Climate change, biodiversity, and food security nexus: A structured data review

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The ECO-READY project has received funding from the European Union's Horizon Europe Research and Innovation Programme under grant agreement n° 101084201

Technical References

Project Acronym	ECO-READY
Project Title	Achieving Ecological Resilient Dynamism for the European food system through consumer - driven policies.
Project Coordinator	Czech University of Life Sciences (CZU)
Project Duration	48 months

Deliverable No.	D1.1
Dissemination level [1]	PU
Work Package	1
Task	1.1
Lead beneficiary	18. Cranfield University
Contributing beneficiary(ies)	**Czech University of Life Science**, **Italian Nation Agency**, Aristotle University of Thessaloniki, **Wageningen Research**, **Cyprus University of Technology**, **Institute of Field and Vegetable Crop**, **University of Edinburgh**, **IFOAM Europe**, General Confederation of Italian Agriculture, Alternet, EC Joint Research Centre, Progis Software GmbH, IUCN EURO
Due date of deliverable	M12 - 30/11/2023
Actual submission date	30/11/2023

[1] PU = Public

PP = Restricted to other programme participants (including the Commission Services)

RE = Restricted to a group specified by the consortium (including the Commission Services)

CO = Confidential, only for members of the consortium (including the Commission Services)

Partners highlighted **in bold** also contributed to Task 1.1

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Document history

V	Date	Beneficiary	Author
1	30/11/2023	Cranfield University	Dr Nam Vu, Professor Michael Bourlakis
2			

Summary

The Structured Data Review (SDR) is the main deliverable of Task 1.1 in Work Package 1 of the ECO-READY project. The aim of this review is two-fold. First, this review identifies climate change and biodiversity-induced drivers of food security. To this end, it is highlighted how climate change and biodiversity can affect various dimensions of food security. Second, this review compiles data (e.g. data sets, data sources, data platforms) that are used to monitor/ report climate change and biodiversity drivers of food security.

To achieve this aim, two methods were employed. A systematic literature review was undertaken to identify studies that address the nexus of climate change – biodiversity – food security, then to synthesize the key insights from the literature and derive the drivers of food security. Subsequently, a search for data related to the identified drivers was conducted, compiling a list of data for monitoring, measuring, and reporting the drivers.

The findings of this report include a list of 20 climate change and 18 biodiversity drivers of food security, an in-depth analysis of how the drivers impact the four pillars of food security (availability, accessibility, utilization, and stability), and data in relation to the drivers from the academic literature, projects (EU level and national level), EUROSTAT, and public platforms on the internet.

This report makes several contributions to industry and policy. The findings of the report inform businesses of the threats and benefits of climate change and biodiversity drivers, advocating for managers to develop appropriate strategies and plans to mitigate adverse consequences as well as to take advantage of useful drivers. For policymakers, important climate change and biodiversity-induced drivers for food security can be used as a useful reference when developing new guidelines/ regulations. For managers in the field and policymakers, the findings demonstrate the availability of data and advocate for stronger use of data in the decision-making process.

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Disclaimer

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1 Introduction

ECO-READY is a European project with the mission of "achieving Ecological Resilient Dynamism for the European food system through consumer-driven policies, socio-ecological challenges, biodiversity, data-driven policy, sustainable futures". ECO-READY recognizes the profound effects of climate change and biological factors on the food system, and subsequently on food security at regional and European levels. To this end, the project will develop a real-time surveillance system, also known as the Observatory platform. This platform will act as a concentrated source of information and data regarding climate change and biodiversity-induced drivers of food security. The Observatory aims to assess, monitor, and manage these vital drivers, and together with the network of 10 Living Labs, to support decision-makers with appropriate data, scenarios, and strategies. To achieve the overall aim of the project, 7 Work Packages (WPs) were formulated. Each of the WPs addresses a specific aspect of the project and is further divided into specific tasks. The Structured Data Review (SDR) is the main deliverable of Task 1.1 of WP1. Being the first task to materialize in this large project, the outcomes of the SDR provide the foundations for subsequent tasks and WPs.

The SDR plays a vital role in the ECO-READY project, as it captures and aggregates necessary knowledge for guiding the future development of other core components in the project, including the Observatory platform and various Living Labs activities. Living Labs introduce the co-creation of policy recommendations, contingency plans, and food network resilience strategies, embedded in the Observatory. Therefore, the objectives of the SDR, and Task 1.1 in WP1, are two-fold: first, to comprehensively identify, categorize, and dissect the drivers (influential factors) of *food security* in relation to *climate change* and *biodiversity*, and second, to illustrate the key data available for measuring and reporting those drivers.

The anticipated results of the SDR include the list of climate change and biodiversity-induced drivers, highlighting their impacts on food security, and identifying gaps in current knowledge about these drivers (acknowledging factors that are novel or less investigated). Furthermore, the SDR will present a list of data sets, data sources, and data platforms in relation to those determined drivers.

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2 Background

The topics of biodiversity, climate change, and food security underpin the SDR. Especially, understanding the dynamics and interrelationships between these three concepts is a key aspect of the SDR scope. Therefore, it is important to define each topic and relevant concepts within each topic.

Biodiversity is the variety of living species on Earth. It includes all organisms, species, and populations, the genetics among these, and their complex assemblages of communities and ecosystems (UNEP, 2011). There are three levels of biodiversity, namely the ecosystems, the species they contain, and the genetic diversity within species (Sunderland, 2011). Genetic diversity is all the different genes contained in all individual plants, animals, fungi, etc. Species diversity refers to the differences within and between populations of species, as well as between different species. Finally, ecosystem diversity is all the different habitats, biological communities, and ecological processes, as well as variation within individual ecosystems. The term “biodiversity” has been coined relatively recently in the scientific community, since 1985, as a contraction of the term *biological diversity (*UNEP, 2011).

Climate change refers to the long-term shifts in temperatures and weather patterns. The shifts could be both natural and man-made. The latter holds much more significance since it is widely believed that human activities have been the main driver of climate change since the 1800s due to the overuse of, and overreliance on fossil fuels (coal, oil, natural gas) (United Nations, 2022).

Lynas et al. (2021) determined, after extensively reviewing the academic literature from 2012, that >99% of the peer-reviewed scientific literature agree that greenhouse gas emissions from human activities (since the Industrial Revolution) are the principal driving force of climate change. Another concept, which is often associated with climate change, is global warming. Global warming is the long-term heating of the Earth’s surface observed since the pre-industrial period (between 1850 and 1900) due to human activities, primarily fossil fuel burning, which increases heat-trapping greenhouse gas levels in the lower atmosphere (NASA, 2020). To make a clear distinction, climate change is different than global warming, in the sense that temperature rise creates various problematic effects in the climate, which are often referred to as climate change. Therefore, climate change is

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the result of global warming. Some adverse impacts of climate change include droughts, rising sea levels, melting ice caps, super storms, natural fires, etc (United Nations, 2022).

Perhaps the most recognized definition of food security is the one proposed by the Committee on World Food Security, which states that: “Food security exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life” (FAO, 2006).

The Committee goes further to determine the four pillars of food security including availability, access, utilization, and stability. Mbow et al. (2019) explained these four pillars as follows:

- Availability means the sufficiency and readiness of food from production and distribution activities.
- Access means people’s ability to obtain food.
- Utilization means the achievement of food potential through nutrition, cooking, and health.
- Stability means the continuous availability and access to food without disruption.

The concept of food resilience is also explained, due to its importance in the broader area of food security. The term resilience can be understood differently under varied perspectives and contexts (e.g. engineering resilience, ecology resilience). Tendall et al. (2015) argued that resilience, and resilience thinking, represent a paradigm and can be characterized as a cluster of concepts.

In this current work, the resilience in food systems is of interest. Tendall et al. (2015) proposed the definition of food system resilience as “the capacity over time of a food system and its units at multiple levels, to provide sufficient, appropriate, and accessible food to all, in the face of various and even unforeseen disturbances”. Taking a more food security orientation, Bullock et al. (2017) implemented a working definition of resilience as “maintaining production of sufficient and nutritious food in the face of chronic and acute environmental perturbations”. The two definitions overlap for the most part, however, the biggest difference is that the latter definition by Bullock et al. puts more emphasis on the production side while Tendall et al. take into consideration both supply and demand. Overall, the essence of resilience, which is rooted in ecology, largely refers to the ability of a system to resist change or to recover from perturbations.

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3 Methodology

In this section, the SDR process is presented and discussed. In essence, there are three main stages for conducting the SDR:

- Stage 1 – Planning: The scope of the study is defined, and the research questions are formulated.
- Stage 2 – Analysing: This stage consists of two main parts. The first one is a systematic literature review to determine climate change and biodiversity-related drivers of food security. The second part is an assessment of available data sources for reporting/ monitoring those drivers.
- Stage 3 – Reporting: The findings from the literature are reported, and the final report is disseminated.

Figure 1 summarizes the process of conducting the SDR.

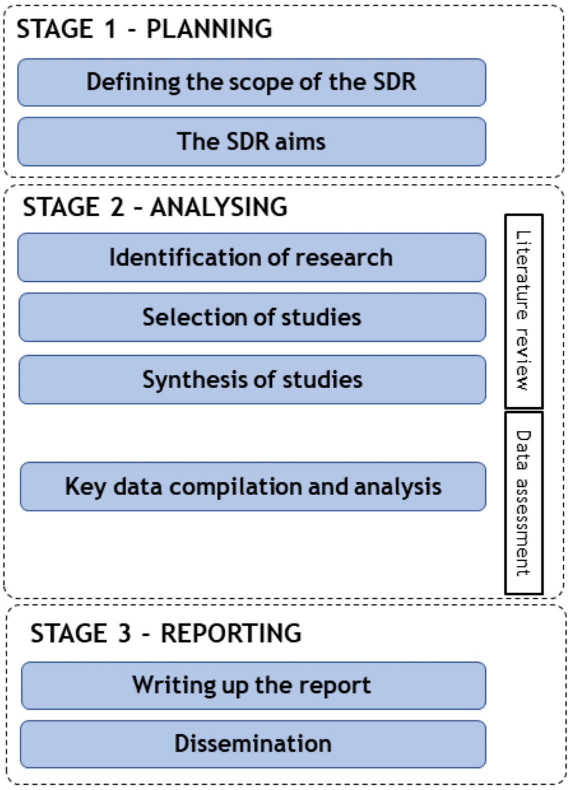

Figure 1. The SDR process.

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3.1 Stage 1 - Planning

In this stage, the foundations for the SDR will be established. This includes a number of important points which need to be agreed upon by the research team before the actual SDR can take place. Particularly, the goals and objectives of the SDR need to be clearly defined. The scope of the research must also be determined. Finally, as the SDR will be structured as a research paper at the end, the research questions are to be formulated.

Based on the official proposal of ECO-READY, and multiple meetings between partners of WP1, the objectives of the SDR, and subsequently Task 1.1 in WP1, are to comprehensively identify, categorize, and dissect the climate change and biodiversity-induced drivers of food security, and to determine available data that monitors and reports these drivers.

Subsequently, the scope of the SDR strictly encompasses the three areas of climate change, biodiversity, and food security.

Finally, the research questions are formulated:

RQ1: What are the climate change and biodiversity-related drivers of food security?

RQ2: What are the available data for reporting and monitoring the underlying drivers of these interrelationships?

3.2 Stage 2 - Analysing

The major research activities take place in this stage. As highlighted in the overview of the SDR process, depicted in Figure 1, the two main tasks in Stage 2 are the Literature review and the Data assessment. The former aims to systematically review the relevant literature to identify key climate change and biodiversity-induced drivers of food security. Based on the results of the first task, the second one aims to construct a list of data that represents those drivers from multiple sources (namely literature, national projects, EU projects, EUROSTAT, and internet search). Thus, the two main activities in this stage are not conducted simultaneously but in chronological order.

3.2.1 Main task number 1 - Systematic literature review

Systematic literature review (SLR) is the adopted methodology for selecting and reviewing the relevant literature. Originating from the medical research domain, SLR has quickly expanded and become a common method of literature review in many other areas, including but not limited to management, economics, sociology, and environmental

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studies. The main advantages of SLR over a traditional narrative approach to reviewing literature are scientific process, robustness, and replicability (Tranfield et al., 2003).

The goal of the SLR is to identify the most relevant academic papers covering the topics of interest and synthesize the key insights from those papers to derive climate change and biodiversity drivers of food security. Following Tranfield et al. (2003) guidelines for conducting an SLR, a procedure for reviewing relevant literature is developed. As noted in Figure 1 ("The SDR Process"), the literature review task encompasses three smaller steps, namely- identification of research, selection of studies, and synthesis of studies. Figure 2 elaborates on these steps further, giving an overview of what each one accomplishes and how they, together, lead to the final output of the literature review.

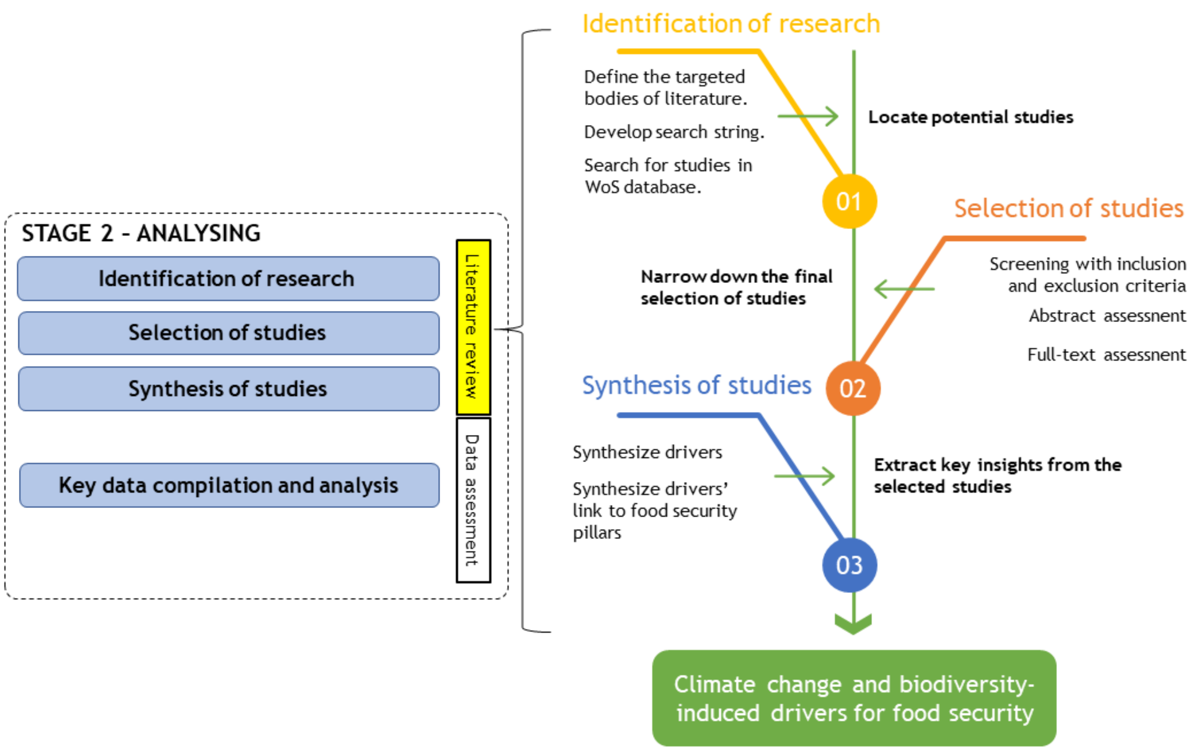

Figure 2. The SLR procedure.

Next, the results of each step are discussed.

Step 1 of the SLR procedure aims to identify relevant research that can be included in the review. Fundamentally, this step determines what researches are pertinent (targeted bodies of literature), how to locate those researches (by developing the search string), and where to find them (the database used). Based on the overarching objective of the SDR, the literature areas of interest are climate change, biodiversity, and food security.

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Therefore, a study is considered relevant when it focuses on these three topics of interest. As visualized in Figure 3, potential studies are at the intersection between the three literature areas of interest – in red colour. This is to ensure that the search will locate studies that specifically address the topics of climate change, biodiversity, and food security, hence providing sufficient insights about climate change and biodiversity drivers of food security.

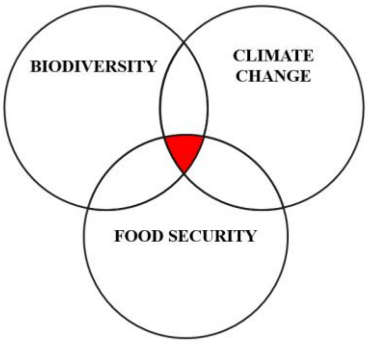

Figure 3. The areas of interest for the SLR.

Subsequently, a search string is developed to locate studies. A search string is formed by connecting keywords using Booleans operators (AND, OR, and NOT). The search string instructs the search engine of the database to narrow down only studies that include the predetermined keywords. In this case, only research that addresses the three topics of interest will be found. The keywords used in this work were recommended by experts in the fields of climate change, biodiversity, and food security. The final search string is:

(biodiversity OR "bio-diversity" OR "biological diversity" OR "ecosystem service" OR "nature-based solution" OR species) AND ("climate change" OR "global warming" OR abiotic) AND ("food security" OR agriculture OR fisheries OR "food resilience" OR "food sustainability")

Last but not the least, the Web of Science database was used to locate relevant studies to this review. This database was chosen because it is among the most reputable and commonly used sources for academic literature.

Step 2 of the literature review procedure is to screen and evaluate the search results, selecting only the most pertinent and appropriate studies for the synthesis. In the SLR approach, the initial search results do not warrant the relevance of the papers to the review objective. Therefore, researchers need to apply inclusion and exclusion criteria to filter the results, then assess the abstracts, and the full text of each paper to narrow down

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the most relevant studies to the topics of interest. Figure 4 depicts the entire process of step 2 of the literature review procedure.

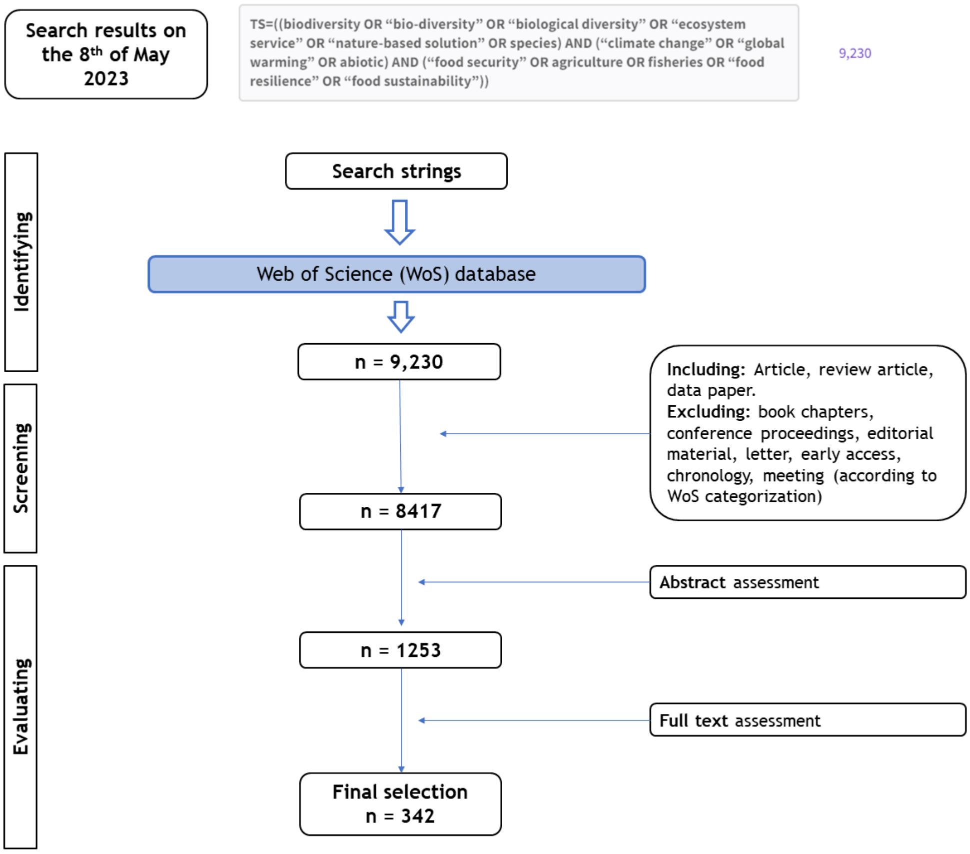

Figure 4. The final collection of papers after multiple rounds of screening and assessment.

The initial search returned 9230 studies that cover the nexus of climate change – biodiversity – food security. Exclusion and inclusion criteria were introduced in the screening round, retaining only peer-reviewed papers. The premise is that peer-reviewed papers, which went through a rigorous process of reviews before publication, will provide reliable insights and findings. 8417 papers remained after this round. Next, the first evaluating round starts with the assessment of the abstracts. The research team read each abstract and scored them in terms of their scopes, relevance to the review objective, and their findings and contributions, on a scale of 0 to 3 (with 0 being absence and 3 being high). The abstract screening criteria are presented in Table 1, with a detailed explanation of what a score means for each element of evaluation. Only an abstract with a score of at least 2 in each element was selected for the next evaluating round. 1253 papers remained after this round. In the next, and final round, the research team read the full study to

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finalize whether it is included in the final collection of papers. The full-text screening criteria are presented in Table 2. Each study was carefully evaluated on its scope, methodology, and findings & analysis, on a scale of 1 to 3. The selected study must address how climate change/ biodiversity impacts food security, with clear implications for the food security pillars. Thus, it must have a high score (at least 2) for scope, methodology, and findings & analysis criteria. Furthermore, our review aims to synthesize findings/ perspectives/ claims that are strongly grounded in empirical data analysis. Hence, selection priority is given to empirical research. During the full-text evaluation round, the research team noted the topic and method of each study. In the end, literature review papers were added for topics that were not covered by empirical research. Finally, 342 studies were selected for the literature review (Details are provided in Appendix A)

Step 3 of the literature review procedure synthesized the key insights from the literature regarding how climate change and biodiversity impact food security. Driven by these findings, the climate change and biodiversity-induced drivers of food security are identified. The results of this step are discussed further in Section 5 of this report.

Element	**0 - Absence**	**1 - Low**	**2 - Medium**	**3 - High**
Scope	The abstract does not provide enough information to assess this criterion. *OR* The scope of the paper does not address any issue related to biodiversity, climate change, and food security.	The abstract mentions biodiversity, climate change, and/or food security once or twice, HOWEVER, the scope of the research does not explicitly address any of those three topics	Biodiversity, climate change, and/or food security are mentioned throughout the abstract AND The abstract clearly addresses an issue in either biodiversity, climate change, and food security.	NOT ONLY the paper strongly illustrate the topic of biodiversity, climate change, and/ or food security in the abstract BUT ALSO the paper addresses the inter-relationship between at least two of the topics in the scope.
Relevance	The abstract does not provide enough information to assess this criterion. *OR*	Some keywords such as “food security”, “food insecurity”, “food sustainability”, and “food resilience” are	The abstract mentions frequently keywords related to food security, and food security and related topics	The abstract clearly indicates that this report is directly addressing a food security-related topic.

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	No mention of food security sustainability, and/or resilience.	mentioned once or twice in the abstract, but they are not the main focus of the study.	are PART of the study's aim.	
Findings/ Contribution	The abstract does not provide enough information to assess this criterion. *OR* Findings do not link to food security, sustainability, and/or resilience	A few implications to food security, sustainability, and/or resilience can be deduced, but not clearly.	The findings link to a good extent to food security, sustainability, and/or resilience. The abstract must explicitly state this.	The findings are exclusively linked to food security, sustainability, and or/ resilience.

Table 1. Abstract screening criteria.

Scope		
Strong relevance **3**	**Moderate relevance** **2**	**Low relevance** **1**
The research questions clearly direct at exploring: - Climate change impacts on food security - Biodiversity impacts on food security Indicated by the research questions and the formulation of the research goal (commonly presented in the Introduction and Background sections)	The research explores the topic of climate change AND/OR biodiversity, and food security is part of the research aim (indicated by statements in the Introduction and Background sections).	Food security, and aspects of food security, are not mentioned as (one of) the reason(s) for conducting the study. OR The study aims to explore different angles of climate change/ biodiversity - food security nexus: -how agriculture impacts climate change/ biodiversity -how to mitigate climate change and biodiversity loss impacts.
Methodology		
High priority **3**	**Acceptable** **2**	**Low Priority** **1**
Empirical studies such as qualitative studies, case studies, quantitative analysis, modelling, simulations, and so on.	Literature review	Not clear or low generalizability.
Findings & Analysis		
Strong relevance	**Moderate relevance**	**Low relevance**

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3	2	1
Findings directly address at least one of the aspects of food security under the influence of climate change AND/OR biodiversity	Findings imply clear impacts of climate change AND/OR biodiversity on at least one of the aspects of food security. The study must contain clear statements/ writings about the implication.	There is no/ weak implication of the results to food security. OR The results found no relationships between a climate change OR biodiversity factors and food security. OR The findings are not about climate change/ biodiversity included impacts on food security

Table 2. Full text screening criteria.

3.2.2 Main task number 2 - Data assessment

The data assessment task follows the literature review. This task aims to determine available data for reporting/monitoring the drivers that underpin the relationships between climate change and food security, and biodiversity and food security. Thus, this task is highly dependent on the result of the literature review findings. According to the ECO-READY project proposal, "data will be searched in the scientific literature, in the EU project reports, but also in the National projects, in EUROSTAT database, and in other sources" (Project proposal, p.9). Based on this guidance, 5 sources are used to locate data in relation to the drivers identified from the previous literature review task: academic papers, EU-level projects, National level projects, EUROSTAT, and internet search. While the ECO-READY WP1 Task 1.1 team is responsible for the majority of the search for data, there are instances where collaboration between partners in the WP1 was necessary. Especially for the case of listing/obtaining data from national projects, input from WP1 partners from different locations in Europe has been extremely valuable. The main task number 2 of the SDR Stage 2 is summarized in Figure 5.

