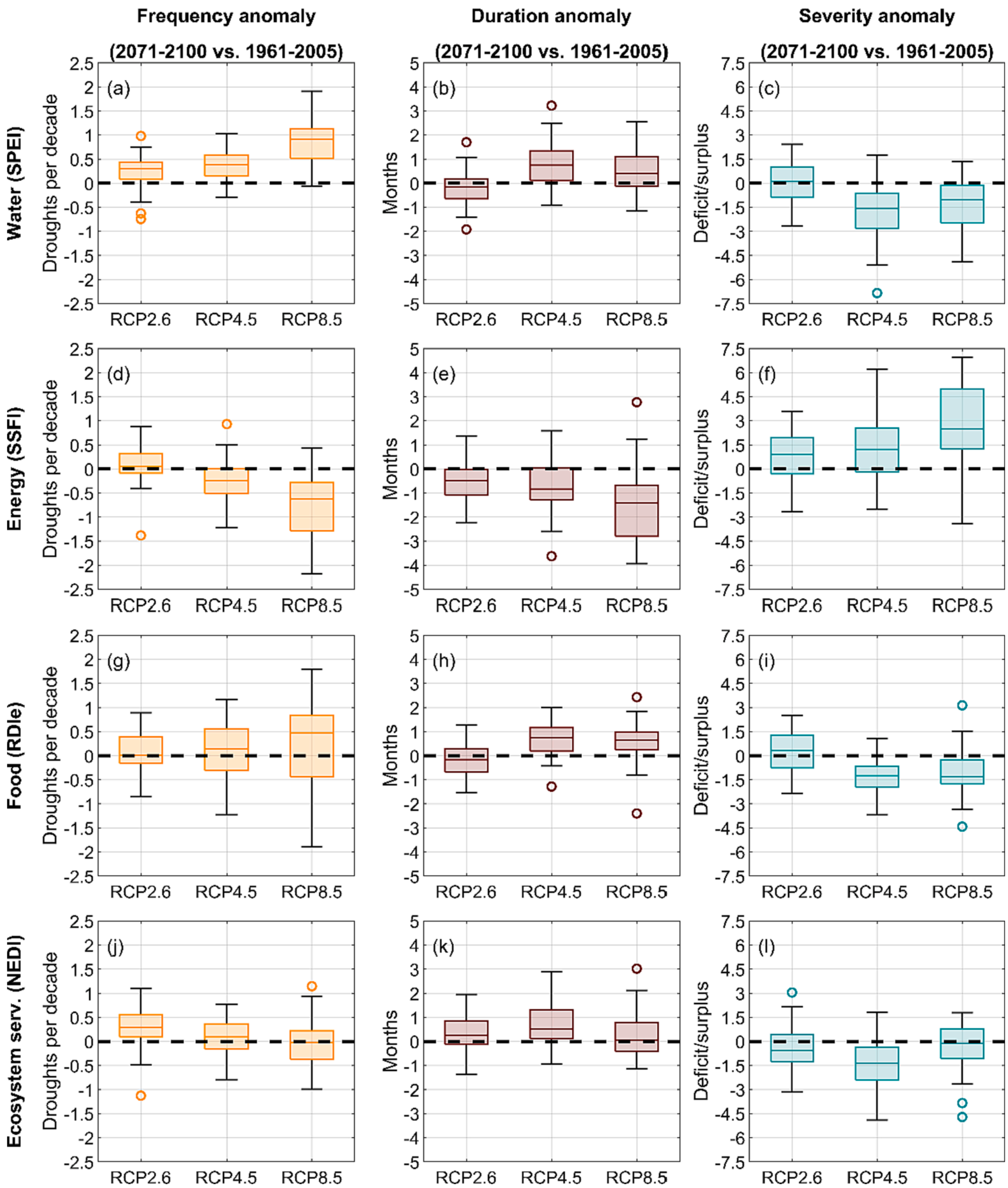

Fig. 7. Range of anomalies in future drought frequencies (left, orange), duration (center, red) and severity (right, turquoise) across the 50 catchments within each of the four nexus sectors. Each box represents the projections for a particular RCP. Positive/negative values indicate more/less frequent droughts (left), longer/shorter droughts (center) or less/more severe droughts (right). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

durations (8.9 months), followed by the water sector (6.7 months), the ecosystem sector (6.6 months) and the food sector (6.3 months). In a future climate, these drought durations are projected to increase for all sectors except for the energy sector (Fig. 8b).