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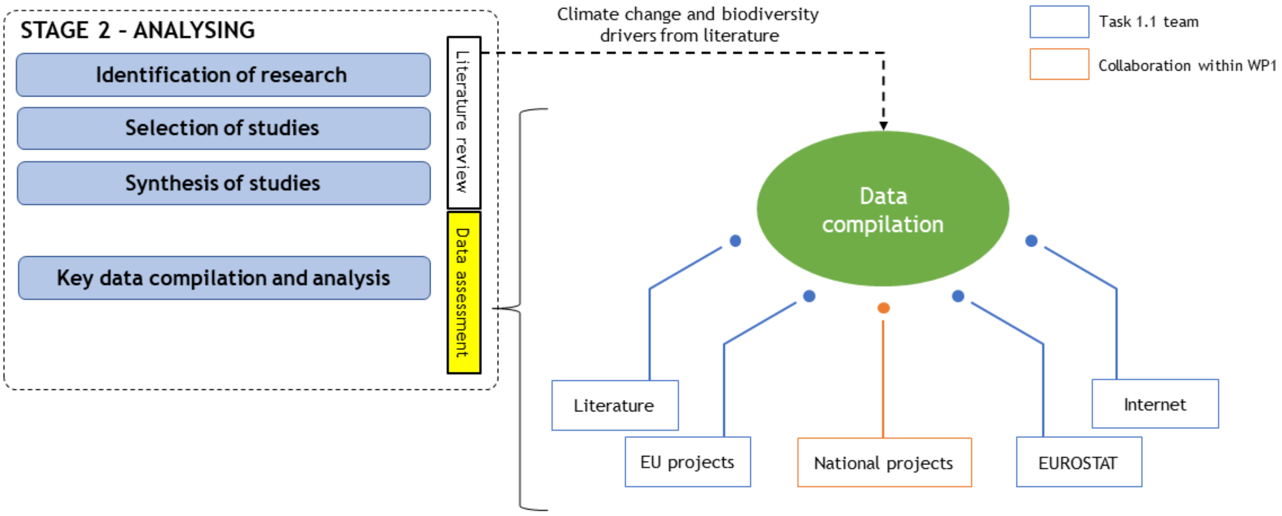

Figure 5. An overview of Task 2 in Stage 2 of the SDR.

3.3 Stage 3

The final stage of the SDR process is reporting the findings of stage 2. Overall, the findings will be presented in three parts, corresponding to the next three main sections of this report. Section 4 presents some overall statistics of the selected papers for the SLR task. Section 5 discusses the thematic analysis and results from the selected papers, specifying the climate change and biodiversity drivers of food security and highlighting their impacts. Section 6 provides a compilation of data sources for monitoring and reporting those drivers.

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4 Descriptive analysis

This section provides an overview of the selected papers for the literature review task. Hence, some statistics are presented and discussed.

Figure 6 summarizes the distribution of the selected papers by year. As showcased in this figure, the topic of climate change – biodiversity – food security is continuing to draw interest from the scientific community, with the number of papers steadily rising throughout the years. There are two notable points in this result. First, the initial search only covers the first 4 months of 2023, therefore the number of selected studies published in 2023 appears to be significantly lower than the previous trend. We fully anticipate that, with the relevance of this topic, the number of pertinent papers in 2023 will rise at the end of the year. Second, this selection of papers does not indicate that there were not any studies covering climate change or biodiversity before the 1992 mark. Rather, there were studies found by the initial search that dated before 1992, however according to the selection criteria in the evaluation rounds, they were not selected. Moreover, the years with no selected papers are not included in the figure.

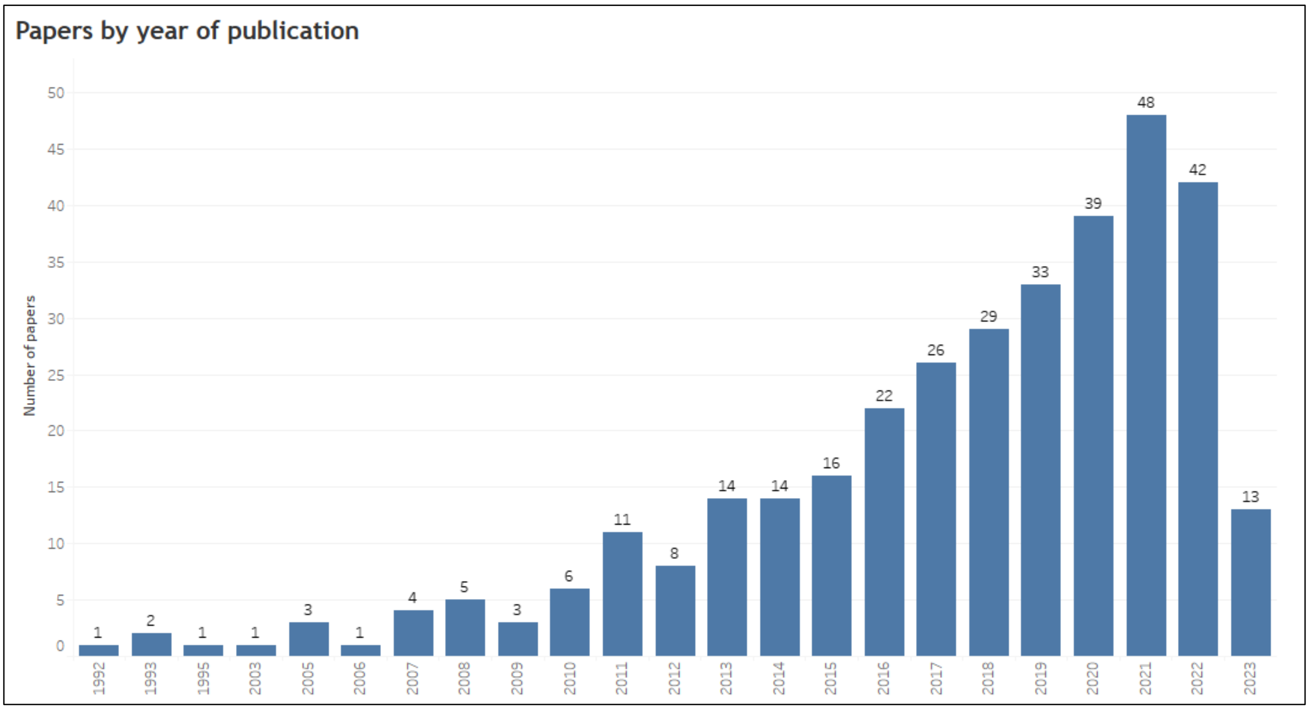

Figure 6. Distribution of selected papers by years.

Figure 7 lists the top 20 journals where the selected papers are published. This statistic helps to ensure that the final selection of papers is from relevant domains of research. As

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depicted in the Figure, reputable journals in the areas of environment, biology, and ecology are presented. This supports the validity of our selection.

Figure 7. Top 20 journals where the selected papers are published.

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5 Climate change and biodiversity-induced drivers of food security

Following the selection of relevant literature, a thematic analysis of 342 papers was carried out to identify climate change and biodiversity-induced drivers of food security. An abductive approach was adopted to synthesize the literature. In essence, an abductive thematic analysis combines both deductive and inductive elements in synthesizing the key insights from the literature (Thompson, 2022). First, based on the research questions, two main dimensions of interest are climate change and biodiversity, shaping the main themes of the findings. This is the deductive element. Second, for each theme (climate change or biodiversity), the research team carefully examined each selected paper and documented any relevant insight about climate change and/or biodiversity's impact on food security, categorizing and forming drivers in each theme. This is the inductive element, as a theme is pre-determined but the content in each theme is driven by findings from the literature.

Sections 5.1 and 5.2 discuss the main findings of the thematic analysis.

5.1 Climate change drivers of food security

Table 3 summarizes the key climate change-induced drivers of food security, as identified in the literature. Key information includes the name of the driver and how it can be measured. Next, each driver is discussed in more depth, highlighting the mechanism by which a driver can impact food security.

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Dimension	Category	Driver	Indicator/ Evaluation approach	Example of data source
Climate change	Surface warming/ increased temperature	Increased air temperature	Mean annual temperature (ºC)	World Clim
			Max/min annual temperature (ºC)	GHCN
			Max temperature of the warmest/coldest month/quarter (ºC)	World Clim
			Mean temperature of the wettest/driest month/quarter (ºC)	World Clim
			Mean temperature of the wettest quarter (ºC)	World Clim
			Mean diurnal range (ºC)	World Clim
			Temperature seasonality (σ × 100) (%)	World Clim
	Increased seawater temperature	Sea surface temperature	Max/min surface temperature (ºC)	Bio Oracle
			Mean annual surface temperature (ºC)	Bio Oracle
		Sea bottom temperature	Max/min bottom temperature (ºC)	Bio Oracle
			Mean annual bottom temperature (ºC)	Bio Oracle
	Increased freshwater and estuary temperature	Increased freshwater and estuary temperature	Daily lake temperature	General lake modelling R package [Hipsey et al (2019)]
			Daily estuary temperature	Region-specific (see Nack et al., 2019)
	Precipitation change	Precipitation change	Mean annual precipitation (mm)	World Clim
			Total annual precipitation (mm)	World Clim
			Seasonality of precipitation (σ × 100) (%)	World Clim

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			Precipitation of the wettest/driest month/ quarter (mm)	World Clim
			Precipitation of the warmest/coldest month/quarter (mm)	World Clim
	Elevated CO_2	CO_2 concentration	CO_2 concentration in the atmosphere (ppm)	Global Monitoring Lab
	Ocean acidification	Ocean acidification	pH	NOAA
	Ocean deoxygenation	Dissolved oxygen	Bottom water dissolved oxygen concentration (μmol/kg)	Earth System Grid Federation (ESGF)
	Salinity	Ocean salinity	Max/min surface salinity (PSU)	Bio Oracle
			Max/min bottom salinity (PSU)	Bio Oracle
		River salinity	PSU	Dasgupta et al 2017
		Soil salinity	Electrical conductivity of saturated soil paste extract (EC_e) measured in dS m^{-1}	World Soil information service (WoSIS)
	Climatic variability	Seasonal variation	Winter severity is calculated from the daily air temperature of the winter month	Dippold et al. (2020)
			Winter chill calculated from min and max daily temperature and ChillR package	Luedeling (2018)
			Number of frost days (daily min temp below 0)	Dippold et al., (2020)
			Number of days with a snow cover	
	Extreme weather events	Drought	Standardized Precipitation Index	Mhenni et al., (2020) measured drought by its intensity,
			Standardized Precipitation Evapotranspiration Index	
			Palmer Drought Severity Index	

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			Soil moisture percentiles	frequency, and duration
		Hurricane, storm	Region-specific monitoring program	
		Marine heatwaves	Annual sea surface temperature anomalies exceeding the 95 percentile of a shifting baseline/fix-based line. - Intensity - Year of occurrence	Cheung et al., (2021)
		Marine cold spells	SST during winter	Leriorato and Nakamura (2019)
		Flood	Precipitation anomalies	Crudata.uae.ac.uk
		Summer heatwave	Number of tropical days (temperature with daily maximum above 30ºC	Trnka et al. (2020)
	Glacier retreat and reduced sea ice cover	Glacier retreat	Modelling glacier retreat, region-specific	Global Glacier Evolution Model
		Reduced ice cover at sea	Annual ice cover index	NOAA

Table 3. Summary of Climate change drivers.

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5.1.1 Defining climate change drivers of food security

In this section, ten major climate change-induced drivers of food security are described in more detail.

Surface warming/ increased temperature is a pronounced feature of climate change. *Increased air temperature* is the driver of this category, as this is the primary variable being studied in this research. While the warming of the earth's surface is the result of both natural and human forcing (Kariyawasam et al., 2021), there is insurmountable evidence of anthropogenic activities speeding up the warming rate (notably via releasing greenhouse gas emissions) far more than natural causes (Rettie et al., 2022). A recent report from the Intergovernmental Panel on Climate Change estimated a rise of 1.5 degrees Celsius in global temperature by 2050 given the current rate of warming (IPCC, 2018). Significant increases in the atmosphere temperature are anticipated to bring serious consequences to the food system, especially in agriculture (Castro-Llanos et al., 2019; Rettie et al., 2022).

Closely related to global warming, increased water temperature is another important climate change-induced driver category. Two categories of drivers are identified from the literature: *increased seawater temperature* and *increased freshwater and estuarine temperatures*. The drivers in these categories, respectively, are *sea surface temperature* and *sea bottom* temperature, and *increased freshwater and estuary temperature*. The ocean is warming at an alarming rate (Free et al., 2019) at both the surface and bottom levels of the sea, leading to changes in marine fisheries productivity (Litzow et al.,2021; Liu et al., 2022). Marine culture is also affected, often negatively, by warmer saltwater conditions (Cubillo et al., 2021). The trend of water temperature increasing is also experienced in freshwater bodies, such as lakes and rivers (Cline et al., 2019), and in estuaries across the world (Nack et al., 2019). This can impact fisheries and aquaculture in those bodies of water.

Precipitation change is the name of the next category, and the driver in this category. Variability in precipitation is often mentioned in the extant literature as a critical driver of change for food systems. As a result of climate change, rainfall occurrence, duration, and amount become difficult to predict (Gebresamuel et al., 2021). Across different regions and regimes, precipitation levels can vary, with some areas experiencing more while others receive less, particularly under future projections of climate change (Rettie et al., 2022). This can cause detrimental stress to farming, as numerous farmers, especially small-holder

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ones in developing countries, have poor irrigation infrastructure and depend greatly on rain for crop production (Wessels et al., 2021). Furthermore, annual precipitation in many areas of the world is predicted to drastically reduce, and when coupled with the warming trend of the earth, it can negatively impact crops and commercial plants (Chemura et al., 2016; Heming et al., 2022).

Elevated CO_2 refers to the rise of carbon dioxide concentration in the atmosphere. To represent this phenomenon, studies use and measure *CO_2 concentration*. Increasing CO_2 levels are considered a catalyst of global warming and other climate change effects. IPCC reported that atmospheric CO_2 has surged approximately 40% since pre-industrial time, and by 2100s a similar magnitude of increase will occur if no interventions are made (Gray et al., 2020). Many studies argue that increased CO_2 is one facet of climate change, and a direct result of anthropogenic activities (mainly the consumption of fossil fuel) (e.g., Toreti et al 2020; Gonzalez et al., 2021). Nevertheless, it is unequivocally found in the literature that elevated CO2 in the atmosphere can affect various areas of food production, particularly plants (Cowie et al., 2020; Toreti et al., 2020). Thus, elevated CO_2 is included here as a climate change-induced driver of food security.

The next two categories of drivers from the climate change dimension are related to the status of global oceans. They are *ocean acidification,* and *ocean deoxygenation,* with ocean acidification and dissolved oxygen, respectively, as their specific drivers. Since they describe the shifts in ocean conditions and habitats caused by climate change, these drivers directly affect important commercial species in the saltwater environment (Wilson et al., 2020; Cheung et al., 2022). Ocean acidification is a direct result of climate change, through increasing CO_2 concentrations in the atmosphere and ocean. Particularly, much of the atmospheric CO_2 is absorbed in the global oceans, increase hydrogen ion when dissolving into seawater, and raise ocean acidity as a result (Townhill et al., 2022). On the other hand, increased atmosphere temperature leads to a global decline of oxygen level in the sea – ocean deoxygenation – due to “warming-induced reduction in O_2 solubility and increased stratification and reduced ventilation” (Kwiatkowski et al., 2020, p.3440). Hypoxia negatively affects marine animals’ physiology, possibly leading to rising mortality in commercially important species (Cheung et al., 2022).

Salinity refers to the amount of soluble salt in terrestrial or marine environments. There are three main groups of drivers related to salinity, which were detected from the selected

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literature, namely *soil salinity, river salinity,* and *ocean salinity*. Large-scale warming and climate change-induced fluctuations in evaporation and precipitation can generate extremes in soluble salt in global seas, with low-salinity regions getting fresher whereas high-salinity regions becoming saltier (Doney et al., 2012). Meanwhile, rising sea levels and climate-induced changes are causing increased aquatic salinity in rivers (Dasgupta et al., 2017). Variability of ocean and river salinity impacts aquatic life and subsequently food supplied from fisheries and aquaculture (Castro-Olivares et al., 2022; Chen et al., 2023). On the other hand, the link between soil salinity and climate change is more nuanced. Hassani et al. (2021) classified soil salinization into two main categories; one is primary salinization due to natural causes (e.g., rainfall or wind dispersing oceanic salts), and the other is secondary soil salinization due to human interventions (e.g., irrigation, use of fertilization). The issue of soil saline stemming from land use activities is well known, and extensively studied in the literature for a considerable amount of time (Zhu, 2001). In this specific research, the interest is on aggravated soil salinity as a direct result of climate change, which is considered a severe global issue for agriculture (Hassani et al., 2021; Haj-Amor et al., 2022).

Compared to the previously discussed climate change drivers, the following are less frequently explored in the selected literature. However, their importance to food systems cannot be overlooked.

Climatic variability refers to the irregular patterns of the weather caused by climate change. Seasonal variation is a driver in this category. Under the impacts of climate change, seasons and other climate events express fluctuations in their frequency, intensity, spatial extent, duration, and timing (Thornton et al., 2014). Subsequently, they can affect the productivity of various important food systems. For example, Trnka et al. (2020) discovered that late frosts and frost without snow cover negatively impact grasslands in central and eastern Europe. Fernandez et al. (2020) linked the reduction of winter severity to a decline in deciduous fruit yields.

The extreme weather events driver also describes a phenomenon that can be considered as the variability of climate, however, these events are more stochastic and intense. The drivers included in this category are *drought, hurricane/storm, marine heatwaves, marine cold spells, floods, and summer heatwaves*. Drought is a prolonged period of dry conditions and is a natural hazard. However, climate change has accelerated the severity and

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frequency of drought, bringing tremendous stress on crops and farmlands (Mhenni et al., 2020). Summer heatwaves on land cause sudden rises in temperature and drops in humidity, negatively affecting plant species (Trnka et al., 2020). A counterpart of the summer heatwave, in the marine environment, is a marine heatwave. Marine heatwaves are prolonged periods of anomalously high sea surface temperatures, driven by a conjunction of oceanographic and atmospheric processes, and predicted to accelerate in frequency, duration, and intensity under global warming (Frolicher et al., 2018). Marine heatwaves carry destructive consequences to fishes, invertebrates, coral, and kelp forests, just to name a few (Cheung and Frolicher, 2020). On the other end of the spectrum, prolonged and intense rainfall often results in the extreme event of flood. Just as negative large precipitation anomalies – drought, large positive precipitation anomalies, and consequently flooding events, can produce adverse impacts on food production in terrestrial systems (Murray-Tortarolo and Jaramillo, 2020). At sea, climate change forced drastic shifts in both ends of the temperature spectrum, introducing marine cold spells alongside marine heatwave. Similar to marine heatwaves, marine cold spells can severely disrupt the structure of the ocean ecosystem (Leriorato and Nakamura, 2019). Sustained periods of extreme drop in seawater temperature can lead to increased mortality in tropical reef fishes and mass coral breaching, reducing the abundance of important species. Last but not least, under the impact of climate change, storms and hurricanes are anticipated to become more extreme with higher amounts of rain, disrupting the ecosystem (Huisman et al., 2018) and the livelihoods of coastal communities (Ramenzoni et al., 2020).

Glacier retreat and reduced sea ice cover is other important driver of food security, especially for poleward communities of the globe and food production activities in these areas. Two drivers in this category are *glacier retreat* and *reduced ice cover* at sea. Glaciers are rapidly contracted and reduced in volume under recent anthropogenic climate warming, as heavily-impacted regions such as western Canada can lose as much as 80% of ice mass by 2100 under future climate projections (Pitman et al., 2021). Satellite monitor data showed that a significant decline in sea ice cover has been recorded since 1979, accelerated by global warming effects (Tai et al., 2019). While these drastic shifts can cause major disturbances to the environment, notably rising sea levels, they can surprisingly open up access to fishing grounds, which were not available previously. The impact of ice loss on food security, therefore, is complex and warrants close examination.

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5.1.2 Linking climate change drivers to food security

In the last section, climate change drivers are described. This section will examine their links to food security. Particularly, the impacts of these drivers on species, that are important food sources for mankind (crops, plants, fish, marine animals, livestock, etc), are analyzed. Subsequently, how these impacts are related to the pillars of food security is discussed.

5.1.2.1 Climate change impacts on ecosystems and organisms

The impacts of climate change on different species are complex, diverse, and manifold. In general, climate change can directly impact the habitat (and subsequently distribution), phenology, physiology, and productivity of species, which are important for food production (Tanaka et al 2020). Further, the climate change impacts on those facets are often the result of multiple drivers combined, even though in some instances, one driver appears to be more dominant than the others. In the same vein, one species can be under stress from more than one driver at once.

Variations in climate can affect the suitable growing habitats of crops and plants. The impact of climate change on crops can be reflected by the concept of climate suitability, which refers to the degree of agreement between climate resources and the requirements of a specific crop to grow and develop (Wang et al., 2021). Plants and crops are dependent on weather and climatic conditions, thus a shift in climatic suitability for crops can lead to a tendency of crops to migrate into more favourable areas. In extreme scenarios, the climatically suitable growing areas might shrink all together, leading to devastating impacts on food production (Gao et al., 2021; Gebresamuel et al., 2021). Among climate change drivers, the spatiotemporal fluctuations in temperature and precipitation pose the most influence on agro-ecosystems (Wang et al., 2021). The projected future change of both temperature and precipitation, under the influence of climate change, was found to cause shifts in important stable crops such as potato (Wang et al., 2021), rice (Castro-Llanos et al., 2019), maize (Beltran-Tolosa et al., 2020; Gao et al., 2021), regionally important crops such as enset – a wild relative of banana (Koch et al., 2021), and commercially important crops such as cacao (Heming et al., 2022), cotton (Cunningham et al., 2021), grape vine (Roehrdanz and Hannah 2016), and sugarcane – for biofuel (Granco et al., 2019). Some cultivars are shown to be shifted due to the variation in either temperature or rainfall. For instance, the geographic distribution of apple orchards in China is predicted to move north

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and westward due to future warming (Xu et al., 2023). Appropriate temperature rise can promote the development of apples, however when exceeding a certain threshold the impact is reversed. Thus, newly suitable climatic regions might emerge with warmer weather, whereas currently, growing areas will encounter challenges in apple cultivation. The stable crop cassava was also found to be majorly dependent on temperature range shifts (Beltran-Tolosa et al., 2020). For precipitation as a sole determinant of climatic suitability shift, important crops such as barley and wheat are found to be susceptible to migration due to variations in future rainfall (Gebresamuel et al., 2021). The shifting of crops to suitable habitats can be disruptive for agriculture and food production. To maintain the current level of production, and possible expansion to cope with the growing population, there must be adequate land and water resources for farming, and various infrastructure (roads, facilities, irrigations, etc) which are not warranted in the new climatically suitable areas (Roehrdanz and Hannah 2016; Wang et al., 2021). Further, experienced and skilled farmers are easily relocated to accommodate the shifts in natural conditions, creating conflicting situations such as nontraditional agriculture areas (urban) becoming more suitable for crops than conventional regions (Kodis et al., 2018).

Similarly, changes in the oceans of the future will have implications for marine livestock and cause shifts in fisheries species. Specifically, increased ocean temperature, ocean acidification, salinity, and ocean deoxygenation are vital drivers for the change in the dispersal of aquatic animals. A common response of fishery species is to shift along the latitudes and/or longitudes to territory with preferable habitat (Schickele et al., 2021; Kim et al., 2022; Liu et al., 2023). Other species (for instance cod and walleye pollock) can migrate vertically – going to deeper water, to seek suitable water temperatures in the same location (Cheung and Oyinlola, 2018; Rooper et al., 2021). Moreover, even though species can move to water with more favourable temperatures and conditions, it does not guarantee that they can find a similar range of sufficient habitat to thrive. Under the projection of climate change worsening ocean habitats, species can experience both forced range shift and contraction of a climatically suitable envelope (Boavida-Portugal et al., 2018). Among the climate change drivers, increased sea temperatures were found to be the most impactful to the distribution of fishery species, especially wild fishes. Studies found that a warmer ocean put current habitat out of the thermal tolerance range for fishes, bring high-magnitude change to oceanographic features, and affects primary production at sea, forcing the shift in distribution for species such as commercial demersal

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fish in the Mediterranean (e.g., European hake, European seabass, common sole) (Ben Lamine et al., 2022), pacific cod, walleye pollock (Rooper et al., 2021), anchovy (Silva et al., 2019), chub mackerel (Torrejón-Magallanes et al., 2021), and yellow croaker (Zhang et al., 2022). Other important commercial species shifting are constituted by additional climate change drivers, aside from temperature. For instance, both ocean warming and ocean acidification contribute to the migrate of coastal lobsters worldwide (Boavida-Portugal et al., 2018). As low pH events in the ocean are exacerbated by ocean acidification, invertebrate species that are dependent on calcium shells (such as crabs, claim, oysters, etc) will negatively respond to climate change (Wilson et al., 2020). Variations of ocean salinity, coupled with changes in surface water temperature, explain the loss of suitable habitat, and the migration of species such as Spanish mackerel (Liu et al., 2023), cuttlefish, and squid (Schickele et al., 2021). Chang et al. (2021) found that ocean deoxygenation is mainly responsible for albacore shifting habitat. Furthermore, non-animal food from the sea can be affected by climate change as well. Khan et al. (2018) found that commercial seaweed will experience range contraction under different climate change scenarios. Biswas et al. (2017) found that increased lake water temperature will introduce shifts in species composition, predicting that catchable species will be much smaller in size due to a reduction in cold-water fish and a concomitant rise in warm-water fish.

Aside from reducing the suitability of habitat through fluctuations of key climatic factors, climate change can affect other facets of the current habitats for plants and animals, ultimately leading to adverse effects on yields and productivity. Changes in temperature and precipitation can lead to the expansion of pests and invasive plants (Qin et al., 2019; Li et al., 2022). This is a serious issue, as insect pests and harmful plants (parasitic plants or invasive alien plant species) are already major threats to agriculture and food security worldwide (Kariyawasam et al., 2021; Youngblood et al., 2022). Climate change exacerbates the situation by expanding suitable conditions (predominantly warmer temperatures and sufficient rainfall/moisture) for pests to spread wider. Some notorious harmful species such as locusts (Youngblood et al., 2022), aphids (Li et al., 2022), fruit fly (Qin et al. 2019), and European corn borer (Trnka et al., 2007) are predicted to expand under future climate. Warmer weather exposes livestock to heatstroke risks, affecting the quantity and quality of their produce (Theusme et al., 2021). Increased air temperature can also lead to a reduction in insects and bees, along with their vital ecosystem services

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such as pollination or biological control, and impeding the productivity of crops (Gonzalez et al., 2021; Outhwaite et al., 2022). Mueter and Litzow (2008) found that the northward ice retreat in the Bering Sea created an opportunity for subarctic taxa to expand further to the north, disturbing the current commercial species communities and distribution in the Artic.

The phenology of species is another aspect that will experience significant disturbances under climate change. Phenology describes the biological events and changes during the life cycle of plants and animals. The impacts of climate change on the timing and duration of vital life events in different species have been examined in the extant literature. These changes cannot be overlooked. Zhang et al. (2020) modelled the change of wheat phenology under different climate projections up to 2050 and found that the number of days from planting to maturity is shortened in general due to changes in temperature and precipitation. This change can potentially interrupt the production and planning of food crops. Further, the elevated temperature was found to speed up the flowering timing in plants (Kumar et al 2012), which subsequently reduces the duration of biomass accumulation before the seed can be set. For important food crops, such as wheat, maize, and groundnut, this interaction will lead to impeded crop yields (DaMatta et al., 2010). Trnk et al. (2020) found that warmer autumns and unstable temperatures in winter and early spring can negatively affect pasture and grazing plants' development timing, indirectly affecting livestock. Climatic variability can considerably affect fruit trees, as temperature fluctuations during winter were found to impact the dormancy period, leading to a reduction of yields for typical orchard trees and deciduous fruit tress (e.g., apple, pear, nuts, cherry, plums, etc.) (Polce et al., 2014; Fernandez et al., 2020). The effect of climate change on phenology is also experienced in aqua-animals. For instance, snappers are expected to spawn earlier under future warming of the Caribbean Sea, whilst food sources are not sufficient to support the population (Gokturk et al., 2022). Ocean temperature and increased acidification of seawater can affect the early life stages of stone crabs, increasing early mortality, reducing the duration of the larval stage, and contracting the dispersal range (Alaerts et al., 2022).

Last but not the least, climate change drivers can directly impact the growth and physiology of organisms. In general, climate change exacerbates the abiotic stress on organisms, directly affecting their development and altering physiological responses to cope with changing weather conditions. Variations in rainfall and, subsequently, moisture can favour

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the frequency and spread of ruminant diseases, affecting cattle wellbeing and productivity (Charlier et al., 2016). Floods and extreme rainfalls can inhibit the growth rate of cattle through the underlying process of reducing food sources and increasing the mortality rate due to increased disease and pathogens (Murray-Tortarolo and Jaramillo, 2020). For wild-caught and aquaculture species, environmental stress related to water temperature, pH imbalance, and salinity prompts changes in the larval survival, growth, and reproduction of the animal (Schickele et al., 2021). For instance, warming estuarine water was found to hinder early-stage survival of seabream (Madeira et al., 2017) and ocean acidification is mainly responsible for an increased mortality rate of cod larvae (Stiasny et al., 2016), because these species' physiology cannot acclimate to a drastic change in their habitat condition. Regarding livestock, heat stress can cause the animals to alter their respiratory rate and energy metabolism to maintain the body's thermal comfort range (Alves et al., 2017). Drought stress, considered among the most severe manifestations of global climate change, inhibits crop growth, reduces normal crop physiological processes and metabolism, and eventually causes the loss of crops (Khan et al., 2019). The extant literature highlights a wide range of species in both terrestrial and marine ecosystems, which experience changes in growth and physiology under climate change. Increased atmosphere temperature reduces the yield of wheat, maize (Rettie et al., 2022), Robusta coffee (Kath et al., 2020), and aquaculture clam produce (Paul et al., 2021). Rising sea temperatures, both at the surface and bottom, negatively affect the development and reproductive rate of species such as brown shrimp (Saborowski and Hunerlage, 2022) and cod (Litzow et al., 2021). Warmer lakes can speed up the growth rate of Artic charr, brining younger populations into the harvestable range (Smalas et al., 2020). Ocean acidification was found to significantly impede the growth and body size of many invertebrate species of mollusks and crustaceans (Tai et al., 2021), and lobster (ibid.). Further, ocean acidification can inhibit tissue development, hence nutrition value deduction, in aqua-cultured shellfish such as oysters (Lemasson et al., 2019). It was theorized that rising carbonate solubility (as the result of ocean acidification) forces invertebrates species with calcium shells to spend more energy to form their exoskeletons, reducing the energy budget towards growth (Cooley et al., 2015). Donelan et al. (2021) also found that oyster growth is strongly affected by ocean deoxygenation. Further, marine species development can be susceptible to many stressors at once, such as stone crabs being affected by both rising temperatures and lowering pH in saltwater (Alaerts et al., 2022). Extreme climatic events are another group of climate

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change drivers that show significant effects on organisms' fitness and development. Drought is well-recognized for its adverse impacts on crops and animals (Khan et al., 2019). Flood causes water logging in the field, limiting crop root growth, exposing plants to hypoxia, and reducing yields (Liu et al., 2017). Marine heatwaves and cold spells can affect the development of a wide range of marine life forms when they are suddenly pushed outside of their thermal comfort range (Leriorato and Nakamura, 2019; Moyano et al., 2020). Winter severity can affect the recruitment rate and process of lake fishery species such as walleye and yellow perch (Dippold et al., 2020).

5.1.2.2 Linking climate change impacts to food security pillars

The last section explains how different climate change drivers can affect ecosystems and organisms. In this section, the implications of those changes to food security are discussed. Overall, four pillars of food security, namely availability, accessibility, utilization, and stability, are impacted.

First, a large amount of climate change impacts found in the literature are closely linked to the availability pillar. Specifically, the food production aspect of this pillar is significantly influenced. As the world population is growing, food systems across the world are constantly under the pressure of supplying an adequate quantity of food without compromising nature. Findings from the literature showed that climate change already influenced food production, and will continue doing so in the foreseeable future. If the negative consequences of climate change on food production are not addressed and mitigated, it will be tremendously difficult to sustain and support human lives, pushing people into food insecurity situations. As noted in section 5.1.2.1, if the rate of climate change remains or is intensified in the future, we will find that it is difficult to acquire food when fishery species are forced to migrate further away and climatically suitable habitats for crops are degraded and/or contracted; in those scenarios that agriculture and fisheries are still viable, the yields of crops, wild-caught species, aquaculture species, and livestock products are projected to be less due to adverse impacts of climate change; and the productivity of such activities will gradually decrease as fitness and growth of crops and animals deteriorate. The decline in food availability and food productivity will first and foremost affect the close community which consumes part of their own produce and can escalate into a national and even global issue (Gao et al., 2021).

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In terms of food accessibility, climate change poses significant economic implications. Agricultural and fishery activities are vital to sustain farmers, fishing communities, and in some cases nations through revenue and employment (Chemura et al., 2016; Rogers et al., 2019; Kim et al., 2022). Therefore, a reduction in the productivity of these activities will indirectly impede the ability of people to procure food for their own consumption. Lower yield and harvest are not the only impacts of accessibility from climate change, as other underlying implications of climate change ultimately hamper household economic stability. For instance, it will be harder for fishermen to catch commercially important species when they migrate deeper or further from shore (Gianelli et al., 2019; Ben Lamine et al., 2022), so investment in gears and vessels must be made to retain the current level of catches without assurance on a return (Rogers et al., 2019); competition between nations might arise due to fish crossing different jurisdictions (Tanaka et al., 2020); and aquaculture may find it economically infeasible to continue the current operation, forcing a change of production site, unemployment, and investment risks (Cubillo et al., 2021; Castro-Olivares et al., 2022). Similarly, farmers might have to switch to different and more suitable crops under climate change, which can be costly and less profitable at the same time (Chemura et al., 2016). Further, extreme events such as storms can physically inhibit fishermen from catching fish, impeding productivity and income (Ramenzoni et al., 2020). A steadily growing population, coupled with reduced catchability of the fishery due to climate change, will very likely result in higher prices for sea food (Lam et al., 2016), affecting food accessibility across the globe. On a brighter note, while glacier retreat and reduced ice cover can have negative consequences in the long run (e.g., rising sea level), in the short term, it presents an opportunity for different species, notably salmon, to occupy new territories. Subsequently, this leads to new fishing grounds, bringing more food supply and income (Tai et al., 2019).

While the majority of the implications of climate change are related to food availability and accessibility, the food security utilization pillar is also affected by foreseeable meteorological variabilities. Elevated CO_2 can enhance crop yields and resilience to adverse weather conditions (such as drought), however, research also showed that high CO_2 concentration leads to reductions in protein, mineral, and vitamin concentrations in a wide range of crops such as barley, wheat, rice, potato, leafy vegetables, and so on (Toreti et al., 2020). The rising temperature during the period of flowering to grain maturity in crops causes a considerable reduction in crop quality, represented by starch accumulation and

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carbohydrate composition (DaMatta et al., 2010). As crops provide important daily nutrients for people, nutrition security is heavily impeded when crop quality declines due to drastic changes in climatic factors (Bahadur et al., 2023). Further, degrading marine environments can directly affect the nutritional values of sea food (Dhurmeea et al., 2020). Shellfish provides a prime example of this, as water temperature and pH level contribute vitally to exploited bivalve species tissue development. Thus, lipid content, protein, and mineral concentrations are reduced/ distorted under warmer and more acidic water (Lemasson et al 2019). This valuable source of vitamins and nutrients is not easily replaced by a substitute, especially for the population with habits of consuming seafood regularly (Marushka et al., 2019).

The negative impacts on the availability and accessibility of food are also closely linked to the stability aspect of food security. The majority of the literature addressing the link between climate change and food systems not only analyzed the current situation but also predicted future trajectories (e.g., 2050, 2100) using different climate change scenarios (most notably Representative Concentration Pathway – RCP – a greenhouse gas concentration trajectory) (e.g., Castro-Llanos et al., 2019; Schickele et al., 2021; Cheung et al., 2022; Rettie et al., 2022; Chen et al., 2023). Therefore, under such predictions, the stability aspect of food security will be challenging to achieve due to the forecasted decline in food sources and productivity across different sectors and regions.

5.1.3 Positive effects of climate change and caveats in projecting the future

Thus far, the majority of the findings from the selected literature has painted a pessimistic picture of climate change driver and the future of food security. That is not always the case, as a number of studies indeed found positive effects of climate change on food production. For instance, elevated CO_2 can strongly stimulate the growth of C3 plants (which include important crops such as rice, wheat, barley, and soybean) (McGranahan and Yurkonis, 2018; Toreti et al., 2020). Nevertheless, it should be noted that when other adverse aspects of climate change are taken into account (drier and hotter habitats), the benefits of elevated CO_2 on crops can be easily offset (DaMatta et al., 2010). The warming of the Earth's surface might put crops out of the thermal tolerance range in regions with currently hot climates. On the contrary, for regions with traditionally colder climates, a warmer atmosphere will make the growth of certain crops possible (Grunig et al., 2020). In the same vein, while some harmful insects and pathogen might expand their range due

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to climate change, others might find their suitable habitat contracting (Guan et al., 2021). Macedo et al. (2017) cite the root rot pathogen in common beans indicating that a warmer temperature will actually limit their spread in Brazil. For fisheries, in special cases such as albacore, it was noted that these species can shift closer to shore in some regions (such as the USA's westside coasts), making it easier to harvest (Smith et al., 2023). Glacial retreats due to global warming can create new fishing grounds and habitats for commercial species such as salmon (Pitman et al., 2021). Despite that climate change can positively reinforce the yields from crops and animals, more often than not it is a trade-off effect. For gains in certain regions, there are often considerable losses in other regions (in terms of cropping, fisheries, and animal husbandry suitability), and the magnitude of the loss can offset or exceed the gain (Schikele et al., 2021). Further, climatic suitability is just one piece of the picture. To realistically expand the agriculture of crops, other constraints such as soil condition, water supply, industrial structure, etc. need to be met. Similarly, for aquatic species, predation, competition, and food availability could dictate whether a population can occupy a newly suitable habitat (Le Corre et al 2020). Even when new fisheries species arrive and settle in new bodies of water, it is not warranted that fishers can harvest them immediately. Factors such as expertise, gears, information, distance to fishing grounds, and so on significantly affect the decision and the adaptation of fishers to switch targets; and in most cases, changes in the fish communities would lag behind the shifts of species (Gamito et al., 2015).

Last but not least, some caveats of literature findings are discussed. While many modelling and simulation studies can project the future under climate change, they typically do not assume the phenotypic plasticity and local adaptation of species. This means that species can evolve to cope with changes in the habitat over time, which is difficult to capture when models are based on the current species' tolerance (Voss et al., 2019). Thus, one could argue that the impacts of climate change might not be as severe as the extant literature has portrayed. While acknowledging this fair criticism, we cannot ignore that all the predictions and modelling results allude to a catastrophic future (especially under high emissions scenarios such as RCP 8.5). Furthermore, regional climatic conditions can significantly affect how species will respond to climate change, therefore the generalization of past findings should always be performed with great care. For example, in studying the future climatic suitability of taro, Mugigyo et al (2022) found that the

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suitable growing area of this crop in South Africa will be contracted while Kodis et al. (2018) found that taro farming areas can be expanded in Hawaii.

5.2 Biodiversity drivers of food security

Table 4 summarizes the key biodiversity-induced drivers of food security, as identified in the literature. Key information includes the name of the driver and how each can be determined. Next, each driver is further described, highlighting the mechanism by which a driver can impact food security.

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<table>
<tr><th>Dimension</th><th>Category</th><th>Drivers</th><th>Indicator/ Evaluation approach</th></tr>
<tr><td rowspan="7">Biodiversity</td><td rowspan="3">Diversity in plants and crops</td><td>Using a diverse crop portfolio</td><td>Types of crop use are regional/ national dependent. To understand the current status of crop biodiversity in a specific country, a nation household survey is commonly used (for instance see Bellon et al., 2020; Bozzola and Smale, 2020).

Participatory research can be used to trial the introduction of more crop types into farming (see Kerr et al., 2019).</td></tr>
<tr><td>Crop rotation</td><td>Mixed and duration of rotational crops can be confirmed by experiments and trials. Some successful examples include:

Winter cereals and spring cereals, multi-species (see Marini et al., 2020)

Wheat – Maize (Xiao, 2022)

Winter wheat – legume (Degani et al., 2019)</td></tr>
<tr><td>Intercropping

- Intra-species
- Inter-species</td><td>Mixed of crops can be confirmed by experiment and trials. A comprehensive list of 939 intercrop observations can be found at Martin-Guay et al. (2018)</td></tr>
<tr><td rowspan="2">Diversity in soil biota</td><td>Fauna (earthworm, ant, termite, etc)</td><td>Soil sampling</td></tr>
<tr><td>Microbial community (fungi, bacteria, etc)</td><td>Beneficial micro-organisms can be found in experiment studies. Some examples include:

Rhizophagus intraradices with tomato

Septoglomus viscosum with strawberry

Piriformosporra indica with wheat

Enterobacter HS9 and Bacillus G9 with bean</td></tr>
<tr><td>Agroforestry</td><td>Agroforestry</td><td>Depends on locations and types of crops</td></tr>
</table>

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	Animal and crop integration system	Animal and crop integration system	Depends on locations and types of crops and animals
	Ecosystem services	Forest provisioning	Depends on locations
		Pollination services	Pollination mapping technique as demonstrated by Picanco et al. (2017) Pollinator availability as a proxy for pollination service, as demonstrated by Polce et al. (2014) List of crops dependent on pollination, as an example of inventory built by Klein et al. (2007)
		Natural pest control	Depends on locations and crop type
	Underwater biodiversity	Primary production at sea	chlorophyll-a
		Macro-algae	Can be monitored in specific regions, for example, see Holland et al., (2021).
		Invasive species	An inventory of invasive/ harmful species and their threat level can be built.
		Bacteria bloom	Srivastava et al. (2013) reviewed numerous approaches to monitor cyanobacteria blooms: - Biological approaches – monitoring directly cyanobacteria strains via cell counting, pigment analysis, and molecular approaches. - Biochemical and physicochemical approaches – monitoring factors that promote or inhibit cyanobacteria bloom such as nutrients, water temperature, pH, and various assays and chromatographic methods.
		Coral, kelp, mangrove, seagrass	Monitoring platforms such as www.goosocean.org/ https://resourcewatch.org
	Pest invasion	Pest invasion	An inventory of invasive/ harmful species and their invasion threat level for specific regions can be built.

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	Underutilised crop species	Underutilised crop species	There is a need to develop an inventory of underutilised crops and wild relatives crops for specific regions. Examples of such inventory from the literature include Rubio Tesso et al. (2018) and Khoury et al. (2019)
	Wild crop relatives	Wild crop relatives	

Table 4. Summary of Biodiversity drivers.

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5.2.1 Defining biodiversity drivers of food security

In essence, biodiversity refers to the variety and variability of organisms. Therefore, it can be noted that the biodiversity driver of food security can be understood as factors and conditions related to the diversity of life forms, that can influence or be taken advantage of by food systems. The following drivers were synthesized from the selected literature for review.

Diversity in plants and crops refers to the utilization of different upper-ground biotic components in one ecosystem, the farm ecosystem. In essence, the selected literature considers this as an approach to boost agricultural productivity by introducing a variety of crops, plants, and vegetables into the farmland. There are different groups of drivers under this category, which can be defined by the biodiversity level and the use of land. *Using a diverse crop portfolio* is a practice where farmers utilize a plethora of food crops, plants, and vegetables in their farmable areas. This includes using various species of crops on different fields (Bellone et al., 2020), or planting crops in fields and fruit trees and vegetables in gardens (Kerr et al., 2019). In the same vein, farmers can explore the use of multiple crops but in the same plotting area, known as *crop rotation* and *intra-species intercropping*. The difference is in the timing. For crop rotation, different species of plants are sowed in cropping sequences, in which one crop is sowed and harvested for a period of time and another crop is planted after (Degani et al., 2019; Xiao et al., 2022). Intra-species intercropping refers to the practice of planting different species in the same plot at the same time (Martin-Guay et al., 2018). The last driver is *inter-species intercropping*, where different types/ cultivars of crops are sowed at the same place and same time (Monaco et al., 2014). Finally, it should be noted that the same concept of crop rotation and intercropping can be applied to utilizing different plant species, such as in pasture (Krusinki et al., 2022), or mixing shrubs in cropping fields (Bright et al., 2017)

Soil biota refers to organisms living in or on the soil, including micro-organisms, soil animals, and plants. In the context of this report, *Diversity in soil biota* driver describes the utilization of different underground micro-organisms and fauna in the farm ecosystem, as the selected literature mainly focused on how microbial communities and soil animals can enhance crop physiology, crop productivity, and soil conditions. According to Barrios (2007, p.271), soil organisms can be broadly classified "on the basis of body width into microflora (1–100 μm, e.g. bacteria, fungi), microfauna (5– 120 μm, e.g. protozoa,

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nematodes), mesofauna (80 μm-2 mm, e.g. collembola, acari) and macrofauna (500 μm–50 mm, e.g. earthworms, termites)". The extant literature found that the presence of *earthworms* (Hu et al., 2018), *fungi* (Chitarra et al., 2016; Rabiey et al., 2017), *rhizobacteria* (Brunetti et al., 2021), *microbes* (Hone et al., 2021), and *soil microbial diversity* (Prudent et al., 2020) to be important to plants growth and resilience.

Agroforestry is inherently a man-made practice in which woody perennials are deliberately integrated into the farmland. While being an anthropogenic-driven decision, agroforestry utilizes the principle of biodiversity by capturing multiple benefits from tree inclusion within an agricultural production system, such as water and nutrient retention in soil, protection from harsh weather, and erosion prevention (Kay et al., 2018; Heming et al., 2022). Agroforestry practices are varied. According to Castle et al. (2021), there are four general categories of agroforestry systems: agrisivicultural (crops and trees), silvopastoral (pasture/animals and trees), agrosilvopastoral (crops, pasture/animals and trees), and agroforestry including insects/fish. Each of these categories encompasses a wide range of specific practices, centered around the mixing of trees in crop/pasture lands in spatial and temporal fashions.

Animal and crop integration system refers to a different type of species diversity in one ecosystem, in which organisms from different trophic levels – animal and crop plants in this case – are introduced in the same agroecosystem. When discussing the coexistence of animals and plants in a farm setting, the majority of the literature explores an integrated livestock-crops system. Other variants exist, such as the rice-fish co-culture (Xie et al 2011). However, such practices are niche. While the production of domestic animals and crops has been part of traditional agriculture in numerous regions, the intensification of farming in the last decades has led to a significant increase in specialized farming systems that focus solely on one of them (de Albuquerque Nunes et al., 2021). Livestock integration in crop systems is studied and promoted to potentially harness the complementarities and synergies between plants and animals, boosting yield, and household income, and reducing vulnerability to adverse weather (Kerr et al., 2019; de Albuquerque Nunes et al., 2021).

Ecosystem services is a broad concept, enveloping a wide range of nature's benefits to human lives. To a certain extent, some aspects of ecosystem services are represented in other drivers, for instance, the provisioning service of crops and ruminants. In this context, the ecosystem services driver refers to the services that are made available due to the

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biodiversity of ecosystems in the same geographic location and species within an ecosystem. Three notable drivers here are *forest provisioning, pollination services,* and *natural pest control*. Forest provisioning includes contributions of forest ecosystems to the livelihood of closeby communities, including extra food supply (Balasubramanian, 2021) and greater pollination services due to spillover effects (from natural and semi-natural habitats to nearby cropland) (Montoya et al., 2021). In general, pollination and pollinator insects play a vital role in agriculture (Picanco, et al., 2017). Finally, natural pest control (e.g., bats can significantly reduce harmful insects on the grapevine as found by Rodriguez-San Pedro et al. 2020) can help suppress harmful organisms in farmland, reducing the use of chemicals and associated environmental issues.

Underwater biodiversity drivers explain how the diversity of underwater plants and species can influence important commercial aquatic animals. From the discussion in section 5.1, many fishery species are influenced by abiotic factors, which are subsequently altered by climate change. The extant literature also found that biotic elements also play important roles in sustaining the growth, fitness, biomass, and distribution of harvested aquatic organisms. Examples include *primary production at sea* – notably phytoplankton as food sources for numerous fish (Silva et al., 2019), *coral reefs* (Lindfield et al., 2016), surge in aquatic *invasive species* such as jelly fish (Baez et al., 2022) or red king crab (Christiansen et al., 2015), *cyanobacteria* mass on freshwater (Huisman et al., 2018), and *macro algae* (Holland et al., 2021).

Pests are harmful organisms. In this context, agriculture pests, including insects, weeds, pathogens, rodents, and nematodes, are considered. *Pest invasion* has become a biodiversity concern because of its close link with climate change. Due to drastic changes in climatic conditions, opportunities for pests to expand and invade new habitats and geographic locations are open up (Santana et al., 2019; Grunig et al., 2020). The introduction and establishment of novel pests in agricultural and forest landscapes add to the diversity of such ecosystems, however, it also comes with a negative effect on crop productivity (Grunig et al., 2020).

Underutilised crop species, sometimes referred to as orphan crops, include fruits, vegetables, legumes, grains, and roots that are niche to a specific region/country and are not mass commercialized, e.g., enset, cocoyam, amaranth (Koch et al., 2021, Mugiyo et al., 2022). Underutilised crop species, while being valuable sources of food, are often

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under-researched and not prioritized in farming, especially in advanced countries. However, with the current effort to address food security issues under accelerating population growth, degraded environment due to algaculture intensification, and volatile climate change, underutilized crops are being recognized as a valid and pertinent mitigation strategy. Underutilized crops can provide an alternative source of food for local communities, potentially increase income, and bring additional nutritional value to the population (Chemura et al., 2022; Koch et al., 2022).

The importance of *wild crop relatives* is recognized, especially in a changing world driven by climate variability. It is well acknowledged that there is a limited number of crop species contributing to the world's food supply, as Harlan wrote in 1992 "Most of the food for mankind comes from a small number of crops and the total number is decreasing steadily… more and more people will be fed by fewer and fewer crops". For instance, wheat is the most widely cultivated crop in the world with more than 220 million ha, however, the modern cultivars are called into question as a global decrease in the yield of this cereal is happening due to harmful climate effects (Carranza-Gallego et al., 2019). To this end, wild relatives of crops are very important sources of useful genetic variations to stabilize and even improve yields under adverse conditions (Khoury et al., 2015), sometimes even replace crops that are no longer suitable for new climatic conditions (Pironon et al., 2019). Therefore, the genetic biodiversity provided by crop wild relatives is of importance for agriculture.

5.2.2 Linking biodiversity drivers to food security pillars

In this section, how biodiversity drivers can affect the food system, and ultimately food security is discussed. Much like climate change drivers, all four pillars of food security are affected by biodiversity. A difference is that the impacts of utilization and stability are more pronounced with biodiversity drivers.

First, biodiversity drivers can strengthen the availability pillar of food security in several ways. Many agricultural practices, which utilize the complementary and harmonizing effects between diverse species, can lead directly to increased outputs. Many experiment studies showed that crop rotation and intercropping can lead to a considerable increase in yields of important crops. Some examples of positive plant mix include shrubs and millet, shrub and groundnut (Bright et al., 2017), wheat and maize (Xiao et al., 2022), winter wheat and legume mixture rotating with brassica and spring bean (Degani et al., 2019),

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mixed maize cultivars (Monaco et al., 2014), and complex pasture (Thivierge et al., 2016). Midega et al. (2017) further found that the forage legume *Desmodium*, when intercropped with sorghum, effectively suppressed noxious striga weeds and led to increases in the yield of the main crop. Underground biodiversity can support the growth of crops, by increasing available nutrients in the soil for plants (especially Nitrogen and Phosphorus) (Barrios, 2007), and stimulating plant growth, photosynthesis, and shoot biomass (Todeschini et al., 2018). Some evidence from the literature includes endophytic fungi *Piriformosporra indica* increasing wheat root biomass (Rabiey et al., 2017), *Trichoderma* fungi boosting root and growth in rapeseed (Poveda, 2020), microbiome bacteria promoting growth and mitigating drought in wheat (Hone et al., 2021), and the diversity of rhizobacteria having positive impacts on velvet bean biomass during water deficit (Brunetti et al., 2021) and on soybean resistance to insects (Konmatsu et al., 2023). Ultimately, better growth and development of crops result in increased yields and food availability. The diversity in ecosystems can also lead to improved yields. Blaser-Hart et al. (2021) found that with an appropriate mix of shade trees among cacao plantations, cacao trees are not exposed to high light levels, pollination services are increased under shade, and cacao trees are maintained under a more favourable microclimate ultimately leading to better productivity and yield.

Furthermore, biodiversity drivers can play important roles in enhancing the environment, notably soil condition and nutrients, and provide important ecosystem services to ultimately boost agriculture yields. Soil biota (fauna and micro-organisms) plays a strong role in engineering the soil structure (e.g., building soil macroaggregates, decomposing and cycling matters, breaking down soil crust), leading to more fertile soil, and preventing degradation (Barrios, 2007). Among the macrofauna in the soil biota, earthworm is perhaps the most highlighted beneficial species. Aside from the recognized key role in mediating soil fertility, earthworms can raise the content of soluble Si, an important element conferring plants resistance to abiotic stress, in soil to maintain Si requirements in crop development (Hu et al., 2018). Similarly, agroforestry provides multiple benefits to soil and agriculture yields. Mixing grass in an orchard can lower the groundwater recharge rate and improve nutrient retention in soil (Kay et al., 2018). Planting trees in farmland can bring environmental benefits to windbreaks, prevent soil erosion, and attract rain and compost (Quandt et al., 2019). The use of shade trees can provide favourable microclimates for crops, fruits, or commercial plants underneath, shielding them from adverse weather conditions (Blaser-Hart et al., 2021). This can ultimately lead to healthier crops and better

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yields. Pollination services are vital to many agriculture systems across the world, and diverse habitats around farmland can increase pollination with a spill-over effect (Montoya et al., 2021). On terrestrial land, the natural means of controlling harmful species cannot be overlooked as it prevents the overuse of pesticides, which can degrade the environment and climate (Montoya et al., 2021). Further, cover grazing crops between intensive cropping seasons can help restore soil conditions and facilitate indirect ecosystem services (e.g., improve biodiversity, control weeds, etc), while providing for livestock at the same time (Lemaire et al 2014). In marine and freshwater environments, fisheries harvest can be supported by primary production at sea (Silva et al., 2019), coral (Pratchett et al., 2014), and macroalgae (Holland et al., 2021. Key species (e.g., coral, kelp, mangrove, undersea macro algae) play a vital role in provisioning fish, sheltering during bad weather, and providing nursery habitat for larvae to grow (Pratchett et al., 2014; Lindfield et al., 2016).