6. Discussion

Using an ensemble of 10 climate models in combination with the hydrological HBV-light model, this paper provides projections of a variety of distinguished drought indices that represent the four sectors water, energy, food and ecosystem services. These sectors are intrinsically connected within the complex WEFE nexus. Our results suggest that the total water input to the water balance in the form of precipitation will increase in a future climate, especially under stronger climate forcings. However, droughts are affected by a number of hydrological processes that are influenced by global warming (Wu et al., 2022). Thus, the SPI alone is not informative enough for all WEFE nexus sectors, and energy-sensitive hydrological processes such as evaporation, snow-rain partitioning, snow accumulation and snowmelt should not be neglected as they will strongly influence the seasonal availability of water. For example, including a snowmelt component as suggested by Staudinger et al. (2014) mostly influences the drought projections for the spring and summer months in northern Sweden, where seasonal snowmelt patterns are expected to shift in a future climate. Additionally, we here show that the evaporation-sensitive indices generally project more frequent, longer and more severe droughts, which is relevant for the water, food and ecosystem sectors. This trend is particularly pronounced in the spring and summer months, which emphasizes that the evaporative

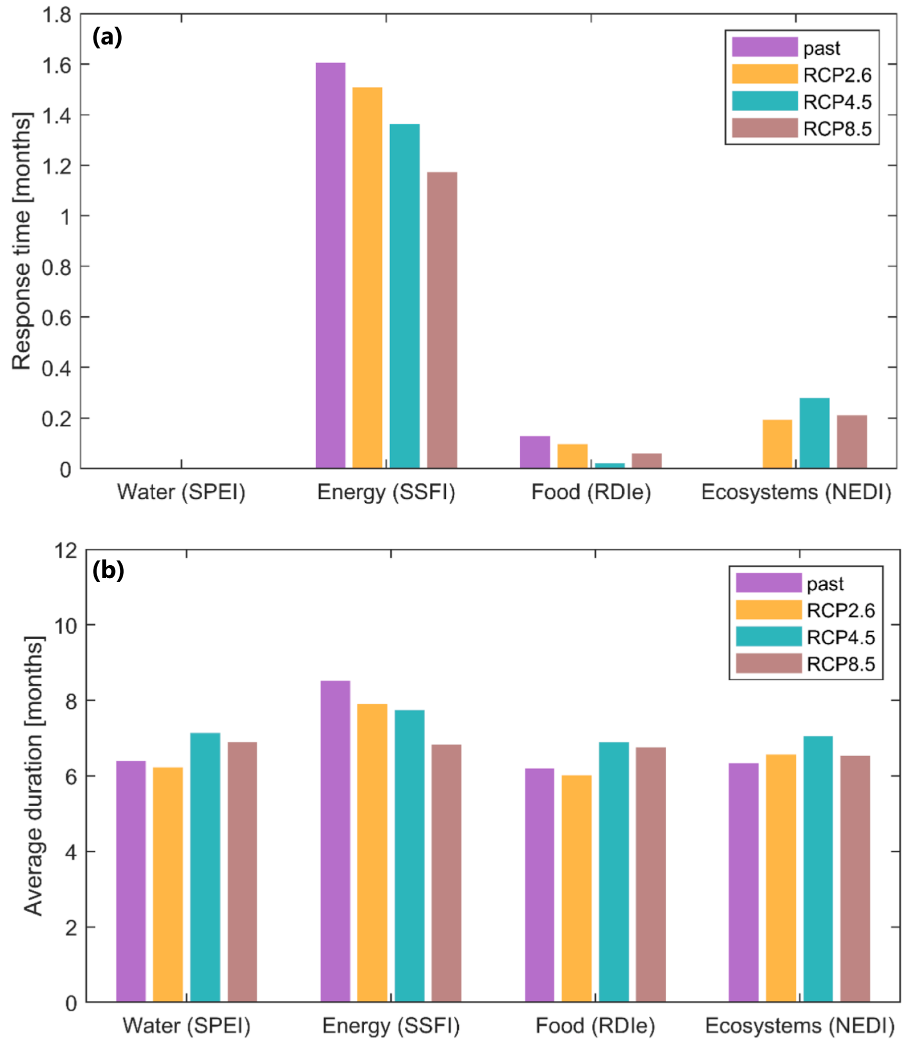

Fig. 8. Sectoral response times and drought durations for past and future climate conditions.

demand and longer growing season in these months will outweigh the water surplus provided by precipitation, and will be further exacerbated by a lack of spring and summer snowmelt in northern regions. This is particularly true for the water, food and ecosystem services sectors.

For the food sector, the change signal in a future climate is not consistent. Especially in central and northern Sweden, some catchments are projected to feature wetter, and other catchments drier conditions for agriculture. These findings have implications for agricultural management, especially for ditching (draining the landscape) and irrigation (watering the landscape). Thus, more research is needed to understand the underlying causes and potential links to catchments properties and local hydrological processes.

The energy sector, which in Sweden mostly relates to the production of hydropower and availability of streamflow for cooling purposes, seems to be an exception among all four studied nexus sectors. Here a transition of catchments in central and northern Sweden from snow-melt dominated to rainfall-driven streamflow regimes provides a seasonally more balanced availability of water, which is expected to be mostly beneficial in a changing climate (van Vliet et al., 2013). These findings corroborate Turner et al. (2017), who also projected benefits for Scandinavian hydropower production in the 21st century.