On the other hand, biodiversity drivers can negatively affect the habitats of crops and exploited animals, leading to a decrease in growth, abundance, and yield. This impact can occur in both terrestrial and aquatic environments. Invasive alien plants aggressively compete with crops for vital resources (e.g., nutrients, water), bring parasitism, and hamper the early development of young crops (Karywasam et al., 2021). Insects and harmful animals can directly feed on plants on the field and/or spread viruses and pathogens to crops (Qin et al., 2019; Li et al., 2022). In aquatic habitats, cyanobacteria bloom (Huisman et al., 2018) and harmful algae bloom (Rensel et al., 2010) can cause mass mortality in fish and aquaculture species by inducing hypoxia and releasing toxic chemicals in the water. Novel invasive species such as jellyfish (Baez et al., 2022) invade new territory to compete and/or prey on exploited fish species, reducing the abundance and possible yield.

Biodiversity drivers can offer additional and alternative food products, enhancing the food availability pillar. Kerr et al. (2019) surveyed smallholder farmers in Malawi and found that the diversity of crops grown has an inverse relationship with food security, as a diverse harvest offers them more options for consumption and a safety net in case one type of crop fails. A forest can supply small communities with fruits to their inventory (Balasubramanian et al., 2021), and additional products from agroforestry can enable households to feed for longer periods compared to the ones without (Quandt et al., 2019). Insects have emerged recently as a viable source of protein for human consumption, even though the practice

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has been documented for a long time (Tang et al., 2019). Orphan crops are traditionally grown in selective regions, and can add to the availability of food for local communities (Chemura et al., 2022; Koch et al., 2022). One caveat of the benefits of these biodiversity drivers is that the majority of the beneficiaries are local, or regional communities and households who consume their own farming produce. There are yet studies on the impact of alternative and regionally niche food crops on a global scale.

Second, multiple biodiversity drivers can help sustain agriculture productivity and maintain a steady level of food supply in the long term, strengthening stability and food security. This facet becomes increasingly important when the impacts of climate change are accelerating across the globe. Under long-term climate change and adverse extreme events, utilizing various types of crops and animals can help farmers mitigate the risk of food supply disruption (Kerr et al., 2019). Under a drought scenario, rotating crops can increase the resilience and strengthen ecosystem services of the field, maintaining steady yields (Degani et al., 2019). Forest harvest can also offer substitutes in times of need to local communities (Balasubramanian et al., 2021). Biodiversity drivers can enhance the resilience, and ultimately food stability, of the cropping field. Evidence from the literature highlighted that arbuscular fungi can help alleviate water stress on tomatoes (Chitara et al., 2016), plants inoculated with *P. indica* endophytic fungi are less affected by drought stress (Azizi et al., 2021), filamentous fungi can increase rapeseed tolerance to salinity and drought (Poveda et al., 2020), and beneficial microbes from wheat seed microbiomes can help mitigate drought impact (Hone et al., 2021). Egli et al. (2021) found a positive effect of crop diversity on agricultural production stability across European regions. Integrating livestock into farmland was found to be effective in improving the long-term stability of the whole system (regarding total outputs and soil condition) without affecting the yields of soybeans (de Albuquerque Nunes et al., 2021). Furthermore, wild relatives and landraces provide important genes for cultivars to adapt to the harsher growing environment of the future (Khoury et al., 2015; Fumia et al., 2022), leading to stability in yields. Philips et al. (2017) found that crop wild relatives in Norway can increase diversity and suitable growing areas in future warming scenarios, becoming viable additional options for farmers to extend their production of food and forage and improve food security.

Third, biodiversity drivers can aid the accessibility pillar of food security, by indirectly increasing household income from agricultural products. The literature has found that a more diverse crop portfolio is positively associated with household income (Belon et al.,

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2020), crop diversity stabilizes income streams for farmers when encountering drought (Kerr et al., 2019), and sometimes the species mixed into traditional farm can have better yields and fetch higher price for farmers (Kozicka et al., 2020). Agroforestry can also contribute to a more resilient social-ecological system, especially when facing shocks and disturbances. In many developing countries, fruit from large gardens contributes a sizable amount of income for farmers, especially when the leading crop (e.g., rice) underperforms (Nguyen et al., 2013). Crops residues after harvesting provide feed for livestock, not only maximizing resource efficiency but also providing extra income in dry seasons (Herrero et al., 2010).

Last but not the least, biodiversity drivers can strengthen the utilization aspect of food security. Particularly, the nutritional values of food products can be boosted with the help of biodiversity drivers. For instance, ruminants fed on complex pasture systems can provide meat with improved fatty acids (Krusinski et al., 2022). Dietary diversity is stronger among households that farm and consume a variety of crops (Kerr et al., 2019). Underutilised crops can provide an important source of micro-nutrient to local communities (Chemura et al., 2022). Plant-promoting bacteria can positively affect the concentration of sugar, resulting in better-quality strawberries (Todeschini et al., 2018).

Even though the focus of this report is on the direct impact of biodiversity on food security, it is noted that the literature emphasizes the positive effects of diversifying crops on carbon sequestration on the field. Since there exists a strong link between soil C sequestration and food security (Bright et al., 2017), and the contribution to global greenhouse gas emissions from agriculture cannot be ignored, it is highlighted here that numerous studies regarding intercropping reported positive impacts of mixing species on sequestering carbon capacity of the planting field (e.g., Bright et al., 2017; Kay et al., 2018). Introducing woody perennials and/or cover crops for animal grazing, if done correctly, could also contribute to the total carbon sequestration of the whole agriculture system (Lemaire et al., 2014; Nyong et al., 2020).

5.2.3 Caveats

Biodiversity drivers can positively enhance many aspects of food security, however, there are several caveats to the successful utilization of these drivers.

For instance, mixed results can be obtained when mixing crops (Timaeus et al 2022), indicating that not every crop species can be sowed in the same field with positive results.

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Moreover, despite the many well-known advantages of mixed cropping, real-life applications can encounter various challenges. To fully take advantage of crop biodiversity, appropriate infrastructure must be in place, such as knowledge, know-how, available market for the additional crops, soil quality, and sufficient labor at the farm, just to name a few (Coromaldi et al., 2015).

While there is evidence of agroforestry benefits, there are inherent caveats to this practice. First, much like intercropping, the combination of trees and crops must be selected with care. Shade trees with low canopies can interfere with sunlight exposure in crops, negatively affecting yields (Blaser-Hart et al., 2021). Further, mixing crops and trees always poses an inherent risk of the natural competition between species, thus the important species might be worsened in terms of performance and yield (Lovell et al., 2018). Second, there are considerable economic and managerial barriers to agroforestry practices. The majority of the agroforestry practices are less competitive, in terms of economic performance than monoculture – farming of specific crops (Thiesmeier and Zander, 2023). Further, to practice agroforestry means that farmers have to reallocate their labour, land, and capital, which are often limited resources, to trees. These can create extra burdens on farmers, hindering their willingness to adopt agroforestry (Quandt et al., 2019; Thiesmeier and Zander, 2023). In the same vein, integrating animals (fish, livestock) into a crop farming system encounters the same challenge, as physical labor capacity is a major determinant in the decision-making of whether to include animals in the system (Lemaire et al., 2014).

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6. Data assessment

As depicted in Figure 1 of the Methodology section, one important task of Stage 2 of the SDR is the assessment of data availability. The purpose of this task is to, based on the factors driving food resilience identified in the Literature review task, identify relevant data sources for monitoring/ reporting such factors. Therefore, this task is related to, and highly dependent on the output of the literature review activity. There are 5 sources for locating the data:

- *Academic literature:* in the process of selecting research for Task 1 Literature review, many studies, which are categorized as “data papers” are identified. In this type of paper, the authors typically collect and report a set of data in relation to climate change or biodiversity. Relevant papers are included in the outcome of the Data assessment.

- *National projects:* identifying projects in different European countries requires a collective effort from all partners in WP1 of the ECO-READY project. We collected information on projects that have and/or generate data in relation to the drivers identified in the previous task.

- *European projects*: are similar to national projects, but on the European scale. https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/projects-results is the main portal for searching. Further, knowledge of other partners in WP1 is also another valuable source of knowledge. Therefore, WP1 partners provided information about relevant projects, of which they know or have been a part.

- *EUROSTAT:* the statistical office of the European Union.

- *Internet search*: searching for suitable databases and platforms.

The data assessment task does not strive for an exhaustive list of data sources related to climate change and biodiversity-induced drivers for food security. Rather, it is a testament to the availability of data for monitoring and reporting such drivers. The final compilation of data can be found in Appendix B of this report. In sum, we determined 29 data sets as the results of academic research, 26 projects (at national and European levels) with relevant data, 28 public data platforms, and 5 EUROSTAT data sets. Public data platforms, in this case, are online databases containing data sets specific to a certain aspect of climate change and/or biodiversity (e.g. worlclim.org, bio-oracle.org, fao.org, eumetsat.int).

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Further, during the process, data sets which can be used to measure food security, were recorded. It is anticipated that such data can be useful for the development of the Observatory at a later stage.

From examining the data compilation, two types of data formulation are observed. The first one is collected and reported data sets at the global level, and a more specific data set can be extracted for specific usage (such as studying the impacts of climate change in a country/ region). Many climate change drivers fall into this category. It is also common for academic researchers to obtain a scaled-down set of data for their modelling works (e.g. Castro-Llanos et al., 2019; Chen et al., 2023). The other type of data is gathered for specific regions because the corresponding drivers affect each region differently. For instance, crop wild relatives can contribute important genes for breeding more resilient cultivars, as found in the literature. However, these species differ by region/country, and further, their adaptions to changes in the environment vary depending on the location and climatic conditions in that location. Therefore, to formulate a data set regarding useful crop wild relatives, the analysis has to be conducted at a regional level. The majority of this data category often is generated by academic research and projects. Table 5 summarizes both categories of data.

Monitor level	Dimension	Drivers	Sources for data
Global	Climate change	Increased air temperature Sea surface temperature Sea bottom temperature Precipitation change CO_2 concentration Ocean acidification Ocean dissolved oxygen Ocean salinity Soil salinity River salinity Seasonal variation Drought Marine heatwaves Marine cold spells Flood Glacier retreat Reduced ice cover at sea	Public data platforms such as: - worldclim.org - bio-oracle.org - resourcewatch.org - fao.org - eswd.eu Some data repositories related to the results of academic literature, such as: - Ivushkin et al. (2019) for global mapping of soil salinity change - Thorslund and Vliet (2020) for a global data set of river salinity
	Biodiversity	Primary production Pollination services Coral Mangrove Algae Pests	Public data platforms such as: - coralreefwatch.noaa.gov - bio-oracle.org - resourcewatch.org (Mangrove Forests category)

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<table>
<tr><td></td><td></td><td></td><td>Literature such as Outhwaite et al. (2022).</td></tr>
<tr><td rowspan="2">Regional</td><td>Climate change</td><td>Storm/ hurricane
Increased freshwater and estuary temperature
Summer heatwave
Extreme events group of drivers*</td><td>Public data platforms reporting a specific region, such as:
- European Severe Weather database (https://eswd.eu/)
- Scotland river temperature monitoring network (https://scotland.shinyapps.io/sg-srtmn-data/)
Literature such as Prodhomme et al. (2022)
Projects (see more details in Appendix B)</td></tr>
<tr><td>Biodiversity</td><td>Diversity in plants and crops group of drivers*
Soil biota group of drivers
Agroforestry
Ecosystem services group of drivers*
Animal and crop integration system
Crop wild relatives
Pest invasion
Wild crop relatives
Underwater biodiversity group of drivers*</td><td>The majority of the data comes from the literature and projects. Some examples include:
- Lopez-Aliste et al. (2021)
- Philips et al. (2016)
- Project LGUMIROSE
- Project IntercropVALUES</td></tr>
</table>

Tabe 5. Data monitored at a global or regional level, their related drivers, and the sources (*Note: refer to Tables 2 and 3 for the detailed drivers within a group of drivers, mark with * in this Table*).

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7. Implications to Land Use

Climate change and biodiversity drivers of food security are influential factors to the current food system. This section specifically addresses how agriculture practices (land use) should take into account the impacts of climate change and biodiversity. Drawing from the findings of the literature, several considerations for agriculture are proposed:

1. Incorporate long-term changes in the environment into strategies: as climate change is projected to continue, there is a need to understand the consequences of such changes and to account for them in future strategies. The level of understanding must be adequate to generate substantive improvements since climate change impacts can vary depending on local settings (Kondis et al., 2018). Therefore, it can be argued that there is not a one-size-fits-all interpretation of climate change consequences, as each region can experience the changes differently. Climate change causes gradual changes in the field, notably in temperature, precipitation, CO_2 concentration, and soil conditions. Thus, food producers need to evaluate the viability of current crops and livestock long into the future, addressing important facets such as whether the current farmed species are feasible under new climatic conditions, what actions can be taken to ensure the longevity and continuity of current practices, and, in the worst case scenario, what the alternative solutions are. Climate change can also induce harmful biodiversity factors, notably novel pest invasions. Practitioners, therefore, must monitor such threats carefully and continuously.
2. Anticipate and respond to short-term climatic events: climate change is projected to increase the frequency and intensity of extreme weather events (e.g., drought, flood, heatwave, etc.) which can have devastating impacts on agricultural production (Mhenni et al., 2020). Unlike gradual climate change effects, extreme events are sudden and abrupt, thus requiring immediate actions from food industry practitioners. The use of data and forecasts can be extremely helpful in mitigating the negative consequences of such extreme climatic events.
3. Consider the use of beneficial biodiversity factors in farming and animal husbandry: as demonstrated in Section 5.2 of this report, there are many biodiversity drivers that practitioners can take advantage of to improve yields and cropland conditions. Particularly, drivers such as using a diverse portfolio of cultivars and/or types of

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crops, mixing trees and shrubs in the field, etc. can potentially be integrated into current agricultural practices to boost yields while reducing chemical inputs. Practitioners can also promote and expand the use of nature-based solutions in supporting crop growth and yield, through utilising beneficial soil biota faunas and micro-organisms, natural pollinators, natural pests control, and so on. Thus, agricultural practices can maintain outputs and promote sustainability at the same time. However, the approaches must be selected taking into account appropriate knowledge, as the effects of biodiversity cannot be generalized without care. For instance, not all mixtures of crops can generate positive outcomes on yields, and an unsuitable mix can reduce overall outputs (Timaeus et al 2022).

4. Explore novel practices in addition to conventional farming: approaches such as agroforestry or animal and crop integration systems can sustain agricultural yields while diversifying the food supply. If utilised appropriately, food producers can obtain extra income and potentially hedge the risk of over-relying on a single means of food production. One caveat in adopting these approaches is that they are resource-demanding, in terms of land, investment, and labour (Quandt et al., 2019). Furthermore, certain agroforestry practices require a suitable location.
5. Explore the use of underutilised crops and crop wild relatives: these biodiversity drivers can be fantastic resources to farmers. Wild crop relatives have the potential to provide breeds that are more suitable for future climates. Underutilised crops can be explored as alternatives/substitutes for conventional crops and as a means to diversify the sources of income to mitigate the risk of main crops failing. Nevertheless, to explore the potential of genes from wild relatives and/or the feasibility of mass-growing underutilised crops, it is likely that other entities such as government agencies and the scientific community must get involved to support food producers.

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8. Conclusions

This report is the main outcome of Task 1.1, WP1 of the ECO-READY project. The aim of the report is two-fold: to identify climate change and biodiversity- induced drivers of food security, and to collect data sources in relation to those drivers.

To achieve the first objective, an SLR was employed to select the most relevant academic literature on the nexus of climate change – biodiversity – food security. After a robust process of searching, screening, and evaluating, 342 academic studies were selected for the review. Insights from those studies were synthesized into two main themes: climate change drivers of food security, and biodiversity drivers of food security. Subsequently, 20 climate change drivers and 18 biodiversity drivers were identified in the literature. Furthermore, detailed discussions of how these drivers affect the four pillars of food security, namely availability, accessibility, stability, and utilisation, were provided. The majority of the impacts are on the availability facet, as the drivers contribute remarkably to the habitats, phenology, and physiology of exploited plants and animals. On one hand, critical changes in the climate (e.g. temperature, precipitation, ocean pH and salinity levels, extreme events frequency) and certain biodiversity factors (e.g. pests, invasive species, cyanobacteria bloom) can inhibit the development and well beings of crops and animals, leading to lower yields. On the other hand, the same climatic variability can favour certain crops or fish in a specific region, and numerous biodiversity drivers (e.g. diverse plantation of crops, mixing woody perennials and shrubs in the field, beneficial soil biota, coral, kelp forest, mangrove) can be utilised to better support crops and animal growth, resulting in improved productivity. Further, drivers such as agroforestry or the provisioning service of forests can directly increase the availability of food for local communities. There are strong implications of climate change and biodiversity drivers on the accessibility, utilization, and stability pillars of food security. Agriculture and fishery outputs contribute to household income and total food supply, thus it can be argued that these drivers indirectly affect people's access to food. Many studies concluded that the quality of crops, fruits, fish, and livestock products can be influenced by the surrounding environment, including both abiotic factors (climate change) and biotic factors (e.g. supportive organisms or diversity of feeds). Subsequently, this affects the nutritional value of food, which is a part of the utilisation aspect of food security. Finally, a projection of continuous climate change in the future and the mitigation effects provided by biodiversity drivers

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contribute to the stability across the other three facets of food security. Thus, this report sheds light on the specific mechanisms by which climate change and biodiversity impact food security.

To achieve the second objective, five sources were utilized to acquire information about data sets, databases, and data platforms for reporting and monitoring the drivers identified from the literature. These sources include academic literature, national projects, European-level projects, EUROSTAT, and internet searches. The assessment of data availability found that there is available data for monitoring/ reporting all drivers, as identified from the review. This is a positive outcome, highlighting that important climate change and biodiversity factors are recognized. As the final results, 27 data sets as the results of academic research, 27 projects (at national and European levels) with relevant data, 28 public data platforms, and 5 EUROSTAT data sets were identified. Public data platforms, in this case, are online databases containing data sets specific to a certain aspect of climate change and/or biodiversity (e.g. worlclim.org, bio-oracle.org, fao.org, eumetsat.int). Efforts from the Task 1.1 leader and various partners in WP1 were presented to aggregate the final list of data, especially regarding the compilation of relevant projects (at national and European levels).

Finally, the implications of the findings are discussed. Broadly, the results of this work make several contributions to industry and policy.

For business, our lists of drivers and their impacts inform managers about critical factors that relate directly to food production activities. Broadly, there are threats and benefits imposed by the drivers, prompting the need for appropriate plans and strategies. Regarding climate change, the impacts can be gradual or abrupt. Increased temperature, variability of precipitation, increased ocean acidity, and changes in soil and ocean salinity can progress steadily over the year, hence businesses need to devise long-term strategies concerning the viability of the current productions and possible alternatives. Extreme events such as drought, flood, heatwave, storms, etc. are more sudden, thus requiring immediate plans to mitigate the adverse consequences (e.g. better ventilation for cattle, drainage, additional irrigation, etc.). Farmers and fishers should also pay attention to harmful biodiversity factors (e.g. pests and invasive species) and the degradation of the habitat due to biodiversity loss (e.g. coral, kelp, and pollinators) to anticipate and minimize their effects on the field and fishing grounds. On the other hand, businesses need

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to be aware of the benefits of utilizing biodiversity for improving yields from crops and animals (diverse crops portfolio, agroforestry, utilization of soil biota, crop wild relatives, etc.), potentially incorporating such beneficial drivers into current practices.

For policymakers, our lists of climate change and biodiversity drivers can serve as useful references for policy development. Based on the suggested drivers in this report, a more granular assessment can be conducted to determine important drivers for a specific region or country. Subsequently, current policies can be evaluated regarding whether they have taken into account such factors, and what facets of food security are likely to be impacted. Thus, new policies can potentially be developed with increased reach and impact. For instance, guidelines can be developed to direct agricultural and fishery practices under the effects of climate change, or regulations can take place to preserve important biodiversity factors in food production. Furthermore, policymakers can promote useful practices such as agroforestry, animal and crop integration systems, and the development of wild crop relatives and underutilised crop species inventories, to further strengthen food systems and food security.

For both industry and policies, our findings advocate for a stronger use of data in decision-making, especially when accounting for climate change and biodiversity drivers. As demonstrated in our data assessment, there are available data for reporting/ monitoring critical drivers of food security. However, a critical question remains, which is how to best use the data and knowledge about climate change and biodiversity effects on food security. We believe that the scientific community can play a strong role in addressing this issue. Scientific outputs have utilised available data to examine the effects of climate change and biodiversity on food systems, as well as to make future projections. Therefore, consultation from the scientific community can be a valuable resource to make sense of the data, contributing to more informed decisions. Further, as climate change and biodiversity drivers can be numerous, as seen in the findings of this work, we see a strong case for the ECO-READY Observatory platform – a single source of information, plans, and strategies for adapting European food systems to future changes.

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APPENDIX A - 342 Selected papers

No	Dimension	Authors	Article Title	Source Title	Year	Method	Topics	Sub topic	Affected Region	Specific location
1	Climate change	Bahadur, KCK; Tzadok	Climate change-driven agricultural frontiers and their ecosystem trade-offs in the hills of Nepal	REGIONAL ENVIRONMENTAL CHANGE	2023	GIS-based method	Crops	Multiple species	Asia	Nepal
2	Climate change	Chen, YL; Shan, XJ; G	Ensemble projections of fish distribution in response to climate changes in the Yellow and Bohai Seas, China	ECOLOGICAL INDICATORS	2023	Modelling	Fishery	Multiple species	Asia	China Yellow and Bohai sea
3	Climate change	Xu, W; Miao, YQ; Zhu,	Modelling the Geographical Distribution Pattern of Apple Trees on the Loess Plateau, China	AGRICULTURE-BASEL	2023	Modelling	Fruit	Apple	Asia	China
4	Climate change	Smith, JA; Buil, MP; M	Projecting climate change impacts from physics to fisheries: A view from three California Current fisheries	PROGRESS IN OCEANOGRAPHY	2023	Modelling	Fishery	Multiple species	North America	USA
5	Climate change	Bacalso, RTM; Romagr	Annual and seasonal environmental drivers of species- and gear-specific catch rates in the Visayan Sea, Philippines	REGIONAL STUDIES IN MARINE SCIENCE	2023	Quant analysis	Fishery	Multiple species	Asia	Philippines Visayan Sea
6	Climate change	Kagnew, B; Assefa, A;	Modeling the Impact of Climate Change on Sustainable Production of Two Legumes Important Economically and for Food Security: Mungbeans and Cowpeas in Ethiopia	SUSTAINABILITY	2023	Modelling	Crops	Legumes (mungbean and cowpea)	Africa	Ethiopia
7	Climate change	Regnier, B; Legrand, J	Developmental Differentiations of Major Maize Stemborers Due to Global Warming in Temperate and Tropical Climates	INSECTS	2023	Simulation	Pests	Maize stemborer	Global	NA
8	Climate change	Ghimire, S; Shrestha,	Integrated assessment of climate change and reservoir operation on flow-regime and fisheries of the Sekong river basin in Lao PDR and Cambodia	ENVIRONMENTAL RESEARCH	2023	Modelling	Fishery	Multiple species	Asia	Mekong river
9	Climate change	Shan, YM; Gao, XY; Hu	Current and future potential distribution of the invasive scale Ceroplastes rusci (L., 1758) (Hemiptera: Coccidae) under climate niche	PEST MANAGEMENT SCIENCE	2023	Modelling	Pests	Insect Ceroplastes rusci	Global	NA
10	Climate change	Youngblood, JP; Cease	Climate change expected to improve digestive rate and trigger range expansion in outbreaking locusts	ECOLOGICAL MONOGRAPHS	2023	Hybrid modelling	Pests	South America locust	South America	Multiple countries
11	Climate change	Pridannikov, MV; Zino	Range Dynamics of Potato Cyst Nematode Globodera rostochiensis (Wollenweber, 1923) (Nematoda, Heteroderidae) under Conditions of Global Climate Change in Russia	RUSSIAN JOURNAL OF BIOLOGICAL INVASIONS	2022	Modelling	Pests	Potato cyst nematode	Asia/ Europe	Russia
12	Climate change	Zhang, XY; Zhao, J; W	Potential distribution prediction of Amaranthus palmeri S. Watson in China under current and future climate scenarios	ECOLOGY AND EVOLUTION	2022	Modelling	Pests	Invasive plant palmeri	Asia	China

13	Climate change	Gokturk, EN; Bartlett,	Loss of suitable ocean habitat and phenological shifts among grouper and snapper spawning aggregations in the Greater Caribbean under climate change	MARINE ECOLOGY PROGRESS SERIES	2022	Modelling	Fishery	Snapper and Grouper	North America	Caribbean Sea
14	Climate change	Cheung, WWL; Palacio	Rebuilding fish biomass for the world's marine ecoregions under climate change	GLOBAL CHANGE BIOLOGY	2022	Modelling	Fishery	Multiple species	Global	NA
15	Climate change	Cheung, WWL; Wei, C	Vulnerability of exploited deep-sea demersal species to ocean warming, deoxygenation, and acidification	ENVIRONMENTAL BIOLOGY OF FISHES	2022	Modelling	Fishery	Deep sea fish	Global	NA
16	Climate change	Boyce, DG; Tittensor,	A climate risk index for marine life	NATURE CLIMATE CHANGE	2022	Risk assessment	Fishery	Multiple species	Global	NA
17	Climate change	Zhang, R; Liu, Y; Tian	Impact of climate change on long-term variations of small yellow croaker (Larimichthys polyactis) winter fishing grounds	FRONTIERS IN MARINE SCIENCE	2022	Modelling	Fishery	Croaker	Asia	China sea
18	Climate change	Castro-Olivares, A; De	Does global warming threaten small-scale bivalve fisheries in NW Spain?	MARINE ENVIRONMENTAL RESEARCH	2022	Modelling	Fishery	Bivalve	Europe	Spain
19	Climate change	Alaerts, L; Dobbelaere	Climate Change Will Fragment Florida Stone Crab Communities	FRONTIERS IN MARINE SCIENCE	2022	Modelling	Fishery	Stonecrab	North America	USA
20	Climate change	Anderson, AB; Bernard	Niche availability and habitat affinities of the red porgy Pagrus pagrus (Linnaeus, 1758): An important ecological player on the world's largest rhodolith beds	JOURNAL OF FISH BIOLOGY	2022	Modelling	Fishery	Red porgy	South America	Brazil
21	Climate change	Liu, XY; Han, XL; Han,	``	JOURNAL OF OCEANOLOGY AND LIMNOLOGY	2022	Modelling	Fishery	Swimming crab	Asia	Bohai, Yellow, East China sea
22	Climate change	Nicolle, P; Hughes, J;	Long-term increase in growth of an estuarine predator, mulloway Argyrosomus japonicus, predicted to continue under future warming scenarios	MARINE ECOLOGY PROGRESS SERIES	2022	Sample analysis	Recreational Fishery	Mulloway	Australia	Australia
23	Climate change	Jiang, TC; Wang, B; X	Identifying sources of uncertainty in wheat production projections with consideration of crop climatic suitability under future climate	AGRICULTURAL AND FOREST METEOROLOGY	2022	Modelling	Crops	Wheat	Asia	China
24	Climate change	Saborowski, R; Hunerl	Hatching phenology of the brown shrimp Crangon crangon in the southern North Sea: inter-annual temperature variations and climate change effects	ICES JOURNAL OF MARINE SCIENCE	2022	Simulation	Fishery	Brown shrimp	Europe	North Sea
25	Climate change	Mazur, MD; Tanaka, K	Incorporating spatial heterogeneity and environmental impacts into stock-recruitment relationships for Gulf of Maine lobster	ICES JOURNAL OF MARINE SCIENCE	2022	Modelling	Fishery	Lobster	North America	USA
26	Climate change	Selvaraj, JJ; Rosero-H	Projecting future changes in distributions of small-scale pelagic fisheries of the southern Colombian Pacific Ocean	HELIYON	2022	Modelling	Fishery	Pelagic fish	South America	Colombian Pacific Sea
27	Climate change	Ropke, C; Pires, THS;	Effects of climate-driven hydrological changes in the reproduction of Amazonian floodplain fishes	JOURNAL OF APPLIED ECOLOGY	2022	Data analysis	Fishery	Freshwater fish	South America	Amazon

28	Climate change	Chasco, BE; Hunsicker	Evidence of Temperature-Driven Shifts in Market Squid Doryteuthis opalescens Densities and Distribution in the California Current Ecosystem	MARINE AND COASTAL FISHERIES	2022	Modelling	Fishery	Squid	North America	USA
29	Climate change	Rettieid, FM; Gayler,	Climate change impact on wheat and maize growth in Ethiopia: A multi-model uncertainty analysis	PLOS ONE	2022	Modelling	Crops	Wheat, maize	Africa	Ethiopia
30	Climate change	Oyinlola, MA; Reygond	Projecting global mariculture production and adaptation pathways under climate change	GLOBAL CHANGE BIOLOGY	2022	Modelling	Aquaculture	Multiple mariculture species	Global	NA
31	Climate change	Gebresamuel, G; Abrh	Empirical modeling of the impact of climate change on altitudinal shift of major cereal crops in South Tigray, Northern Ethiopia	JOURNAL OF CROP IMPROVEMENT	2022	Modelling	Crops	Cereal crops	Africa	Ethiopia
32	Climate change	Litzow, MA; Malick, M	Using a climate attribution statistic to inform judgments about changing fisheries sustainability	SCIENTIFIC REPORTS	2021	Data analysis	Fishery	Cod Pollock	North America	Gulf of Alaska
33	Climate change	Pitman, KJ; Moore, JV	Glacier retreat creating new Pacific salmon habitat in western North America	NATURE COMMUNICATIONS	2021	Modelling	Fishery	Salmon	North America	Canada
34	Climate change	Tai, TC; Calosi, P; Gur	Modelling ocean acidification effects with life stage-specific responses alters spatiotemporal patterns of catch and revenues of American lobster, Homarus americanus	SCIENTIFIC REPORTS	2021	Modelling	Fishery	Lobster	North America	USA
35	Climate change	Mason, JG; Woods, PJ	Projecting climate-driven shifts in demersal fish thermal habitat in Iceland's waters	ICES JOURNAL OF MARINE SCIENCE	2021	Modelling	Fishery	Demersal fish	Europe	Iceland
36	Climate change	Wilson, RJ; Sailley, SF	Large projected reductions in marine fish biomass for Kenya and Tanzania in the absence of climate mitigation	OCEAN & COASTAL MANAGEMENT	2021	Modelling	Fishery	Multiple species	Africa	Kenya and Tanzania
37	Climate change	Cheung, WWL; Frolich	Marine high temperature extremes amplify the impacts of climate change on fish and fisheries	SCIENCE ADVANCES	2021	Modelling	Fishery	Multiple species	Global	NA
38	Climate change	Zhu, LL; Wen, W; Tho	Combining Heat Stress with Pre-Existing Drought Exacerbated the Effects on Chlorophyll Fluorescence Rise Kinetics in Four Contrasting Plant Species	INTERNATIONAL JOURNAL OF MOLECULAR SCIENCES	2021	Experiment	Crops	Multiple species	Not specified	
39	Climate change	Chang, YJ; Hsu, J; Lai	Evaluation of the Impacts of Climate Change on Albacore Distribution in the South Pacific Ocean by Using Ensemble Forecast	FRONTIERS IN MARINE SCIENCE	2021	Modelling	Fishery	Albacore	Asia	South Pacific Ocean
40	Climate change	Maire, E; Graham, NA	Micronutrient supply from global marine fisheries under climate change and overfishing	CURRENT BIOLOGY	2021	Data analysis	Fishery	Multiple species	Global	NA
41	Climate change	Torrejon-Magallanes,	Modeling the Pacific chub mackerel (Scomber japonicus) ecological niche and future scenarios in the northern Peruvian Current System	PROGRESS IN OCEANOGRAPHY	2021	Modelling	Fishery	Chub mackerel	South America	Peru

42	Climate change	Bell, JD; Senina, I; Ad	Pathways to sustaining tuna-dependent Pacific Island economies during climate change	NATURE SUSTAINABILITY	2021	Modelling	Fishery	Tuna	Australia	Pacific Islands
43	Climate change	Angeles-Gonzalez, LE;	Climate change effect on Octopus maya (Voss and Solis-Ramirez, 1966) suitability and distribution in the Yucatan Peninsula, Gulf of Mexico: A correlative and mechanistic approach	ESTUARINE COASTAL AND SHELF SCIENCE	2021	Modelling	Fishery	Octopus maya	North America	Mexico
44	Climate change	Tai, TVC; Sumaila, UR	Ocean Acidification Amplifies Multi-Stressor Impacts on Global Marine Invertebrate Fisheries	FRONTIERS IN MARINE SCIENCE	2021	Modelling	Fishery	Interverbrate fish	Global	NA
45	Climate change	Paul, TT; Panikker, P;	Assessing vulnerability and adopting alternative climate resilient strategies for livelihood security and sustainable management of aquatic biodiversity of Vembanad lake in India	JOURNAL OF WATER AND CLIMATE CHANGE	2021	Sample analysis	Fishery	Clam and fish	Asia	India
46	Climate change	Molto, V; Palmer, M; (	Projected effects of ocean warming on an iconic pelagic fish and its fishery	SCIENTIFIC REPORTS	2021	Modelling	Fishery	Dophinfish	Europe	Mediterranean Sea
47	Climate change	Hussain, SV; Ulahanna	Impact of climate change on the fishery of Indian mackerel (Rastrelliger kanagurta) along the Kerala coast off the southeastern Arabian Sea	REGIONAL STUDIES IN MARINE SCIENCE	2021	Modelling	Fishery	Indian mackerel	Asia	Arabian Sea
48	Climate change	Cubillo, AM; Ferreira,	Direct effects of climate change on productivity of European aquaculture	AQUACULTURE INTERNATIONAL	2021	Modelling	Aquaculture	Multiple species	Europe	Multiple countries
49	Climate change	Cunningham, MA; Wri	Mapping Vulnerability of Cotton to Climate Change in West Africa: Challenges for Sustainable Development	CLIMATE	2021	Modelling	Cash crops	Cotton	Africa	West Africa countries
50	Climate change	Donelan, SC; Breitbur	Context-dependent carryover effects of hypoxia and warming in a coastal ecosystem engineer	ECOLOGICAL APPLICATIONS	2021	Experiment	Fishery Aquaculture	Oyster	Not specified	
51	Climate change	Gao, Y; Zhang, AY; Yu	Predicting Shifts in Land Suitability for Maize Cultivation Worldwide Due to Climate Change: A Modeling Approach	LAND	2021	Modelling	Crops	Maize	Global	NA
52	Climate change	Schickele, A; Francou	European cephalopods distribution under climate-change scenarios	SCIENTIFIC REPORTS	2021	Modelling	Fishery	Cephalopods	Europe	Multiple countries
53	Climate change	Rocha, V; Duarte, MC;	Cabo Verde's Poaceae Flora: A Reservoir of Crop Wild Relatives Diversity for Crop Improvement	FRONTIERS IN PLANT SCIENCE	2021	Data collection	Crops	Crop wild relatives	Africa	
54	Climate change	Su, P; Zhang, AY; Wan	Prediction of Future Natural Suitable Areas for Rice under Representative Concentration Pathways (RCPs)	SUSTAINABILITY	2021	Modelling	Crops	Rice	Global	NA
55	Climate change	Le Corre, N; Pepin, P;	Potential impact of climate change on northern shrimp habitats and connectivity on the Newfoundland and Labrador continental shelves	FISHERIES OCEANOGRAPHY	2021	Modelling	Fishery	Shrimp	North America	Canada

56	Climate change	Layton, KKS; Snelgrov	Genomic evidence of past and future climate-linked loss in a migratory Arctic fish	NATURE CLIMATE CHANGE	2021	Genomic data & Machine learning	Fishery	Artic fish	North America	Canada
57	Climate change	Theusme, C; Avendan	Climate change vulnerability of confined livestock systems predicted using bioclimatic indexes in an arid region of Mexico	SCIENCE OF THE TOTAL ENVIRONMENT	2021	Data analysis	Livestock	Multiple species	North America	Mexico
58	Climate change	Wang, C; Shi, XY; Liu,	Interdecadal variation of potato climate suitability in China	AGRICULTURE ECOSYSTEMS & ENVIRONMENT	2021	Modelling	Crops	Potato	Asia	China
59	Climate change	Khalil, T; Asad, SA; Kh	Climate change and potential distribution of potato (Solanum tuberosum) crop cultivation in Pakistan using Maxent	AIMS AGRICULTURE AND FOOD	2021	Modelling	Crops	Potato	Asia	Pakistan
60	Climate change	Rooper, CN; Ortiz, I; H	Predicted shifts of groundfish distribution in the Eastern Bering Sea under climate change, with implications for fish populations and fisheries management	ICES JOURNAL OF MARINE SCIENCE	2021	Modelling	Fishery	Multiple species	North America	Bering sea
61	Climate change	Ben Mhenni, N; Shinoc	Assessment of drought frequency, severity, and duration and its impacts on vegetation greenness and agriculture production in Mediterranean dryland: A case study in Tunisia	NATURAL HAZARDS	2021	Data analysis Case study	Crops	Multiple species	Africa	Tusinia
62	Climate change	Brown, CJ; Mellin, C;	Direct and indirect effects of heatwaves on a coral reef fishery	GLOBAL CHANGE BIOLOGY	2020	Data analysis	Fishery	Reef fish	Australia	Australia
63	Climate change	Shelton, AO; Sullaway	Redistribution of salmon populations in the northeast Pacific ocean in response to climate	FISH AND FISHERIES	2020	Modelling	Fishery	Salmon	North America	USA Canada
64	Climate change	Toreti, A; Deryng, D;	Narrowing uncertainties in the effects of elevated CO2 on crops	NATURE FOOD	2020	Review	Crops	Multiple species	Global	NA
65	Climate change	Murray-Tortarolo, GN;	Precipitation extremes in recent decades impact cattle populations at the global and national scales	SCIENCE OF THE TOTAL ENVIRONMENT	2020	Data analysis	Livestock	Multiple species	Global	NA
66	Climate change	Ramenzoni, VC; Escue	Vulnerability of Fishery-Based Livelihoods to Extreme Events: Local Perceptions of Damages from Hurricane Irma and Tropical Storm Alberto in Yaguajay, Central Cuba	COASTAL MANAGEMENT	2020	Case study	Fishery	Multiple species	North America	Cuba
67	Climate change	Das, I; Lauria, V; Kay,	Effects of climate change and management policies on marine fisheries productivity in the north-east coast of India	SCIENCE OF THE TOTAL ENVIRONMENT	2020	Modelling	Fishery	Multiple species	Asia	India
68	Climate change	Dhurmeea, Z; Pethybr	Spatial variation in stable isotopes and fatty acid trophic markers in albacore tuna (Thunnus alalunga) from the western Indian Ocean	DEEP-SEA RESEARCH PART I-OCEANOGRAPHIC RESEARCH PAPERS	2020	Sample analysis	Fishery	Tuna	Asia	Indian Ocean

69	Climate change	Zheng, Z; Cai, HJ; Wa	Simulation of Climate Change Impacts on Phenology and Production of Winter Wheat in Northwestern China Using CERES-Wheat Model	ATMOSPHERE	2020	Modelling	Crops	Winter wheat	Asia	China
70	Climate change	Beltran-Tolosa, LM; Na	Action needed for staple crops in the Andean-Amazon foothills because of climate change	MITIGATION AND ADAPTATION STRATEGIES FOR GLOBAL CHANGE	2020	Modelling	Crops	Stable crops	South America	Multiple countries
71	Climate change	Magel, CL; Lee, EMJ; S	Connecting Crabs, Currents, and Coastal Communities: Examining the Impacts of Changing Ocean Conditions on the Distribution of US West Coast Dungeness Crab Commercial Catch	FRONTIERS IN MARINE SCIENCE	2020	Modelling	Fishery	Dungeness crab	North America	USA
72	Climate change	Moyano, M; Illing, B; F	Linking individual physiological indicators to the productivity of fish populations: A case study of Atlantic herring	ECOLOGICAL INDICATORS	2020	Experiment	Fishery	Atlantic herring	Europe	Baltic
73	Climate change	Zeng, YZ	Shifts in Herring and Mackerel Resources in the North Sea under Global Warming	JOURNAL OF COASTAL RESEARCH	2020	Modelling	Fishery	Herring and mackerel	Europe	North Sea
74	Climate change	Erauskin-Extramiana,	Are shifts in species distribution triggered by climate change? A swordfish case study	DEEP-SEA RESEARCH PART II-TOPICAL STUDIES IN OCEANOGRAPHY	2020	Modelling	Fishery	Tuna	Asia	Japan
75	Climate change	Tanaka, KR; Torre, MP	An ensemble high-resolution projection of changes in the future habitat of American lobster and sea scallop in the Northeast US continental shelf	DIVERSITY AND DISTRIBUTIONS	2020	Modelling	Fishery	Lobster, scallop	North America	USA
76	Climate change	Cheung, WWL; Frolich	Marine heatwaves exacerbate climate change impacts for fisheries in the northeast Pacific	SCIENTIFIC REPORTS	2020	Simulation	Fishery	Multiple species	North America	North East Pacific
77	Climate change	Kath, J; Byrareddy, VM	Not so robust: Robusta coffee production is highly sensitive to temperature	GLOBAL CHANGE BIOLOGY	2020	Modelling	Cash crops	Coffee	Africa	Congo
78	Climate change	Luitel, DR; Siwakoti, M	Potential suitable habitat of Eleusine coracana (L) gaertn (Finger millet) under the climate change scenarios in Nepal	BMC ECOLOGY	2020	Modelling	Crops	Finger millet	Asia	Nepal
79	Climate change	Chhogyel, N; Kumar, L	Prediction of Bhutan's ecological distribution of rice (Oryza sativaL.) under the impact of climate change through maximum entropy modelling	JOURNAL OF AGRICULTURAL SCIENCE	2020	Modelling	Crops	Rice	Asia	Bhutan
80	Climate change	Gray, SB; Rodriguez-M	Translational regulation contributes to the elevated CO2 response in two Solanum species	PLANT JOURNAL	2020	Experiment	Crops	Tomato	Not specified	
81	Climate change	Wilson, TJB; Cooley, S	Potential socioeconomic impacts from ocean acidification and climate change effects on Atlantic Canadian fisheries	PLOS ONE	2020	Modelling	Fishery	Shellfish fishery	North America	Canada
82	Climate change	Fernandez, E; Whitney	Prospects of decreasing winter chill for deciduous fruit production in Chile throughout the 21st century	CLIMATIC CHANGE	2020	Data analysis	Fruit	Decidous fruit	South America	Chile
83	Climate change	Trnka, M; Balek, J; Se	Future agroclimatic conditions and implications for European grasslands	BIOLOGIA PLANTARUM	2020	Modelling	Pasture		Europe	Multiple countries

84	Climate change	Smalas, A; Strom, JF;	Climate warming is predicted to enhance the negative effects of harvesting on high-latitude lake fish	JOURNAL OF APPLIED ECOLOGY	2020	Modelling	Fishery	Artic charr	Europe	Norway
85	Climate change	Castro-Llanos, F; Hym	Climate change favors rice production at higher elevations in Colombia	MITIGATION AND ADAPTATION STRATEGIES FOR GLOBAL CHANGE	2019	Modelling	Crops	Rice	South America	Colombia
86	Climate change	Goode, AG; Brady, DC	The brighter side of climate change: How local oceanography amplified a lobster boom in the Gulf of Maine	GLOBAL CHANGE BIOLOGY	2019	Data analysis	Fishery	Lobster	North America	USA
87	Climate change	Tai, TC; Steiner, NS; I	Evaluating present and future potential of arctic fisheries in Canada	MARINE POLICY	2019	Modelling	Fishery	Artic fish	North America	Canada
88	Climate change	Zhang, ZX; Xu, SY; Ca	Using species distribution model to predict the impact of climate change on the potential distribution of Japanese whiting Sillago japonica	ECOLOGICAL INDICATORS	2019	Modelling	Fishery Recreational fishery	Japanese whiting	Asia	Coasts of China, Korea, Japan
89	Climate change	Gianelli, I; Ortega, L;	Evidence of ocean warming in Uruguay's fisheries landings: the mean temperature of the catch approach	MARINE ECOLOGY PROGRESS SERIES	2019	Mean of the catch (MTC) approach and modelling	Fishery	Multiple species	South America	Uruguay
90	Climate change	Leriorato, JC; Nakamu	Unpredictable extreme cold events: a threat to range-shifting tropical reef fishes in temperate waters	MARINE BIOLOGY	2019	Sample analysis	Fishery	Reef fish	Asia	Japan
91	Climate change	Litskas, VD; Migeon, A	Impacts of climate change on tomato, a notorious pest and its natural enemy: small scale agriculture at higher risk	ENVIRONMENTAL RESEARCH LETTERS	2019	Modelling	Crops Pests	Tomato Spider mite	Global	NA
92	Climate change	Rogers, LA; Griffin, R;	Shifting habitats expose fishing communities to risk under climate change	NATURE CLIMATE CHANGE	2019	Modelling	Fishery	Multiple species	North America	USA
93	Climate change	Cline, TJ; Ohlberger,	Effects of warming climate and competition in the ocean for life-histories of Pacific salmon	NATURE ECOLOGY & EVOLUTION	2019	Data analysis	Fishery	Salmon	North America	USA
94	Climate change	Erauskin-Extramiana,	Large-scale distribution of tuna species in a warming ocean	GLOBAL CHANGE BIOLOGY	2019	Modelling	Fishery	Tuna	Global	NA
95	Climate change	Nack, CC; Swaney, DP	Historical and Projected Changes in Spawning Phenologies of American Shad and Striped Bass in the Hudson River Estuary	MARINE AND COASTAL FISHERIES	2019	Data analysis	Fishery	American shad Bass	North America	USA
96	Climate change	Voss, R; Quaas, MF; St	Ecological-economic sustainability of the Baltic cod fisheries under ocean warming and acidification	JOURNAL OF ENVIRONMENTAL MANAGEMENT	2019	Data analysis	Fishery	Cod	Europe	Baltic sea
97	Climate change	Granco, G; Caldas, M;	Potential effects of climate change on Brazil's land use policy for renewable energy from sugarcane	RESOURCES CONSERVATION AND RECYCLING	2019	Modelling	Cash crops	Sugarcane	South America	Brazil
98	Climate change	Khan, M; Sakaram, S;	Detection of biochemical and molecular changes in Oryza sativa L during drought stress	BIOCATALYSIS AND AGRICULTURAL BIOTECHNOLOGY	2019	Experiment	Crops	Rice	Not specified	
99	Climate change	Free, CM; Thorson, JT	Impacts of historical warming on marine fisheries production	SCIENCE	2019	Modelling	Fishery	Multiple species	Global	NA

100	Climate change	Marushka, L; Kenny, T	Potential impacts of climate-related decline of seafood harvest on nutritional status of coastal First Nations in British Columbia, Canada	PLOS ONE	2019	Mixed-method	Fishery	Nutritional value	North America	Canada
101	Climate change	Champion, C; Hobday,	Changing windows of opportunity: past and future climate-driven shifts in temporal persistence of kingfish (Seriola lalandi) oceanographic habitat within south-eastern Australian bioregions	MARINE AND FRESHWATER RESEARCH	2019	Modelling	Recreational	Kingfish	Australia	Australia
102	Climate change	Lemasson, AJ; Hall-Sp	Changes in the biochemical and nutrient composition of seafood due to ocean acidification and warming	MARINE ENVIRONMENTAL RESEARCH	2019	Experiment	Fishery	Nutritional value oyster	Not specified	
103	Climate change	Mangano, MC; Giacole	Dynamic Energy Budget provides mechanistic derived quantities to implement the ecosystem based management approach	JOURNAL OF SEA RESEARCH	2019	Simulation	Fishery Aquaculture	Multiple species	Europe	Mediterranean Sea
104	Climate change	Boavida-Portugal, J; R	Climate change impacts on the distribution of coastal lobsters	MARINE BIOLOGY	2018	Modelling	Fishery	Lobster	Global	NA
105	Climate change	Pang, YM; Tian, YJ; Fu	Variability of coastal cephalopods in overexploited China Seas under climate change with implications on fisheries management	FISHERIES RESEARCH	2018	Modelling	Fishery	Cephalopods	Asia	China Sea
106	Climate change	Froehlich, HE; Gentry	Global change in marine aquaculture production potential under climate change	NATURE ECOLOGY & EVOLUTION	2018	Modelling	Aquaculture	Multiple species	Global	NA
107	Climate change	Jalali, A; Young, M; H	Modelling current and future abundances of benthic invertebrates using bathymetric LiDAR and oceanographic variables	FISHERIES OCEANOGRAPHY	2018	Modelling	Fishery	Benthic species	Australia	Australia
108	Climate change	Cheung, WWL; Oyinlol	Vulnerability of flatfish and their fisheries to climate change	JOURNAL OF SEA RESEARCH	2018	Modelling	Aquaculture	Flatfish	Global	NA
109	Climate change	Mangi, SC; Lee, J; Pin	The economic impacts of ocean acidification on shellfish fisheries and aquaculture in the United Kingdom	ENVIRONMENTAL SCIENCE & POLICY	2018	NPV and modelling	Fishery Aquaculture	Shellfish	Europe	UK
110	Climate change	Gateau-Rey, L; Tanne	Climate change could threaten cocoa production: Effects of 2015-16 El Nino-related drought on cocoa agroforests in Bahia, Brazil	PLOS ONE	2018	Experiment	Crops	Cocoa/ cash crops	South America	Brazil
111	Climate change	Kodis, M; Galante, P;	Ecological niche modeling for a cultivated plant species: a case study on taro (Colocasia esculenta) in Hawaii	ECOLOGICAL APPLICATIONS	2018	Modelling	Crops	Taro	North America	USA
112	Climate change	McGranahan, DA; Yurk	Variability in grass forage quality and quantity in response to elevated CO2 and water limitation	GRASS AND FORAGE SCIENCE	2018	Experiemnnet	Pasture	C3 grass	North America	USA
113	Climate change	Wang, B; Liu, D; O'Lea	Australian wheat production expected to decrease by the late 21st century	GLOBAL CHANGE BIOLOGY	2018	Modelling	Crops	Wheat	Australia	Australia
114	Climate change	Hussain, A; Rasul, G; M	Climate change-induced hazards and local adaptations in agriculture: a study from Koshi River Basin, Nepal	NATURAL HAZARDS	2018	Case study	Crops Livestocks	Multiple species	Asia	Nepal

115	Climate change	Khan, AH; Levac, E; V	The effect of global climate change on the future distribution of economically important macroalgae (seaweeds) in the northwest Atlantic	FACETS	2018	Modelling	Commercial seaweed		North America	USA
116	Climate change	Asch, RG; Cheung, WV	Future marine ecosystem drivers, biodiversity, and fisheries maximum catch potential in Pacific Island countries and territories under climate change	MARINE POLICY	2018	Modelling	Fishery	Multiple species	Australia	Pacific Islands
117	Climate change	Heider, K; Weinzierl,	Future agricultural conditions in the Nepal Himalaya - A fuzzy logic approach using high resolution climate scenarios	ERDE	2018	Spatial analysis and fuzzy logic approach	Crops	Maize, Potato, Rice, Wheat	Asia	Nepal
118	Climate change	Lopes, PFM; Pennino,	Climate change can reduce shrimp catches in equatorial Brazil	REGIONAL ENVIRONMENTAL CHANGE	2018	Modelling	Fishery	Shrimp	South America	Brazil
119	Climate change	Madeira, D; Araujo, JE	Molecular Plasticity under Ocean Warming: Proteomics and Fitness Data Provides Clues for a Better Understanding of the Thermal Tolerance in Fish	FRONTIERS IN PHYSIOLOGY	2017	Experiement	Fishery	Gilt-head sea bream	Not specified	
120	Climate change	Serpetti, N; Baudron,	Impact of ocean warming on sustainable fisheries management informs the Ecosystem Approach to Fisheries	SCIENTIFIC REPORTS	2017	Modelling	Fishery	Multiple species	Global	NA
121	Climate change	Klinger, DH; Levin, SA	The growth of finfish in global open-ocean aquaculture under climate change	PROCEEDINGS OF THE ROYAL SOCIETY B-BIOLOGICAL SCIENCES	2017	Modelling	Aquaculture	Multiple species	Global	NA
122	Climate change	Liu, SM; Wang, H; Yan	Crop Growth Characteristics and Waterlogging Risk Analysis of Huaibei Plain in Anhui Province, China	JOURNAL OF IRRIGATION AND DRAINAGE ENGINEERING	2017	Experiement	Crops	Soybean, Maize, Wheat	Asia	China
123	Climate change	Townhill, BL; van der	Consequences of climate-induced low oxygen conditions for commercially important fish	MARINE ECOLOGY PROGRESS SERIES	2017	Modelling	Fishery	Multiple species	Europe	North Sea
124	Climate change	Dasgupta, S; Huq, M; /	The Impact of Aquatic Salinization on Fish Habitats and Poor Communities in a Changing Climate: Evidence from Southwest Coastal Bangladesh	ECOLOGICAL ECONOMICS	2017	Data analysis	Fishery	Freshwater fish	Asia	Bangladesh
125	Climate change	Ramirez-Cabral, NYZ;	Global alterations in areas of suitability for maize production from climate change and using a mechanistic species distribution model (CLIMEX)	SCIENTIFIC REPORTS	2017	Modelling	Crops	Maize	Global	NA
126	Climate change	Langowska, A; Zawilak	Long-term effect of temperature on honey yield and honeybee phenology	INTERNATIONAL JOURNAL OF BIOMETEOROLOGY	2017	Data analysis	Other agriculture product	Honey	Europe	UK
127	Climate change	Fernandes, JA; Papath	Estimating the ecological, economic and social impacts of ocean acidification and warming on UK fisheries	FISH AND FISHERIES	2017	Modelling	Fishery	Multiple species	Europe	UK
128	Climate change	Raybaud, V; Bacha, M	Forecasting climate-driven changes in the geographical range of the European anchovy (Engraulis encrasicolus)	ICES JOURNAL OF MARINE SCIENCE	2017	Modelling	Fishery	Anchovy	Europe Africa	Multiple countries