It is, however, important to also consider the spatial distribution and local clustering of particular sectors. For instance, in Sweden, most of the hydropower is produced in northern regions, where catchments are especially sensitive to warming temperatures and shifts in snow dynamics. In contrast, arable land and most of the agriculture are predominantly located in southern Sweden, which are regions prone to increasing evaporation rates as well as water demands by humans (consumption) and vegetation. The water supply and ecosystem services sectors are spread across the entire country, but here it might also be worth to consider population distributions as densely-populated areas suffer from higher pressures on the available water resources (Henrichs and Alcamo, 2001).

Based on the results in this paper, certain inferences can be made about the chronology of emerging drought events and their propagation through the WEFE nexus: The water sector has the shortest response time to deficits in precipitation, which is closely followed by the food and ecosystem sectors. The energy sector sticks out as having one of the longest response times and, thus, taking substantially longer time to exhibit drought impacts. At the same time, droughts in the energy sector seem to last longer than in the other sectors.

The selection of tailored drought indices in this paper is beneficial for identifying and characterizing drought properties within each sector, and for providing projections for how these sectors are expected to evolve with time over the 21st century throughout Sweden. In addition to those employed in this study, other standardized indices might also be appropriate to represent particular sectors. For example, the Standardized Soil Moisture Index (Leeper et al., 2021) may be used to characterize the food sector, whereas the Standardized Reservoir Supply Index (Shiau, 2003) may be helpful to represent the energy or water supply sector. Other types such as Palmer-based indices (Palmer, 1965), which are based on simple water balance models, or multivariate drought indices (Rajsekhar et al., 2015) might also be suitable in such a context. For the ecosystem service sector, the NEDI was in this study particularly chosen as it was specifically developed to represent the water availability for plants (Chang et al., 2018; Soleimani-Motlagh et al., 2022). However, one of its key limitations is that it is a meteorological drought index and does not necessarily reflect vegetative stress. Other indices, such as streamflow normalized by environmental flow for freshwater ecosystems (Tharme, 2003) or the leaf area index for terrestrial ecosystems (Lawal et al., 2022), might be more suitable to represent ecosystem health and should be tested in future WEFE nexus studies.