129	Climate change	Kleisner, KM; Fogarty,	Marine species distribution shifts on the US Northeast Continental Shelf under continued ocean warming	PROGRESS IN OCEANOGRAPHY	2017	Modelling	Fishery	Multiple species	North America	USA
130	Climate change	Marshall, KN; Kaplan,	Risks of ocean acidification in the California Current food web and fisheries: ecosystem model projections	GLOBAL CHANGE BIOLOGY	2017	Ecosystem model	Fishery	Multiple species	North America	USA
131	Climate change	Woodworth-Jefcoats,	Climate change is projected to reduce carrying capacity and redistribute species richness in North Pacific pelagic marine ecosystems	GLOBAL CHANGE BIOLOGY	2017	Modelling	Fishery	Tuna and billfish	North America	North Pacific
132	Climate change	Mi, CR; Zu, Q; He, L; I	Climate change would enlarge suitable planting areas of sugarcanes in China	INTERNATIONAL JOURNAL OF PLANT PRODUCTION	2017	Modelling	Crops Cash Crops	Sugarcane	Asia	China
133	Climate change	Cheung, WWL; Reygor	Large benefits to marine fisheries of meeting the 1.5 degrees C global warming target	SCIENCE	2016	Modelling	Fishery	Multiple spcecies	Global	NA
134	Climate change	Yen, KW; Su, NJ; Teer	PREDICTING THE CATCH POTENTIAL OF SKIPJACK TUNA IN THE WESTERN AND CENTRAL PACIFIC OCEAN UNDER DIFFERENT CLIMATE CHANGE SCENARIOS	JOURNAL OF MARINE SCIENCE AND TECHNOLOGY-TAIWAN	2016	Modelling	Fishery	Skipjack tuna	Asia	West and Central Pacific
135	Climate change	van der Kooij, J; Enge	Climate change and squid range expansion in the North Sea	JOURNAL OF BIOGEOGRAPHY	2016	Data analysis	Fishery	Squid	Europe	North Sea
136	Climate change	Ranjitkar, S; Sujakhu,	Suitability Analysis and Projected Climate Change Impact on Banana and Coffee Production Zones in Nepal	PLOS ONE	2016	Modelling	Crops	Banana Coffee	Asia	Nepal
137	Climate change	Lam, VWY; Cheung, W	Projected change in global fisheries revenues under climate change	SCIENTIFIC REPORTS	2016	Modelling	Fishery	Multiple species	Global	NA
138	Climate change	Stiasny, MH; Mitterma	Ocean Acidification Effects on Atlantic Cod Larval Survival and Recruitment to the Fished Population	PLOS ONE	2016	Experiment	Aquaculture	Atlantic cod	Europe	Baltic Sea
139	Climate change	Madeira, D; Araujo, JE	Ocean warming alters cellular metabolism and induces mortality in fish early life stages: A proteomic approach	ENVIRONMENTAL RESEARCH	2016	Experiment	Fishery	Sea bream	Europe	Portugal
140	Climate change	Roehrdanz, PR; Hanna	Climate Change, California Wine, and Wildlife Habitat	JOURNAL OF WINE ECONOMICS	2016	Modelling	Cash crops	Grapevine	North America	USA
141	Climate change	Madeira, D; Vinagre, C	Are fish in hot water? Effects of warming on oxidative stress metabolism in the commercial species Sparus aurata	ECOLOGICAL INDICATORS	2016	Experiment	Fishery	Sea bream	Europe	Portugal
142	Climate change	Ramirez-Cabral, NYZ;	Crop niche modeling projects major shifts in common bean growing areas	AGRICULTURAL AND FOREST METEOROLOGY	2016	Modelling	Crops	Comon bean	Global	NA
143	Climate change	Hare, JA; Morrison, W	A Vulnerability Assessment of Fish and Invertebrates to Climate Change on the Northeast US Continental Shelf	PLOS ONE	2016	Vulnerability assessment	Fishery	Multiple species	North America	USA
144	Climate change	Chemura, A; Kutyway	Bioclimatic modelling of current and projected climatic suitability of coffee (Coffea arabica) production in Zimbabwe	REGIONAL ENVIRONMENTAL CHANGE	2016	Modelling	Cash crops	Coffee	Africa	Zimbabwe

145	Climate change	Johansen, JL; Pratche	Large predatory coral trout species unlikely to meet increasing energetic demands in a warming ocean	SCIENTIFIC REPORTS	2015	Experiment	Fishery	Trout	Not specified	
146	Climate change	Fortibuoni, T; Aldighie	Climate impact on Italian fisheries (Mediterranean Sea)	REGIONAL ENVIRONMENTAL CHANGE	2015	Data analysis	Fishery	Multiple species	Europe	Italy
147	Climate change	Rutterford, LA; Simps	Future fish distributions constrained by depth in warming seas	NATURE CLIMATE CHANGE	2015	Modelling	Fishery	Multiple species	Europe	North Sea
148	Climate change	Cooley, SR; Rheuban,	An Integrated Assessment Model for Helping the United States Sea Scallop (Placopecten magellanicus) Fishery Plan Ahead for Ocean Acidification and Warming	PLOS ONE	2015	Modelling	Fishery	Scallop	North America	USA
149	Climate change	Silva, C; Yanez, E; Bar	Forecasts of swordfish (Xiphias gladius) and common sardine (Strangomera bentincki) off Chile under the A2 IPCC climate change scenario	PROGRESS IN OCEANOGRAPHY	2015	Modelling	Fishery	Swordfish Sardine	South America	Chile
150	Climate change	Dell, JT; Wilcox, C; M	Potential impacts of climate change on the distribution of longline catches of yellowfin tuna (Thunnus albacares) in the Tasman sea	DEEP-SEA RESEARCH PART II-TOPICAL STUDIES IN OCEANOGRAPHY	2015	Modelling	Fishery	Tuna	Australia	Tasman Sea
151	Climate change	Gamito, R; Teixeira, C	Are regional fisheries' catches changing with climate?	FISHERIES RESEARCH	2015	Data analysis	Fishery	Multiple species	Europe	Portugal
152	Climate change	Gamito, R; Costa, MJ;	Fisheries in a warming ocean: trends in fish catches in the large marine ecosystems of the world	REGIONAL ENVIRONMENTAL CHANGE	2015	Data analysis	Fishery	Multiple species	Global	NA
153	Climate change	Monaco, E; Bonfante,	Climate change, effective water use for irrigation and adaptability of maize: A case study in southern Italy	BIOSYSTEMS ENGINEERING	2014	Simulation	Crops	Crops diversity	Europe	Italy
154	Climate change	Lan, KW; Lee, MA; Zha	Effects of climate variability and climate change on the fishing conditions for grey mullet (Mugil cephalus L.) in the Taiwan Strait	CLIMATIC CHANGE	2014	Data analysis	Fishery	Grey mullet	Asia	Taiwan
155	Climate change	Frommel, AY; Maneja,	Organ damage in Atlantic herring larvae as a result of ocean acidification	ECOLOGICAL APPLICATIONS	2014	Experiment	Fishery	Atlantic herring	Not specified	
156	Climate change	Jung, S; Pang, IC; Lee	Latitudinal shifts in the distribution of exploited fishes in Korean waters during the last 30 years: a consequence of climate change	REVIEWS IN FISH BIOLOGY AND FISHERIES	2014	Data analysis	Fishery	Multiple species	Asia	Korea
157	Climate change	Teixeira, CM; Gamito,	Trends in landings of fish species potentially affected by climate change in Portuguese fisheries	REGIONAL ENVIRONMENTAL CHANGE	2014	Data analysis	Fishery	Multiple species	Europe	Portugal
158	Climate change	Phelan, DC; Parsons, D	Beneficial impacts of climate change on pastoral and broadacre agriculture in cool-temperate Tasmania	CROP & PASTURE SCIENCE	2014	Modelling	Pasture	Mutiple species	Australia	Australia
159	Climate change	Thornton	climate variability and vulnerability to climate change: a review	GLOBAL CHANGE BIOLOGY	2014	Review	Crops Livestocks	Multiple species	Not specified	

160	Climate change	Su, NJ; Sun, CL; Punt,	An ensemble analysis to predict future habitats of striped marlin (Kajikia audax) in the North Pacific Ocean	ICES JOURNAL OF MARINE SCIENCE	2013	Modelling	Fishery	Striped malin	Asia North America	North Pacific
161	Climate change	Evangelista, P; Young,	How will climate change spatially affect agriculture production in Ethiopia? Case studies of important cereal crops	CLIMATIC CHANGE	2013	Case study	Crops	Cereal crops	Africa	Ethiopia
162	Climate change	Lehodey, P; Senina, I;	Modelling the impact of climate change on Pacific skipjack tuna population and fisheries	CLIMATIC CHANGE	2013	Modelling	Fishery	Skipjack tuna	Multiple	Pacific Ocean
163	Climate change	Cheung, WWL; Watson	Signature of ocean warming in global fisheries catch	NATURE	2013	MTC	Fishery	Multiple species	Global	NA
164	Climate change	Hannah, L; Roehrdanz	Climate change, wine, and conservation	PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF THE UNITED STATES OF AMERICA	2013	Modelling	Cash crops	Grapevine	Global	NA
165	Climate change	Beck, J	Predicting climate change effects on agriculture from ecological niche modeling: who profits, who loses?	CLIMATIC CHANGE	2013	Modelling	Crops	Multiple species	Global	NA
166	Climate change	Doubleday, ZA; Clarke	Assessing the risk of climate change to aquaculture: a case study from south-east Australia	AQUACULTURE ENVIRONMENT INTERACTIONS	2013	Risk assessment	Aquaculture	Multiple species	Australia	Australia
167	Climate change	Li, DX; Liu, HL; Qiao,	Physiological regulation of soybean (Glycine max L. Merr.) growth in response to drought under elevated CO2	JOURNAL OF FOOD AGRICULTURE & ENVIRONMENT	2013	Experiment	Crops	Soybean	Not specified	
168	Climate change	McGrath, JM; Lobell,	Regional disparities in the CO2 fertilization effect and implications for crop yields	ENVIRONMENTAL RESEARCH LETTERS	2013	Data analysis	Crops	Multiple species	Global	NA
169	Climate change	Russell, BD; Connell,	Predicting the Distribution of Commercially Important Invertebrate Stocks under Future Climate	PLOS ONE	2012	Modelling	Fishery	Invertebrate species	Australia	Australia
170	Climate change	Kumar, SV; Lucyshyn,	Transcription factor PIF4 controls the thermosensory activation of flowering	NATURE	2012	Experiment	Crops	Flowering time	Not specified	
171	Climate change	Richards, RA; Fogarty,	Climate change and northern shrimp recruitment variability in the Gulf of Maine	MARINE ECOLOGY PROGRESS SERIES	2012	Data analysis	Fishery	Shrimp	North America	USA
172	Climate change	Vinagre, C; Santos, FD	Impact of climate warming upon the fish assemblages of the Portuguese coast under different scenarios	REGIONAL ENVIRONMENTAL CHANGE	2011	Data analysis	Fishery	Multiple species	Europe	Portugal
173	Climate change	Simpson, SD; Jennings	Continental Shelf-Wide Response of a Fish Assemblage to Rapid Warming of the Sea	CURRENT BIOLOGY	2011	Data analysis	Fishery	Multiple species	Europe	North Sea
174	Climate change	Abdul-Aziz, OI; Mantu	Potential climate change impacts on thermal habitats of Pacific salmon (Oncorhynchus spp.) in the North Pacific Ocean and adjacent seas	CANADIAN JOURNAL OF FISHERIES AND AQUATIC SCIENCES	2011	Modelling	Fishery	Salmon	North America	North Pacific
175	Climate change	Muhling, BA; Lee, SK;	Predicting the effects of climate change on bluefin tuna (Thunnus thynnus) spawning habitat in the Gulf of Mexico	ICES JOURNAL OF MARINE SCIENCE	2011	Modelling	Fishery	Bluefin tuna	North America	Gulf of Mexico
176	Climate change	Su, NJ; Sun, CL; Punt,	Modelling the impacts of environmental variation on the distribution of blue marlin, Makaira nigricans, in the Pacific Ocean	ICES JOURNAL OF MARINE SCIENCE	2011	Modelling	Fishery	Blue marlin	Asia America	Pacific

177	Climate change	Valiente, AG; Juanes,	Increasing Regional Temperatures Associated with Delays in Atlantic Salmon Sea-Run Timing at the Southern Edge of the European Distribution	TRANSACTIONS OF THE AMERICAN FISHERIES SOCIETY	2011	Data analysis	Fishery	Salmon	Europe	South Europe rivers
178	Climate change	Elliott, JM; Elliott, JA	Temperature requirements of Atlantic salmon Salmo salar, brown trout Salmo trutta and Arctic charr Salvelinus alpinus: predicting the effects of climate change	JOURNAL OF FISH BIOLOGY	2010	Modelling	Fishery	Salmon Artic charr	Europe	UK
179	Climate change	Thorsen, SM; Hoglind,	Assessing winter survival of forage grasses in Norway under future climate scenarios by simulating potential frost tolerance in combination with simple agroclimatic indices	AGRICULTURAL AND FOREST METEOROLOGY	2010	Modelling	Pasture	Multiple species	Europe	Norway
180	Climate change	DaMatta, FM; Grandis,	Impacts of climate changes on crop physiology and food quality	FOOD RESEARCH INTERNATIONAL	2010	Review	Crops	Multiple species	Not specified	
181	Climate change	Winfield, IJ; Hateley,	Population trends of Arctic charr (Salvelinus alpinus) in the UK: assessing the evidence for a widespread decline in response to climate change	HYDROBIOLOGIA	2010	Data analysis	Fishery	Artic charr	Europe	UK
182	Climate change	Hsieh, CH; Kim, HJ; W	Climate-driven changes in abundance and distribution of larvae of oceanic fishes in the southern California region	GLOBAL CHANGE BIOLOGY	2009	Data analysis	Fishery	Multiple species	North America	USA
183	Climate change	Kirby, RR; Beaugrand,	Synergistic Effects of Climate and Fishing in a Marine Ecosystem	ECOSYSTEMS	2009	Data analysis	Fishery	Multiple species	Europe	North Sea
184	Climate change	Dulvy, NK; Rogers, SI;	Climate change and deepening of the North Sea fish assemblage: a biotic indicator of warming seas	JOURNAL OF APPLIED ECOLOGY	2008	Data analysis	Fishery	Multiple species	Europe	North Sea
185	Climate change	Brassard, JP; Singh, B	Impacts of climate change and CO2 increase on agricultural production and adaptation options for Southern Quebec, Canada	MITIGATION AND ADAPTATION STRATEGIES FOR GLOBAL CHANGE	2008	Modelling	Crops	Multiple species	North America	Canada
186	Climate change	Eide, A	An integrated study of economic effects of and vulnerabilities to global warming on the Barents Sea cod fisheries	CLIMATIC CHANGE	2008	Modelling	Fishery	Cod	Europe	Barents Sea
187	Climate change	Mueter, FJ; Litzow, M	Sea ice retreat alters the biogeography of the Bering Sea continental shelf	ECOLOGICAL APPLICATIONS	2008	Modelling	Fishery	Artic species	North America	Bering Sea
188	Climate change	Cheung, WWL; Close,	Application of macroecological theory to predict effects of climate change on global fisheries potential	MARINE ECOLOGY PROGRESS SERIES	2008	Modelling	Fishery	Multiple species	Global	NA
189	Climate change	Thresher, RE; Koslow,	Depth-mediated reversal of the effects of climate change on long-term growth rates of exploited marine fish	PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF THE UNITED STATES OF AMERICA	2007	Sample analysis	Fishery	Multiple species	Australia	Southwest Pacific
190	Climate change	Meynecke, JO; Lee, S\	Effect of rainfall as a component of climate change on estuarine fish production in Queensland, Australia	ESTUARINE COASTAL AND SHELF SCIENCE	2006	Modelling	Fishery	Estuarine fish	Australia	Australia
191	Climate change	Perry, AL; Low, PJ; El	Climate change and distribution shifts in marine fishes	SCIENCE	2005	Data analysis	Fishery	Demersal fish	Europe	North Sea

192	Climate change	Vilchis, LI; Tegner, MJ	Ocean warming effects on growth, reproduction, and survivorship of Southern California abalone	ECOLOGICAL APPLICATIONS	2005	Experiment	Fishery	Abalone	North America	USA
193	Climate change	Schulze, RE; Kunz, RP	Potential shifts in optimum growth areas of selected commercial tree species and subtropical crops in southern Africa due to global warming	JOURNAL OF BIOGEOGRAPHY	1995	Case study	Fruit	Multiple species	Africa	
194	Climate change	MURAWSKI, SA	CLIMATE-CHANGE AND MARINE FISH DISTRIBUTIONS - FORECASTING FROM HISTORICAL ANALOGY	AGRONOMY JOURNAL	1993	Data analysis	Fishery	Atlantic herring Atlantic mackerel	North America	USA
195	Climate change	SINCLAIR, TR; RAWLIN	INTER-SEASONAL VARIATION IN SOYBEAN AND MAIZE YIELDS UNDER GLOBAL ENVIRONMENTAL-CHANGE	FOOD RESEARCH INTERNATIONAL	1993	Modelling	Crops	Soybean Maize	North America	USA
196	Climate change	MINNS, CK; MOORE, JE	PREDICTING THE IMPACT OF CLIMATE CHANGE ON THE SPATIAL PATTERN OF FRESH-WATER FISH YIELD CAPABILITY IN EASTERN CANADIAN LAKES	NORTHWEST ENVIRONMENTAL JOURNAL	1992	Modelling	Fishery	Freshwater fish	North America	Canada
197	Climate/Bio	Liu, SH; Tian, YJ; Liu,	Development of a prey-predator species distribution model for a large piscivorous fish: A case study for Japanese Spanish mackerel Scomberomorus niphonius and Japanese anchovy Engraulis japonicus	DEEP-SEA RESEARCH PART II-TOPICAL STUDIES IN OCEANOGRAPHY	2023	Modelling	Fishery	Mackerel and anchovy	Asia	Japan
198	Climate/Bio	Li, DX; Li, ZX; Liu, ZW	Climate change simulations revealed potentially drastic shifts in insect community structure and crop yields in China's farmland	JOURNAL OF PEST SCIENCE	2023	Modelling	Pests	Aphids vs natural enemies, crop yield	Asia	China
199	Climate/Bio	Kim, H; Kang, H; Zhan	Ecosystem-based fisheries risk assessment and forecasting considering a spatio-temporal component in Korean waters	OCEAN & COASTAL MANAGEMENT	2022	Extended IFRAME	Fishery	Mackerel	Asia	Korean Sea
200	Climate/Bio	Mugiyo, H; Chimonyo,	Mapping the spatial distribution of underutilised crop species under climate change using the MaxEnt model: A case of KwaZulu-Natal, South Africa	CLIMATE SERVICES	2022	Modelling	Crops	Underutilised crops	Africa	South Africa
201	Climate/Bio	Bang, M; Sohn, D; Kim	Future changes in the seasonal habitat suitability for anchovy (Engraulis japonicus) in Korean waters projected by a maximum entropy model	FRONTIERS IN MARINE SCIENCE	2022	Modelling	Fishery	Anchovy	Asia	Korea
202	Climate/Bio	Cai, CN; Xiao, JH; Wa	Implications of climate change for environmental niche overlap between five Cuscuta pest species and their two main Leguminosae host crop species	WEED SCIENCE	2022	Modelling	Pests	Cucusta and leguminosae host	Global	NA
203	Climate/Bio	Lima, ARA; Garrido, S	Seasonal approach to forecast the suitability of spawning habitats of a temperate small pelagic fish under a high-emission climate change scenario	FRONTIERS IN MARINE SCIENCE	2022	Modelling	Fishery	Pelagic fish	Europe	Atlantic and Mediterranean sea

204	Climate/Bio	Chemura, A; Kutyway	Climate change and cocoyam (Colocasia esculenta (L.) Schott) production: assessing impacts and potential adaptation strategies in Zimbabwe	MITIGATION AND ADAPTATION STRATEGIES FOR GLOBAL CHANGE	2022	Modelling	Crops	Cocoyam - underutilised	Africa	Zimbabwe
205	Climate/Bio	Duque, TS; da Silva, R	Potential Distribution of and Sensitivity Analysis for Urochloa panicoides Weed Using Modeling: An Implication of Invasion Risk Analysis for China and Europe	PLANTS-BASEL	2022	Modelling	Pests	Harmful weed Urochloa panicoides	Europe Asia	China and EU countries
206	Climate/Bio	Ben Lamine, E; Schick	Expected contraction in the distribution ranges of demersal fish of high economic value in the Mediterranean and European Seas	SCIENTIFIC REPORTS	2022	Modelling	Fishery Aquaculture	Demersal fish	Europe	Mediterranean
207	Climate/Bio	Heming, NM; Schroth,	Cabruca agroforestry systems reduce vulnerability of cacao plantations to climate change in southern Bahia	AGRONOMY FOR SUSTAINABLE DEVELOPMENT	2022	Modelling	Agroforestry	Trees and cacao	South America	Brazil
208	Climate/Bio	Li, DX; Li, ZX; Wang, X	Increasing risk of aphids spreading plant viruses in maize fields on both sides of China's Heihe-Tengchong line under climate change	PEST MANAGEMENT SCIENCE	2022	Modelling	Pests	aphids	Asia	China
209	Climate/Bio	Outhwaite, CL; McCan	Agriculture and climate change are reshaping insect biodiversity worldwide	NATURE	2022	Data analysis	Pollination Pest control	Multiple species	Global	NA
210	Climate/Bio	Fumia, N; Pironon, S;	Wild relatives of potato may bolster its adaptation to new niches under future climate scenarios	FOOD AND ENERGY SECURITY	2022	Modelling	Crops	Wild potato relatives	Global	NA
211	Climate/Bio	Baez, JC; Pennino, MG	Effects of environmental conditions and jellyfish blooms on small pelagic fish and fisheries from the Western Mediterranean Sea	ESTUARINE COASTAL AND SHELF SCIENCE	2022	Modelling	Fishery Invasive species	Fish and jelly fish bloom	Europe	Mediterranean sea
212	Climate/Bio	Koch, O; Mengesha, W	Modelling potential range expansion of an underutilised food security crop in Sub-Saharan Africa	ENVIRONMENTAL RESEARCH LETTERS	2022	Modelling	Crops	Enset - underrutilised crop	Africa	Sub-Saharan Africa
213	Climate/Bio	Zhang, NN; Liao, ZY; V	Impact of climate change on wheat security through an alternate host of stripe rust	FOOD AND ENERGY SECURITY	2022	Modelling	Pests	Alternate host of stripe rust	Asia	China
214	Climate/Bio	Boyce, DG; Petrie, B;	Fishing, predation, and temperature drive herring decline in a large marine ecosystem	ECOLOGY AND EVOLUTION	2021	Data analysis	Fishery	Herring	North America	Canada north Atlantic sea
215	Climate/Bio	Kamaruzzaman, YN; M	Impacts of Sea Temperature Rise on Rastrelliger kanagurta Potential Fishing Grounds in the Exclusive Economic Zone (EEZ) off South China Sea	SAINS MALAYSIANA	2021	Modelling	Fishery	Indian mackerel	Asia	Malaysia
216	Climate/Bio	Guan, JY; Li, MY; Ju, J	The potential habitat of desert locusts is contracting: predictions under climate change scenarios	PEERJ	2021	Modelling	Pests	Locust	Africa Asia	Multiple countries
217	Climate/Bio	Holland, OJ; Young, M	Ocean warming threatens key trophic interactions supporting a commercial fishery in a climate change hotspot	GLOBAL CHANGE BIOLOGY	2021	Sample analysis	Fishery	Blacklip Abalone	Australia	Australia

218	Climate/Bio	Fiechter, J; Buil, MP;	Projected Shifts in 21st Century Sardine Distribution and Catch in the California Current	FRONTIERS IN MARINE SCIENCE	2021	Modelling	Fishery	Sardine	North America	USA
219	Climate/Bio	Hone, H; Mann, R; Yar	Profiling, isolation and characterisation of beneficial microbes from the seed microbiomes of drought tolerant wheat	SCIENTIFIC REPORTS	2021	Experiment	Crops Soil biota	Wheat, microbiomes	Not specified	
220	Climate/Bio	Wessels, C; Merow, C;	Climate change risk to southern African wild food plants	REGIONAL ENVIRONMENTAL CHANGE	2021	Modelling	Crops	Wild crop relatives	Africa	South Africa
221	Climate/Bio	Ceccarelli, V; Fremou	Climate change impact on cultivated and wild cacao in Peru and the search of climate change-tolerant genotypes	DIVERSITY AND DISTRIBUTIONS	2021	Modelling	Crops	Wild cacao	South America	Peru
222	Climate/Bio	Gomes, H; Kersulec, C	The Major Roles of Climate Warming and Ecological Competition in the Small-scale Coastal Fishery in French Guiana	ENVIRONMENTAL MODELING & ASSESSMENT	2021	Modelling	Fishery	Multiple species	South America	French Guiana
223	Climate/Bio	Gonzalez, VH; Cobos,	Climate change will reduce the potential distribution ranges of Colombia's most valuable pollinators	PERSPECTIVES IN ECOLOGY AND CONSERVATION	2021	Modelling	Pollination		South America	Colombian
224	Climate/Bio	Kariyawasam, CS; Kun	Potential risks of invasive alien plant species on agriculture under climate change scenarios in Sri Lanka	CURRENT RESEARCH IN ENVIRONMENTAL SUSTAINABILITY	2021	Modelling	Pests	Invasive alient plant	Asia	Sri Lanka
225	Climate/Bio	Dippold, DA; Aloysius,	Forecasting the combined effects of anticipated climate change and agricultural conservation practices on fish recruitment dynamics in Lake Erie	FRESHWATER BIOLOGY	2020	Modelling	Fishery	Freshwater fish	North America	USA
226	Climate/Bio	Grunig, M; Mazzi, D; C	Crop and forest pest metawebs shift towards increased linkage and suitability overlap under climate change	COMMUNICATIONS BIOLOGY	2020	Metaweb approach	Pests	Agricultural pests	Europe	Multiple countries
227	Climate/Bio	Zacarias, DA	Global bioclimatic suitability for the fall armyworm, Spodoptera frugiperda (Lepidoptera: Noctuidae), and potential co-occurrence with major host crops under climate change scenarios	CLIMATIC CHANGE	2020	Modelling	Pests	fall anyworm	Global	NA
228	Climate/Bio	Morato, T; Gonzalez-I	Climate-induced changes in the suitable habitat of cold-water corals and commercially important deep-sea fishes in the North Atlantic	GLOBAL CHANGE BIOLOGY	2020	Modelling	Fishery	Deep sea fish	Europe	North Atlantic
229	Climate/Bio	Cowie, BW; Venter, N	Implications of elevated carbon dioxide on the susceptibility of the globally invasive weed, Parthenium hysterophorus, to glyphosate herbicide	PEST MANAGEMENT SCIENCE	2020	Experiment	Pests	Invasive weed	Not specified	
230	Climate/Bio	Sudo, K; Watanabe, K;	Predictions of kelp distribution shifts along the northern coast of Japan	ECOLOGICAL RESEARCH	2020	Modelling	Fishery	Kelp forest	Asia	Japan
231	Climate/Bio	Bauer, B; Gustafsson,	Food web and fisheries in the future Baltic Sea	AMBIO	2019	Simulation	Fishery	Multiple species	Europe	Baltic sea
232	Climate/Bio	Rogers-Bennett, L; Ca	Marine heat wave and multiple stressors tip bull kelp forest to sea urchin barrens	SCIENTIFIC REPORTS	2019	Case study	Kelp Fisheries		North America	USA

233	Climate/Bio	Santana, PA; Kumar, L	Global geographic distribution of Tuta absoluta as affected by climate change	JOURNAL OF PEST SCIENCE	2019	Modelling	Pests	Tomato pinworm	Global	NA
234	Climate/Bio	Qin, YJ; Wang, C; Zha	Climate change impacts on the global potential geographical distribution of the agricultural invasive pest, Bactrocera dorsalis (Hendel) (Diptera: Tephritidae)	CLIMATIC CHANGE	2019	Modelling	Pests	Oriental fruit fly	Global	NA
235	Climate/Bio	Silva, C; Leiva, F; Last	Predicting the current and future suitable habitat distributions of the anchovy (Engraulis ringens) using the Maxent model in the coastal areas off central-northern Chile	FISHERIES OCEANOGRAPHY	2019	Modelling	Fishery	Anchovy	South America	Chile
236	Climate/Bio	Tian, BL; Yu, ZZ; Pei,	Elevated temperature reduces wheat grain yield by increasing pests and decreasing soil mutualists	PEST MANAGEMENT SCIENCE	2019	Experiment	Crops Pests	Wheat, pests	Asia	China
237	Climate/Bio	St-Marseille, AFG; Bou	Simulating the impacts of climate change on soybean cyst nematode and the distribution of soybean	AGRICULTURAL AND FOREST METEOROLOGY	2019	Modelling	Pests	Soybean Cyst nematode	North America	Canada
238	Climate/Bio	Ramirez-Cabral, NYZ;	Suitable areas of Phakopsora pachyrhizi, Spodoptera exigua, and their host plant Phaseolus vulgaris are projected to reduce and shift due to climate change	THEORETICAL AND APPLIED CLIMATOLOGY	2019	Modelling	Pests	Potato bettle Yellow rust	Global	NA
239	Climate/Bio	Derocles, SAP; Lunt, D	Climate warming alters the structure of farmland tritrophic ecological networks and reduces crop yield	MOLECULAR ECOLOGY	2018	Experiment	Crops Pests	Wheat Aphid	Not specified	
240	Climate/Bio	Yang, YB; Liu, G; Shi,	Where will Invasive Plants Colonize in Response to Climate Change: Predicting the Invasion of Galinsoga quadriradiata in China	INTERNATIONAL JOURNAL OF ENVIRONMENTAL RESEARCH	2018	Modelling	Pests	Invasive plant Galinsoga quadriradiata	Asia	China
241	Climate/Bio	Mori, E; Sforzi, A; Bog	Range expansion and redefinition of a crop-raiding rodent associated with global warming and temperature increase	CLIMATIC CHANGE	2018	Modelling	Pests	Rodent	Europe	Italy
242	Climate/Bio	Milicic, M; Vujic, A; C	Effects of climate change on the distribution of hoverfly species (Diptera: Syrphidae) in Southeast Europe	BIODIVERSITY AND CONSERVATION	2018	Modelling	Pollination	Hoverfly	Europe	South East Europe
243	Climate/Bio	Macedo, R; Sales, LP;	Potential worldwide distribution of Fusarium dry root rot in common beans based on the optimal environment for disease occurrence	PLOS ONE	2017	Modelling	Crops Pests	Common bean Root rot		
244	Climate/Bio	Phillips, J; Brehm, JM	Climate change and national crop wild relative conservation planning	AMBIO	2017	Data collection	Crops	Crop wild relatives	Europe	Norway
245	Climate/Bio	Imbach, P; Fung, E; H	Coupling of pollination services and coffee suitability under climate change	PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF THE UNITED STATES OF AMERICA	2017	Modelling	Crops Pollination	Coffee, Pollination	South America	Multiple countries
246	Climate/Bio	Biswas, SR; Vogt, RJ; S	Projected compositional shifts and loss of ecosystem services in freshwater fish communities under climate change scenarios	HYDROBIOLOGIA	2017	Modelling	Fishery	Freshwater fish	North America	Canada

247	Climate/Bio	Giannini, TC; Costa, W	Projected climate change threatens pollinators and crop production in Brazil	PLOS ONE	2017	Modelling	Crops Pollination	Multiple species	South America	Brazil
248	Climate/Bio	Mason, NWH; Palmer,	Combining field experiments and predictive models to assess potential for increased plant diversity to climate-proof intensive agriculture	ECOLOGY AND EVOLUTION	2017	Experiement	Crops	Crops diversity	Australia	New Zealand
249	Climate/Bio	Yan, YW; Wang, YC; F	Potential distributional changes of invasive crop pest species associated with global climate change	APPLIED GEOGRAPHY	2017	Modelling	Pests	Multiple species	Global	NA
250	Climate/Bio	da Silva, RS; Kumar, L	Potential risk levels of invasive Neoleucinodes elegantalis (small tomato borer) in areas optimal for open-field Solanum lycopersicum (tomato) cultivation in the present and under predicted climate change	PEST MANAGEMENT SCIENCE	2017	Modelling	Pests	Tomato borer	Global	NA
251	Climate/Bio	Charlier, J; Ghebretin	Climate-driven longitudinal trends in pasture-borne helminth infections of dairy cattle	INTERNATIONAL JOURNAL FOR PARASITOLOGY	2016	Data analysis	Livestock	Pathogen	Europe	Multiple countries
252	Climate/Bio	Silva, C; Andrade, I; Y	Predicting habitat suitability and geographic distribution of anchovy (Engraulis ringens) due to climate change in the coastal areas off Chile	PROGRESS IN OCEANOGRAPHY	2016	Modelling	Fishery	Anchovy	South America	Chile
253	Climate/Bio	Duffy, JE; Lefcheck, J	Biodiversity enhances reef fish biomass and resistance to climate change	PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF THE UNITED STATES OF AMERICA	2016	Data analysis	Fishery	Reef fish	Global	NA
254	Climate/Bio	Hill, MP; Bertelsmeier	Predicted decrease in global climate suitability masks regional complexity of invasive fruit fly species response to climate change	BIOLOGICAL INVASIONS	2016	Modelling	Pests	Fruit fly	Global	NA
255	Climate/Bio	Christiansen, JS; Spar	Thermal behaviour and the prospect spread of an invasive benthic top predator onto the Euro-Arctic shelves	DIVERSITY AND DISTRIBUTIONS	2015	Experiment	Invasive speci	Red king crab	Europe	Multiple countries
256	Climate/Bio	Gethings, OJ; Rose, H	Asynchrony in host and parasite phenology may decrease disease risk in livestock under climate warming: Nematodirus battus in lambs as a case study	PARASITOLOGY	2015	Modelling	Pests Livestock	Lamb Nematode	Europe	UK
257	Climate/Bio	Wilson, MJ; Digweed,	Invasive slug pests and their parasites-temperature responses and potential implications of climate change	BIOLOGY AND FERTILITY OF SOILS	2015	Experiment	Pests	Slugs	Europe	UK
258	Climate/Bio	Hinojosa, IA; Green, B	Settlement and early survival of southern rock lobster, Jasus edwardsii, under climate-driven decline of kelp habitats	ICES JOURNAL OF MARINE SCIENCE	2015	Experiment	Fishery Underwater biodivesity	Rock lobster Kelp	Australia	Australia
259	Climate/Bio	Rose, H; Wang, T; van	GLOWORM-FL: A simulation model of the effects of climate and climate change on the free-living stages of gastro-intestinal nematode parasites of ruminants	ECOLOGICAL MODELLING	2015	Modelling	Livestock Pests	Livestock Nematode	Europe	UK

260	Climate/Bio	Alva-Basurto, JC; Aria	Modelling the effects of climate change on a Caribbean coral reef food web	ECOLOGICAL MODELLING	2014	Modelling	Coral		North America	Caribbean Sea
261	Climate/Bio	Polce, C; Garratt, MP;	Climate-driven spatial mismatches between British orchards and their pollinators: increased risks of pollination deficits	GLOBAL CHANGE BIOLOGY	2014	Modelling	Fruit Pollination	Orchards and pollination	Europe	UK
262	Climate/Bio	Eickerman, M; Beyer,	Shifted migration of the rape stem weevil Ceutorhynchus napi (Coleoptera: Curculionidae) linked to climate change	EUROPEAN JOURNAL OF ENTOMOLOGY	2014	Modelling	Pest	Rape stem weevil	Europe	Luxembourg
263	Climate/Bio	Hill, SL; Phillips, T; At	Potential Climate Change Effects on the Habitat of Antarctic Krill in the Weddell Quadrant of the Southern Ocean	PLOS ONE	2013	Modelling	Fishery	Krill	Australia	Southern Ocean
264	Climate/Bio	Giannini, TC; Acosta,	Identifying the areas to preserve passion fruit pollination service in Brazilian Tropical Savannas under climate change	AGRICULTURE ECOSYSTEMS & ENVIRONMENT	2013	Modelling	Fruit Pollination	Passion fruit	South America	Brazil
265	Climate/Bio	Giannini, TC; Acosta,	Pollination services at risk: Bee habitats will decrease owing to climate change in Brazil	ECOLOGICAL MODELLING	2012	Modelling	Pollination		South America	Brazil
266	Climate/Bio	Civantos, E; Thuiller,	Potential Impacts of Climate Change on Ecosystem Services in Europe: The Case of Pest Control by Vertebrates	BIOSCIENCE	2012	Modelling	Natural pest c	Multiple species	Europe	Multiple countries
267	Climate/Bio	Ureta, C; Martinez-Me	Projecting the effects of climate change on the distribution of maize races and their wild relatives in Mexico	GLOBAL CHANGE BIOLOGY	2012	Modelling	Crops	Maize Maize wild relatives	North America	Mexico
268	Climate/Bio	Aragon, P; Lobo, JM	Predicted effect of climate change on the invasibility and distribution of the Western corn root-worm	AGRICULTURAL AND FOREST ENTOMOLOGY	2012	Modelling	Pests	Corn root-worm	Europe North America Asia	Northern Hemisphere countries
269	Climate/Bio	Jaramillo, J; Muchugu	Some Like It Hot: The Influence and Implications of Climate Change on Coffee Berry Borer (Hypothenemus hampei) and Coffee Production in East Africa	PLOS ONE	2011	Modelling	Pests	Coffee berry borer	Africa	East Africa countries
270	Climate/Bio	Ainsworth, CH; Samho	Potential impacts of climate change on Northeast Pacific marine foodwebs and fisheries	ICES JOURNAL OF MARINE SCIENCE	2011	Simulation	Fishery	Multiple species	North America	North Pacific
271	Climate/Bio	Cheung, WWL; Dunne,	Integrating ecophysiology and plankton dynamics into projected maximum fisheries catch potential under climate change in the Northeast Atlantic	ICES JOURNAL OF MARINE SCIENCE	2011	Modelling	Underwater biodiversity		Europe	Northest Atlantic
272	Climate/Bio	Trnka, M; Muska, F; Se	European Corn Borer life stage model: Regional estimates of pest development and spatial distribution under present and future climate	ECOLOGICAL MODELLING	2007	Modelling	Pests	Corn borer	Europe	Austria
273	Climate/Bio	Beukema, JJ; Dekker,	Decline of recruitment success in cockles and other bivalves in the Wadden Sea: possible role of climate change, predation on postlarvae and fisheries	MARINE ECOLOGY PROGRESS SERIES	2005	Data analysis	Fishery	Cockles Other bivalves	Europe	Wadden sea
274	Climate/Bio	Beaugrand, G; Reid, P	Long-term changes in phytoplankton, zooplankton and salmon related to climate	GLOBAL CHANGE BIOLOGY	2003	Data analysis	Fishery Underwater biodivesity	Salmon	Europe	North Atlantic

275	Biodiversity	Komatsu, KJ; Esch, NL	Rhizobial diversity impacts soybean resistance, but not tolerance, to herbivory during drought	BASIC AND APPLIED ECOLOGY	2023	Experiement	Crops	Rhizonial and soybean	Not specified	NA
276	Biodiversity	Krusinski, L; Maciel, I(	Evaluation of fatty acid and antioxidant variation in a complex pasture system as compared to standard cattle feed in the Great Lakes region	FRONTIERS IN SUSTAINABLE FOOD SYSTEMS	2022	Experiement	Livestock, pas	Cattle	North America	USA
277	Biodiversity	Lorenzetti, E; Carlesi,	Mixtures of Commercial Lentil Cultivars Show Inconsistent Results on Agronomic Parameters but Positive Effects on Yield Stability	AGRONOMY-BASEL	2022	Experiment	Crops	Lentil	Not specified	
278	Biodiversity	Xiao, H; van Es, HM; C	Crop Rotational Diversity Influences Wheat-Maize Production Through Soil Legacy Effects in the North China Plain	INTERNATIONAL JOURNAL OF PLANT PRODUCTION	2022	Experiment	Crops	Wheat maize	Asia	China
279	Biodiversity	McGuigan, A; Ticktin,	Post-cyclone resilience of an agroforest-based food system in the Pacific Islands	REGIONAL ENVIRONMENTAL CHANGE	2022	Case study	Agroforestry		Australia	Pacific Islands
280	Biodiversity	Coghlan, C; Bhagwat,	Geographical patterns in food availability from pollinator-dependent crops: Towards a Pollinator Threat Index of food security	GLOBAL FOOD SECURITY-AGRICULTURE POLICY ECONOMICS AND ENVIRONMENT	2022	Scenario analysis	Pollination	Pollination	Global	NA
281	Biodiversity	Dardonville, M; Bockst	Resilience of agricultural systems: biodiversity-based systems are stable, while intensified ones are resistant and high-yielding	AGRICULTURAL SYSTEMS	2022	Data analysis	Crops	Multiple species	Europe	France
282	Biodiversity	Balasubramanian, M	Forest ecosystem services contribution to food security of vulnerable group: a case study from India	ENVIRONMENTAL MONITORING AND ASSESSMENT	2021	Case study	Forest provisioning		Asia	India
283	Biodiversity	Egli, L; Schroter, M; S	Crop diversity effects on temporal agricultural production stability across European regions	REGIONAL ENVIRONMENTAL CHANGE	2021	Data analysis	Crops	Crop diversity	Europe	Multiple countries
284	Biodiversity	Montoya, D; Haegema	Habitat fragmentation and food security in crop pollination systems	JOURNAL OF ECOLOGY	2021	Modelling	Pollination		Not specified	
285	Biodiversity	Azizi, M; Fard, EM; Gh	Piriformospora indica affect drought tolerance by regulation of genes expression and some morphophysiological parameters in tomato (Solanum lycopersicum L.)	SCIENTIA HORTICULTURAE	2021	Experiment	Crops Soil Biota	Tomato, endophytic fungi P. indica	Not specified	
286	Biodiversity	Brunetti, C; Saleem, A	Effects of plant growth-promoting rhizobacteria strains producing ACC deaminase on photosynthesis, isoprene emission, ethylene formation and growth of Mucuna pruriens (L.) DC. in response to water deficit	JOURNAL OF BIOTECHNOLOGY	2021	Experiment	Crops Soil biota	Velvet bean, rhizobacteria strains	Not specified	
287	Biodiversity	Nunes, PAD; Laca, EA;	Livestock integration into soybean systems improves long-term system stability and profits without compromising crop yields	SCIENTIFIC REPORTS	2021	Experiment	Crop and lives	Soybean, pasture, livestock	South America	Brazil

288	Biodiversity	Blaser-Hart, WJ; Hart, SP; Oppong, J; Kyereh, D; Yeboah, E; Six, J	The effectiveness of cocoa agroforests depends on shade-tree canopy height	AGRICULTURE ECOSYSTEMS & ENVIRONMENT	2021	Field study	Agroforestry	Cocoa and shade trees	Africa	Ghana
289	Biodiversity	Marini, L; St-Martin, A	Crop rotations sustain cereal yields under a changing climate	ENVIRONMENTAL RESEARCH LETTERS	2020	Experiment	Crops	Cereal crops	Not specified	
290	Biodiversity	Bozzola, M; Smale, M	The welfare effects of crop biodiversity as an adaptation to climate shocks in Kenya	WORLD DEVELOPMENT	2020	Case study	Crops	Multiple species	Africa	Kenya
291	Biodiversity	Rodriguez-San Pedro,	Quantifying ecological and economic value of pest control services provided by bats in a vineyard landscape of central Chile	AGRICULTURE ECOSYSTEMS & ENVIRONMENT	2020	Natural pest control	Cash crops	Vineyard, bat	South America	Chile
292	Biodiversity	Diaz-Gonzalez, S; Mar	Mutualistic Fungal Endophyte Colletotrichum tofieldiae Ct0861 Colonizes and Increases Growth and Yield of Maize and Tomato Plants	AGRONOMY-BASEL	2020	Experiment	Crops Soil biota	Fungal endophyte, Tomato, Maize	Not specified	
293	Biodiversity	Kozicka, M; Gotor, E;	Responding to future regime shifts with agrobiodiversity: A multi-level perspective on small-scale farming in Uganda	AGRICULTURAL SYSTEMS	2020	Case study	Crops	Crop diversity	Africa	Uganda
294	Biodiversity	Fulton, CJ; Berkstrom	Macroalgal meadow habitats support fish and fisheries in diverse tropical seascapes	FISH AND FISHERIES	2020	Review	Macroalgae		Global	NA
295	Biodiversity	Nyong, AP; Ngankam,	Enhancement of resilience to climate variability and change through agroforestry practices in smallholder farming systems in Cameroon	AGROFORESTRY SYSTEMS	2020	Case study	Agroforestry		Africa	Cameroon
296	Biodiversity	Prudent, M; Dequiedt,	The diversity of soil microbial communities matters when legumes face drought	PLANT CELL AND ENVIRONMENT	2020	Experiment	Crops Soil biota	Soil microbial communities, Legumes	Not specified	
297	Biodiversity	Bellon, MR; Kotu, BH;	To diversify or not to diversify, that is the question. Pursuing agricultural development for smallholder farmers in marginal areas of Ghana	WORLD DEVELOPMENT	2020	Case study	Crops	Crops diversity	Africa	Ghana
298	Biodiversity	Poveda, J	Trichoderma parareesei Favors the Tolerance of Rapeseed (Brassica napus L.) to Salinity and Drought Due to a Chorismate Mutase	AGRONOMY-BASEL	2020	Experiment	Crops Soil biota	Filamentous fungi Trichoderma, rapeseed	Not specified	
299	Biodiversity	Degani, E; Leigh, SG;	Crop rotations in a climate change scenario: short-term effects of crop diversity on resilience and ecosystem service provision under drought	AGRICULTURE ECOSYSTEMS & ENVIRONMENT	2019	Experiment	Crops	Crop rotation	Europe	UK
300	Biodiversity	Carranza-Gallego, G; (	Addressing the Role of Landraces in the Sustainability of Mediterranean Agroecosystems	SUSTAINABILITY	2019	Experiment	Crops	Crop wild relatives	Europe	Spain
301	Biodiversity	Pironon, S; Etheringto	Potential adaptive strategies for 29 sub-Saharan crops under future climate change	NATURE CLIMATE CHANGE	2019	Review	Crops	Crop wild relatives	Africa	Multiple countries
302	Biodiversity	Quandt, A; Neufeldt,	Building livelihood resilience: what role does agroforestry play?	CLIMATE AND DEVELOPMENT	2019	Case study	Agroforestry		Africa	Kenya

303	Biodiversity	Kerr, RB; Kangmenna	Participatory agroecological research on climate change adaptation improves smallholder farmer household food security and dietary diversity in Malawi	AGRICULTURE ECOSYSTEMS & ENVIRONMENT	2019	Case study	Crops	Crops diversity	Africa	Malawi
304	Biodiversity	Castillo-Lorenzo, E; Fi	Adaptive significance of functional germination traits in crop wild relatives of Brassica	AGRICULTURAL AND FOREST METEOROLOGY	2019	Experiment	Crops	Grapevine wild relatives	Europe	
305	Biodiversity	Todeschini, V; AitLahr	Impact of Beneficial Microorganisms on Strawberry Growth, Fruit Production, Nutritional Quality, and Volatilome	FRONTIERS IN PLANT SCIENCE	2018	Experiment	Fruit Soil biota	Strawberry Fungi Plan growth promoting bacteria	Not specified	
306	Biodiversity	Volpe, V; Chitarra, W;	The Association With Two Different Arbuscular Mycorrhizal Fungi Differently Affects Water Stress Tolerance in Tomato	FRONTIERS IN PLANT SCIENCE	2018	Experiment	Crops Soil biota	Arbuscular mycorrhizal, Tomato	Not specified	
307	Biodiversity	Hu, L; Xia, M; Lin, XH;	Earthworm gut bacteria increase silicon bioavailability and acquisition by maize	SOIL BIOLOGY & BIOCHEMISTRY	2018	Experiment	Crops Soil biota	Earthworm Maize	Not specified	
308	Biodiversity	Lovell, ST; Dupraz, C;	Temperate agroforestry research: considering multifunctional woody polycultures and the design of long-term field trials	AGROFORESTRY SYSTEMS	2018	Experiment	Agroforestry		Not specified	
309	Biodiversity	Kay, S; Crous-Duran, J	Landscape-scale modelling of agroforestry ecosystems services in Swiss orchards: a methodological approach	LANDSCAPE ECOLOGY	2018	Field study	Agroforestry	Orchard and pasture	Europe	Switzerland
310	Biodiversity	Helgadottir, A; Suter,	Grass-legume mixtures sustain strong yield advantage over monocultures under cool maritime growing conditions over a period of 5 years	ANNALS OF BOTANY	2018	Experiment	Crops	Grass-legume mixture	Not specified	
311	Biodiversity	Huisman, J; Codd, GA	Cyanobacterial blooms	NATURE REVIEWS MICROBIOLOGY	2018	Review	Fishery	Cyanobacteria	Global	NA
312	Biodiversity	Bauer, B; Meier, HEM;	Reducing eutrophication increases spatial extent of communities supporting commercial fisheries: a model case study	ICES JOURNAL OF MARINE SCIENCE	2018	Modelling	Fishery	Fish support communities	Europe	Baltic Sea
313	Biodiversity	Williams, NE; Carrico,	Assessing the Impacts of Agrobiodiversity Maintenance on Food Security Among Farming Households in Sri Lanka's Dry Zone	ECONOMIC BOTANY	2018	Case study	Crops	Crops diversity	Asia	Sri Lanka
314	Biodiversity	Martin-Guay, MO; Paq	The new Green Revolution: Sustainable intensification of agriculture by intercropping	SCIENCE OF THE TOTAL ENVIRONMENT	2018	Review	Crops	Crops diversity	Global	NA
315	Biodiversity	Midega, CAO; Wasong	Drought-tolerant Desmodium species effectively suppress parasitic striga weed and improve cereal grain yields in western Kenya	CROP PROTECTION	2017	Experiement	Natural pest c	Rotation legumes Desmodium	Not specified	
316	Biodiversity	Bright, MBH; Diedhiou	Long-term Piliostigma reticulatum intercropping in the Sahel: Crop productivity, carbon sequestration, nutrient cycling, and soil quality	AGRICULTURE ECOSYSTEMS & ENVIRONMENT	2017	Experiement	Crops	Crops diversity	Africa	Senegal