While the traditional selection of standardized drought indices is typically guided by research needs, data and tools, we argue that a careful selection of indices in combination with modeling approaches can help shaping policy decisions. For instance, we here see clear cross-sectoral, temporal (winter versus summer), spatial (cross-catchment) and cross-pathway (RCP) differences that have severe consequences for decision making at local and national scale.

Spring and summer months are projected to be more affected in a future climate, which will exacerbate already existing water stress during these warmer months of the year (Ahopelto et al., 2019). This might potentially intensify the already competing interests of water users within the WEFE nexus (Madani, 2010), which in combination with population growth and increasing consumption (Flörke et al., 2018) could lead to severe water shortages throughout the summer (Kummu et al., 2016). This calls for relevant policies (e.g., Swedish or European drought directive) or economic instruments to assist water allocation and management/regulation of potential conflicts (Rey et al., 2019; Wimmer et al., 2015), especially during the warmer spring and summer months.

Likewise, catchments in southern Sweden, which are generally more densely populated and, thus, are affected by greater water withdrawals, are projected to suffer from more severe drought conditions in the future, especially in relation to the water, food and ecosystem services sectors. Only for the energy sector, wetting trends prevail in southern regions (located in the Dfb climate), which are characterized by little or no snow accumulation during winter and which are entirely affected by increasing rainfall amounts. However, the majority of hydropower production is located in northern Sweden, a region which today is characterized by snow accumulation during winter and a snowmelt in spring or early summer. Here, a drying trend can be seen until the end of the century in the energy sector due to the diminishing snow layers and earlier spring flood peaks in a warming climate (Teutschbein et al., 2015), which has implications on hydro-dam operation strategies in a future climate. Our results also suggest that drought occurrence and severity will only marginally change under the lowest RCP2.6. Thus, keeping greenhouse emissions at a minimum is essential for reaching the Agenda 2030 sustainable development goals (UN General Assembly, 2015), and for guaranteeing properly functioning hydrological and catchment processes.

7. Conclusions

We analyzed various drought indices relevant for the water, energy, food and ecosystem sectors over the 21st century in Sweden, using bias-corrected climate model data driven by different greenhouse gas trajectories in combination with hydrological modelling outputs for an ensemble of 50 catchments. Indices were chosen according to sector suitability, data availability, and ease of use, and were then analyzed for trends and correlations at different time scales. These trends were then used to predict impacts to different sectors within the WEFE-nexus. Thus, our new approach implies that drought indices are no longer used to merely judge the drought hazard and the propagation through the hydrological system. Instead, there is a need to shift the view towards the impacted sectors, thus providing an essential foundation for studying drought propagation through the WEFE nexus lens, and focusing on impact-based drought assessment and forecasting.

Different patterns in the response of the four nexus sectors water, energy, food and ecosystem services to future climate change emerged, with different response times and drought durations across the four sectors. In particular, the warmer spring and summer months are projected to be subject to more severe, frequent and long-lasting droughts across all four nexus sectors in a future climate. These changes are more pronounced for stronger radiative forcings (RCP4.5 or RCP8.5). Consequently, our results offer new insights into the propagation of droughts through the WEFE nexus. This also provides a promising basis for further research on the representativeness of other potentially suitable drought indices for the water, energy, food and ecosystem service sectors. We finally argue that future drought projections can be better geared towards decision makers by basing them on standardized drought indices that are specifically tailored to represent specific nexus sectors.

CRediT authorship contribution statement

Claudia Teutschbein: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing - original draft, Writing - review & editing. **Elise Jonsson:** Conceptualization, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing - original draft, Writing - review & editing. **Andrijana Todorović:** Conceptualization, Data curation, Investigation, Methodology, Software, Supervision, Writing - review & editing. **Faranak Tootoonchi:** Conceptualization, Data curation, Investigation, Methodology, Software, Supervision, Writing - review & editing. **Elin Stenfors:** Validation, Writing - review & editing. **Thomas Grabs:** Methodology, Supervision, Validation, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All the data used in this study is freely available in public databases hosted by the Swedish Meteorological and Hydrological Institute. Relevant references and links are provided in the paper.

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