317	Biodiversity	Picanco, A; Gil, A; Rig	Pollination services mapping and economic valuation from insect communities: a case study in the Azores (Terceira Island)	NATURE CONSERVATION-BULGARIA	2017	Modelling	Pollination		Europe	Portugal
318	Biodiversity	Rabiey, M; Ullah, I; Sh	Potential ecological effects of Piriformospora indica, a possible biocontrol agent, in UK agricultural systems	BIOLOGICAL CONTROL	2017	Experiment	Soil biota	endophytic fungus	Europe	UK
319	Biodiversity	Chitarra, W; Pagliaran	Insights on the Impact of Arbuscular Mycorrhizal Symbiosis on Tomato Tolerance to Water Stress	PLANT PHYSIOLOGY	2016	Experiment	Soil biota	Arbuscular mycorrhizal fungi	Not specified	
320	Biodiversity	Matsushita, K; Yamane	Linkage between diversity and agro-ecosystem resilience: Nonmonotonic agricultural response under alternate regimes	ECOLOGICAL ECONOMICS	2016	Data analysis	Crops	Rice driversity	Asia	Japan
321	Biodiversity	Kritzer, JP; Delucia, M	The Importance of Benthic Habitats for Coastal Fisheries	BIOSCIENCE	2016	Expert ranking	Underwater biodiversity	Multiple species	Global	NA
322	Biodiversity	Bogner, CW; Kariuki, G	Fungal root endophytes of tomato from Kenya and their nematode biocontrol potential	MYCOLOGICAL PROGRESS	2016	Experiment	Soil biota	fungal endophytes	Africa	Kenya
323	Biodiversity	Lindfield, SJ; Harvey,	Mesophotic depths as refuge areas for fishery-targeted species on coral reefs	CORAL REEFS	2016	Field study	Underwater biodiversity	Coral	Australia	Australia
324	Biodiversity	Thivierge, MN; Jego, G	Predicted Yield and Nutritive Value of an Alfalfa-Timothy Mixture under Climate Change and Elevated Atmospheric Carbon Dioxide	AGRONOMY JOURNAL	2016	Experiment	Pasture	Plant diversity	Not specified	
325	Biodiversity	Coromaldi, M; Pallante	Adoption of modern varieties, farmers' welfare and crop biodiversity: Evidence from Uganda	ECOLOGICAL ECONOMICS	2015	Case study	Crops	Crops diversity	Africa	Uganda
326	Biodiversity	Jacobi, J; Schneider,	Agroecosystem resilience and farmers' perceptions of climate change impacts on cocoa farms in Alto Beni, Bolivia	RENEWABLE AGRICULTURE AND FOOD SYSTEMS	2015	Case study	Agroforestry	Cocoa	South America	Bolivia
327	Biodiversity	Khoury, CK; Castaneda	Crop wild relatives of pigeonpea [Cajanus cajan (L.) Millsp.]: Distributions, ex situ conservation status, and potential genetic resources for abiotic stress tolerance	BIOLOGICAL CONSERVATION	2015	Data collection	Crops	Crop wild relatives	Global	NA
328	Biodiversity	Krishnan, SG; Waters,	Australian Wild Rice Reveals Pre-Domestication Origin of Polymorphism Deserts in Rice Genome	PLOS ONE	2014	Genomes sequencing	Crops	Rice wild relatives	Australia	Australia
329	Biodiversity	Lemaire, G; Franzlueb	Integrated crop-livestock systems: Strategies to achieve synergy between agricultural production and environmental quality	AGRICULTURE ECOSYSTEMS & ENVIRONMENT	2014	Review	Livestock Crops	Integration system	Not specified	
330	Biodiversity	Pratchett, MS; Hoey, A	Reef degradation and the loss of critical ecosystem goods and services provided by coral reef fishes	CURRENT OPINION IN ENVIRONMENTAL SUSTAINABILITY	2014	Review	Coral		Global	NA
331	Biodiversity	Toft, JE; Burke, JL; Ca	From mountains to sound: modelling the sensitivity of Dungeness crab and Pacific oyster to landsea interactions in Hood Canal, WA	ICES JOURNAL OF MARINE SCIENCE	2014	Modelling	Fishery	Dungeness crab Pacific oyster	North America	USA

332	Biodiversity	Rader, R; Reilly, J; Ba	Native bees buffer the negative impact of climate warming on honey bee pollination of watermelon crops	GLOBAL CHANGE BIOLOGY	2013	Simulation	Pollination	Watermelon	North America	USA
333	Biodiversity	Himanen, SJ; Ketoja,	Cultivar diversity has great potential to increase yield of feed barley	AGRONOMY FOR SUSTAINABLE DEVELOPMENT	2013	Data analysis	Crops	Crop diversity	Europe	Finland
334	Biodiversity	Nguyen, Q; Hoang, MH	Multipurpose agroforestry as a climate change resiliency option for farmers: an example of local adaptation in Vietnam	CLIMATIC CHANGE	2013	Case study	Agroforestry		Asia	Vietnam
335	Biodiversity	Bourou, S; Bowe, C; D	Ecological and human impacts on stand density and distribution of tamarind (Tamarindus indica L.) in Senegal	AFRICAN JOURNAL OF ECOLOGY	2012	Modelling	Forest provisioning		Africa	Senegal
336	Biodiversity	Xie, J; Hu, LL; Tang, J	Ecological mechanisms underlying the sustainability of the agricultural heritage rice-fish coculture system	PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF THE UNITED STATES OF AMERICA	2011	Field study	Animal and crop system: fish and rice co-culture		Asia	China
337	Biodiversity	Bennett, RG; Ryan, MH	Prioritisation of novel pasture species for use in water-limited agriculture: a case study of Cullen in the Western Australian wheatbelt	GENETIC RESOURCES AND CROP EVOLUTION	2011	Case study	Pasture	Plant diversity	Australia	Australia
338	Biodiversity	Rensel, JEJ; Haigh, N;	Fraser river sockeye salmon marine survival decline and harmful blooms of Heterosigrna akashiwo	HARMFUL ALGAE	2010	Case study	Fishery Invasive species	Sockeye salmon Harmful algea	North America	Canada
339	Biodiversity	Potts, SG; Biesmeijer,	Global pollinator declines: trends, impacts and drivers	TRENDS IN ECOLOGY & EVOLUTION	2010	Review	Pollination		Global	NA
340	Biodiversity	Sharma, S; Jackson, D	Quantifying the potential effects of climate change and the invasion of smallmouth bass on native lake trout populations across Canadian lakes	ECOGRAPHY	2009	Data analysis	Invasive speci	Bass Native trout	North America	Canada
341	Biodiversity	Graham, NAJ; Wilson,	Lag effects in the impacts of mass coral bleaching on coral reef fish, fisheries, and ecosystems	CONSERVATION BIOLOGY	2007	Field study	Coral	Reef fish	Multiple	Indian Ocean
342	Biodiversity	Barrios	Soil biota, ecosystem services and land productivity	ECOLOGICAL ECONOMICS	2007	Review	Soil biota		Not specified	

APPENDIX B - Data compilation for Task 2 of Stage 2

Literature

Literature can provide relevant data that is of interest to ECO-READY project.
There are published works that report the effforts of the author in indexing, compiling, and categorizing various databases and data sets in the areas of biodiversity and climate change.
Even though this part belongs to the Data assessment, the process of locating papers with data can be intergrated into the SLR process, which is conducted prior to the data assessment part.

No	Category	Related drivers	Authors	Title	Year	Data repository (if applicable)	Region (if applicable)
1	Climate change	Precipitation change	Trabucco and Zomer	Global Aridity Index and Potential Evapo-Transpiration (ET0) Climate Dat	2018	https://cgiarcsi.community/	Global
2	Climate change	Soil salinity	Hassani et al.	Global predictions of primary soil salinization under changing climate in	2021	https://figshare.com/articles/dataset/Global_predictions_of_primary_soil_salinization_under_changing_climate_in_the_21st_century/14548947	Global
3	Climate change	Summer heatwave	Prodhomme et al.	Seasonal prediction of European summer heatwaves	2022	https://www.ecmwf.int/	Europe
4	Climate change	Temperature Precipitation	Navarro-Racines et al.	High-resolution and bias-corrected CMIP5 projections for climate change impact assessments	2020	http://ccafs-climate.org/downscaling/	Global
5	Climate change	Soil salinity	Ivushkin et al	Global mapping of soil salinity change	2019	https://code.earthengine.google.com/d43e5a92ae1deed32a0929f57b572756	Global
6	Climate change	River salinity	Thorslund and Vliet	A global dataset of surface water and groundwater salinity measuremen	2020	https://springernature.figshare.com/articles/dataset/Metadata_record_for_A_global_dataset_of_surface_water_and_groundwater_salinity_measurements_from_1980-2019/12455954	Global
7	Biodiversity	Underwater biodiversity - Kelp	Malone et al	Large-scale, multidecade monitoring data from kelp forestecosystems in California and Oregon (USA)	2021	https://data.piscoweb.org/metacatui/view/doi:10.6085/AA/PISCO_kelpforest.1.6	USA
8	Biodiversity	Diversity in plants and crops group of drivers	Glaser et al.	AgriWeedClim database: A repository of vegetation plot data from Central European arable habitats over 100 years	2022	https://www.givd.info/ID/EU-00-035	Europe
9	Biodiversity	Intercropping	Martin-Guay et al.	The new Green Revolution: Sustainable intensification of agriculture by intercropping	2018		Global
10	Biodiversity	Possible Agroforesty Possible Ecosystem service - Forest provisioning	Pucher et al.	An Improved Forest Structure Data Set for Europe	2022	ftp://palantir.boku.ac.at/Public/ImprovedForestCharacteristics/ https://efi.int/knowledge/models/efiscen	
11	Biodiversity	Underwater biodiversity - invasive species	Vilizzi et al.	A global-scale screening of non-native aquatic organisms to identify potentially invasive species under current and future climate conditions	2021	https://www.sciencedirect.com/science/article/pii/S0048969721029399	Global
12	Biodiversity	Underwater biodiversity - invasive species	Anastacio et al.	Non-native freshwater fauna in Portugal: A review	2019	https://www.sciencedirect.com/science/article/abs/pii/S0048969718336957	Portugal
13	Biodiversity	Underwater biodiversity	Atkinson et al.	KRILLBASE: a circumpolar database of Antarctic krill and salp numerical densities, 1926-2016	2016	https://www.bas.ac.uk/project/krillbase/	
14	Biodiversity	Underwater biodiversity - Algae	Davidson et al.	HABreports: Online Early Warning of Harmful Algal and Biotoxin Risk for the Scottish Shellfish and Finfish Aquaculture Industries	2021	https://www.habreports.org/	UK
15	Biodiversity	Crop wild relatives	Khoury et al.	Comprehensiveness of conservation of useful wild plants: An operational indicator for biodiversity and sustainable development targets	2019	https://github.com/DFJL/SamplingUtil	
16	Biodiversity	Crop wild relatives	Khoury et al.	Crop wild relatives of the United States require urgent conservation action	2020	https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/BV4I06	USA

17	Biodiversity	Crop wild relatives	Tesso et al.	National inventory and prioritization of crop wild relatives in Spain	2018	https://pgrsecurespain.weebly.com/	Spain
18	Biodiversity	Crop wild relatives	Philips et al.	In situ and ex situ diversity analysis of priority crop wild relatives in Norway	2016	https://onlinelibrary.wiley.com/action/downloadSupplement?doi=10.1111%2Fddi.12470&file=ddi12470-sup-0001-SupInfo.pdf	Norway
19	Biodiversity	Crop wild relatives	Velcheva et al.	ESTABLISHMENT OF NATIONAL INFORMATION SYSTEM OF PLANT GENETIC RESOURCES IN BULGARIA	2022	http://ipgrbg.com/en/	Bulgaria
20	Biodiversity	Crop wild relatives	Zair et al.	Ex situ and in situ conservation gap analysis of crop wild relative diversity in the Fertile Crescent of the Middle East	2021	https://link.springer.com/article/10.1007/s10722-020-01017-z	Middel East
21	Biodiversity	Crop wild relatives	Fielder et al.	Enhancing the conservation of crop wild relatives in Scotland	2016	https://www.sciencedirect.com/science/article/pii/S1617138115300303?	Scotland
22	Biodiversity	Crop wild relatives	Fitzgerald et al.	A regional approach to Nordic crop wild relative in situ conservation planning	2019	https://www.cambridge.org/core/journals/plant-genetic-resources/article/regional-approach-to-nordic-crop-wild-relative-in-situ-conservation-planning/0DF42C7069E39E0FE1E1B56B86DE07C1#supplementary-materials	Nordic countries
23	Biodiversity	Underutilised crops	Nizar et al.	Underutilised crops database for supporting agricultural diversification	2021	https://cropbase.co.uk/cropbasev5/	Global
24	Biodiversity	Multiple	Stephenson and Stengel	An inventory of biodiversity data sources for conservation monitoring	2020	https://www.speciesmonitoring.org/data-sources.html	Global
25	Biodiversity	Pest	Courson et al.	Weather and landscape drivers of the regional level of pest occurrence in arable agriculture: A multi-pest analysis at the French national scale	2022	https://agriculture.gouv.fr/epidemiosurveillance-le-systeme-dinformation-epiphyt	France
26	Biodiversity	Ecosystem service - Pollinators Pests	Outhwaite et al.	Agriculture and climate change are reshaping insect biodiversity worldwide	2022	https://www.nhm.ac.uk/our-science/our-work/biodiversity/predicts.html	Global
27	Biodiversity	Ecosystem service - Pollinators	Lopez-Aliste et al.	Wild bees of Chile: a database on taxonomy, sociality, and ecology	2021	https://esajournals.onlinelibrary.wiley.com/doi/full/10.1002/ecy.3377#support-information-section	Chile
28	Food security	Fisheries risk due to climate change	Boyce et al.	A climate risk index for marine life	2022	https://datadryad.org/stash/dataset/doi:10.5061/dryad.7wm37pvwr	Global
29	Food security	Fish shifting in US economic zone	Heimann et al.	Mobilizing the fishing industry to address data gaps created by shifting species distribution	2023	https://www.accsp.org/	USA

EU Project reports/ outcomes

Outcome and deliverables of European projects, which have synergy with ECO-READY.

Only publicly funded projects are selected.

No	Acronym	Project Title	Website (if applicable)	Start	End	Funding amount	Link to database (if applicable)	Drivers in relation to the data	Category	Coordinator/ PI	Contact detail
1		Emerging ecosystem-based Maritime Spatial Planning topics in North and Baltic Seas Region	https://www.emspproject.eu/	31 08 2021	28 02 2024	3123394 EUR		Climate change in ocean Possible drivers: - Sea temperature - Ocean acidification - Ocean salinity	Climate change	Ministry of Economic Affairs and Climate	
2	LEGUMIROSE	Legume-cereal intercropping for sustainable agriculture across Europe	https://www.leguminose.eu/	1 11 2022	31 10 2026	7,188,013 EUR		Diversity in plants and crop Driver: Intercropping	Biodiversity	Giacomo Pietramellara	giacomo.pietramellara[at]unifi.it
3	ReMix	Redesigning European cropping systems based on species MIXtures	https://www.remix-intercrops.eu/	01 05 2017	30 04 2021	5 986 158 EUR		Intercropping (intra species)	Biodiversity	Eric Justes	eric.justes@cirad.fr
4	IntercropVALUES	Developing Intercropping for agrifood Value chains and Ecosystem Services delivery in Europe and Southern countries	https://intercropvalues.eu/	01 11 2022	31 10 2026	7 419 463 EUR		Intercropping (intra species)	Biodiversity	Eric Justes	eric.justes@cirad.fr
5	DiverIMPACTS	Diversification through Rotation, Intercropping, Multiple cropping, Promoted with Actors and value-Chains Towards Sustainability	https://www.diverimpacts.net/about.html	01 06 2017	31 05 2022	9 999 985 EUR		Crop rotation	Biodiversity	Antoine Messéan	antoine.messean(at)inrae.fr
6	AGROMIX	AGROforestry and MIXed farming systems - Participatory research to drive the transition to a resilient and efficient land use in Europe	AGROMIX | Homepage (agromixproject.eu)	01 11 2020	31 10 2024	6 999 256 EUR		Agroforestry	Biodiversity	Ulrich Schmutz	Ulrich Schmutz — Coventry University
7	LIBERATION	LInking farmland Biodiversity to Ecosystem seRvices for effective ecofunctional intensificATION	LInking farmland Biodiversity to Ecosystem seRvi	01 02 2013	31 01 2017	3 808 561 EUR		Farmland biodiversity, Ecosystem services	Biodiversity		
8	BioMonitor4CAP	Advanced biodiversity monitoring for results-based and effective agricultural policy and transformation	Home - BioMonitor4CAP	01 12 2022	01 12 2026	6953352 EUR		Farmland biodiversity	Biodiversity	Christoph Scherber	biomonitor4cap@leibniz-lib.de
9	BioBio	Indicators for biodiversity in organic and low-input farming systems		01 03 2009	31 08 2012	3 920 679 EUR		Farmland biodiversity	Biodiversity	EIDGENOESSISCHES DEPARTEMENT FUER WIRTSCHAFT, BILDUNG UND FORSCHUNG	
10	BioAgora	Bio Knowledge Agora: Developing the Science Service for European Research and Biodiversity Policymaking	BioAgora, connecting biodiversity knowledge and	01 07 2022	30 06 2027	11 827 270 EUR		Biodiversity research & policy makers	Biodiversity	Kati Vierikko	contact@bioagora.eu
11	SHOWCASE	SHOWCASing synergies between agriculture, biodiversity and Ecosystem services to help farmers capitalising on native biodiversity	News (showcase-project.eu)	01 11 2020	31 10 2025	7 999 837 EUR		Ecosystem services provided by biodivers	Biodiversity	Prof. David Kleijn	david.kleijn[at]wur.nl
12	AQUA-USERS	AQUAculture USEr driven operational Remote Sensing information services		17 09 2013	1 11 2016	3 214 775 EUR		Underwater biodiversity - Algae	Biodiversity		
13	REFOREST	Agroforestry at the forefront of farming sustainabi	https://reforest.euromed-economists.org/	06 2022	06 2026			Agroforestry	Biodiversity		
14	BIPESCO	BIOCONTROL OF IMPORTANT SOIL DWELLING PES	https://www.swansea.ac.uk/bioscience/research-and-impact/banp/bipesc			2,443,297 EUR		Ecosystem services - Natural pests control	Biodiversity	Dr Hermann Strasser, Leopold-Franzens University Innsbruck	
15	CAP and NATURE	Inclusion of CAP strategic plans and nature implications in MAGNET (AgEconEUrope II Framework Co		2022	2023	82000 EUR	INCA database	Ecosystem services provided by biodiversity	Biodiversity	Dr. Heleen Bartelings	heleen.bartelings@wur.nl

National projects
Outcomes and deliverables of projects at the national level.

The focus is on projects at European countries. WP1 and ECO-READY project partners are consulted for locating relevant projects.

Only publicly funded projects are selected.

No	Country	Acronym	Project Title	Website (if applicable)	Start	End	Funding amount	Key products	Drivers in relation to the data	Category	Coordinator/ PI	Contact detail
1	UK	SWEET	Super-Warm Early Eocene Temperatures and climate: understanding the response of the Earth to high CO2 through integrated modelling and data		01 10 2017	22 09 2023		Models of earth system responses to elevated CO2 across the world. Data set.	Elevated Co2	Climate change	Professor C Lear, Cardiff University, Sch of Earth and Environmental Sciences	
2	UK		A Carbon and transient tracer measurement programme in the Atlantic and Southern Ocean under Oceans 2025		1 11 2008	31 10 2012		Carbon measurement Carbon budget for Atlantic and Southern Oceans	Elevated Co2 Ocean acidification	Climate change	Professor A Watson, University of East Anglia, Environmental Sciences	
3	UK		A deep-sea perspective on coral resilience in a changing world		9 01 2023	8 01 2026		Ecosystem service assessment of coral	Underwater biodiversity	Biodiversity	Professor L Robinson, University of Bristol, Earth Sciences	
4	UK	BEGIN	Biodiversity of European Grasslands - the impact of Atmospheric Nitrogen Deposition		1 01 2007	31 12 2009		Grassland biodiversity and ecosystem	Ecosystem services Diversity in plants and crops	Biodiversity	Professor DJG Gowing, The Open University, Life, Health & Chemical Sciences	
5	UK	21EJP SOIL	Preadapting soil biology for increased tolerance to elevated salinities due to climate change		03 2022	03 2025	508,430	Report on soil community evolution to acclimate to soil salinity	Soil biota - micro-organism Soil salinity	Climate change Biodiversity	Professor Matthew Goddard, University of Lincoln	
6	UK	TRADE	TRAnsforming the DEbate about livestock systems transformation		05 2022	05 2025	677,396	Delphi study to identify transformation of livestock through breeding; consensus between stakeholders on transformative changes of livestock sector	Possibe drivers: Animal and crop integration system	Biodiversity	Professor Dominic Moran, University of Edinburgh	dominic.moran@ed.ac.uk
7	Cyprus		Innovative Approaches Promoting Functional Microbial Diversity for a Sustainable Grapevine Health and Productivity in Vineyard Systems of Mediterranean Areas		01 06 21	01 06 2023	189832.09		Soil biota - micro-organism	Biodiversity	Nikolaos Tzortzakis, Cyprus University of Technology	
8	Cyprus		Projecting temperature climate extremes at regional to urban scales		01 2019	01 2023	250,000		Extreme events	Climate change	Panos Hadjinicolaou	
9	Cyprus		Bio-Ecological and molecular study of red palm weevil rhynchophorus ferrugineus and palm borer paysandisia archon and their integrated managemen		2012		100,843		Pests	Biodiversity		
10	Netherlands	CropMix	Designing mixed cropping systems and transition paths towards sustainable ecology based agriculture	https://cropmix.nl/en/	15-Jul-05	19-Jul-05	10 million EUR		Crop diversity	Biodiversity		
11	Netherlands		Macro-Economische modellen voor integrale besluitvormin		2022	2025	1092252.48	Better macro-economic assessments at the European, national and regional levels		Biodiversity	dr.ir. NBP (Nico) Polman	

Eurostat is the statistical office of the European Union
https://ec.europa.eu/eurostat/databrowser/explore/all/all_themes

Categories of data that could be of interest to ECO-READY:
- Agriculture, forestry and fisheries.
- Environment (sub-set of Environemt and energy data theme).

No	Name	Data category (Eurostat)	Link
1	At risk of poverty thresholds	Living condition	https://ec.europa.eu/eurostat/databrowser/view/ilc_li01/default/table?lang=en
2	Food price indices	Food price	https://ec.europa.eu/eurostat/databrowser/view/apri_pi15_ina/default/table?lang=en
3	Agriculture	Farm structure Economic aaccounts for agriculture Agricultural prices and price indices Agricultural production Organic farming Structure of orchards and vineyards Agriculture and environemnt	https://ec.europa.eu/eurostat/databrowser/explore/all/all_themes
4	Forestry	Forest resource Environmental functions	https://ec.europa.eu/eurostat/cache/metadata/en/for_sfm_esms.htm
5	Fisheries	Catches by fishing area Aquaculture production by species Landings of fishery products Fishing fleet	https://ec.europa.eu/eurostat/cache/metadata/en/fish_ca_esms.htm https://ec.europa.eu/eurostat/cache/metadata/en/fish_aq_esms.htm https://ec.europa.eu/eurostat/cache/metadata/en/fish_ld_esms.htm https://ec.europa.eu/eurostat/cache/metadata/en/fish_fleet_esms.htm

Internet search
Using common internet search tool to locate data sources related to the topics of interest for ECO-READY

No	Dimensions	Drivers	Source	Link
1	Climate change	Increased air temperature	World Climate	https://www.worldclim.org/data/index.html
			Climate change knowledge portal - World Bank	https://climateknowledgeportal.worldbank.org/download-data
2	Climate change	Sea surface temperature	Oracle	https://www.bio-oracle.org/explore-data.php
			Copernicus data & EUMESTAT	https://www.eumetsat.int/sea-surface-temperature-services
3	Climate change	Sea bottom temperature	Oracle	https://www.bio-oracle.org/explore-data.php
4	Climate change	Increased freshwater and estuary temperature	National Estuarine Research Reserve system	https://cdmo.baruch.sc.edu/dges/
			Scotland river temperature monitoring network	https://scotland.shinyapps.io/sg-srtmn-data/
5	Climate change	Precipitation change	World Climate	https://www.worldclim.org/data/index.html
			Climate change knowledge portal - World Bank	https://climateknowledgeportal.worldbank.org/download-data
6	Climate change	CO2 concentration	Global Monitoring Laboratory	https://gml.noaa.gov/ccgg/trends/
7	Climate change	Ocean acidificaiton	National centers for Environmental Information	https://www.ncei.noaa.gov/access/ocean-carbon-acidification-data-system-portal/
			Global Ocean Acidification Observing network	http://portal.goa-on.org/Explorer
8	Climate change	Ocean Dissolved oxygen	Oracle	https://www.bio-oracle.org/explore-data.php
			Resource Watch	https://resourcewatch.org/data/explore/ocn020c-Dissolved-Oxygen-Concentration?
9	Climate change	Ocean salinity	Oracle	https://www.bio-oracle.org/explore-data.php
10	Climate change	Soil salinity	FAO Soil support porta	https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/harmonized-world-soil-database-v12/en/
11	Climate change	Seasonal variation	Nasa Earth Observation - Snow cover	https://neo.gsfc.nasa.gov/view.php?datasetId=MOD10C1_M_SNOW
12	Climate change	Storm/ hurricane	European Severe Weather database	https://eswd.eu/
13	Climate change	Drought	Nasa Earth Observation - Water Equivalent Anomaly	https://neo.gsfc.nasa.gov/view.php?datasetId=GRACE_LWE_M
			Corpernicus Emergency Management service	https://edo.jrc.ec.europa.eu/tumbo/gdo/map/
14	Climate change	Marine heatwaves	Marine heatwaves International working group	https://www.marineheatwaves.org/tracker.html
15	Climate change	Marine cold spells	Copernicus marine service	https://marine.copernicus.eu/access-data/ocean-monitoring-indicators
16	Climate change	Flood	Resource Watch - Coastal flood risk	https://resourcewatch.org/data/explore/Projected-Sea-Level-Rise?
			Nasa Earth Observation - Water Equivalent Anomaly	https://neo.gsfc.nasa.gov/view.php?datasetId=GRACE_LWE_M
			Corpernicus Emergency Management service	https://www.efas.eu/efas_frontend/#/home
17	Climate change	Glacier retreat	Physical Oceanography Distributed Active Archive Center	https://podaac.jpl.nasa.gov/cloud-datasets?ids=Keywords&values=Cryosphere%3AGlaciers%2FIce%20Sheets
18	Climate change	Reduced ice cover at sea	Oracle	https://www.bio-oracle.org/explore-data.php
			Nasa Earth Observation	https://neo.gsfc.nasa.gov/view.php?datasetId=NISE_D
19	Biodiversity	Underwater Biodiversity - Primary production	Oracle	https://www.bio-oracle.org/explore-data.php
			Nasa Earth Observation	https://neo.gsfc.nasa.gov/view.php?datasetId=MY1DMM_CHLORA
20	Biodiversity	Underwater Biodiversity - Coral	NOAA Satellite and information service	https://coralreefwatch.noaa.gov/
21	Biodiversity	Underwater Biodiversity - Mangrove Fo	Resource Watch	https://resourcewatch.org/data/explore/for005a-Mangrove-Forests?
22	Biodiversity	Underwater Biodiversity - Algae	OBIS Ocean Biodiversity Information system	https://obis.org/
23	Biodiversity	Crop wild relatives	European cooperatuve Programme for Plant Genetic Resources EURISCO	https://eurisco.ipk-gatersleben.de/apex/eurisco_ws/r/eurisco/home
24	Biodiversity	Crop wild relatives	Crop Trust	https://germinateplatform.github.io/get-germinate/#databases
25	Biodiversity	Pests	Discontools	https://www.discontools.eu/database.html
26	Food security		The food foundation UK	https://foodfoundation.org.uk/initiatives/food-insecurity-tracking
27	Food security		Global Agricultural Information Network	https://gain.fas.usda.gov/#/home
28	Food security		Our world in data	https://ourworldindata.org/