Structural Analysis of Major trends in the Epistemological and Institutional History of Ocean Science

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Abstract

At the start of the United Nations' Decade of Ocean Science for Sustainable Development (2021-2030), this working paper explores key epistemological and institutional trends in global and European ocean science. Noting differences in how both scholars from diverse disciplines and policy makers define the boundaries of and within ocean science and the FluidKnowledge project's focus on diverse ocean science areas, we analyse two inclusive field delineations of ocean science, and we do so in three ways. First, we study key topics and their temporal and geographic variability using term co-occurrence networks. Second, we study changes in key journals using bar charts. Third, we study key institutions and their research foci using bar charts, co-authorship networks and term co-occurrence networks. We hope this report can facilitate ongoing discussions about the present and future of ocean science. To this end, we include links to online, interactive network visualisations readers can explore.

Contents

1 Introduction

At the start of the United Nations' Decade of Ocean Science for Sustainable Development (2021-2030), the question of how research priorities in ocean science have evolved until now is highly pertinent. The UN Decade highlights the essential role oceans play in both the global economy as well as the climate. Not only is ocean science expected to contribute to understanding the ocean as an ecosystem of interconnected seas and oceans, it is also called on to analyze environmental effects of pollution, overfishing, and climate change (e.g. rising sea levels), and to assist in constraining the effects of intensified ocean exploitation. The UN calls for a 'globally coordinated' ocean science to explore sustainable uses and protection of oceans, seas and coastal environments. (How) can coordination be achieved when today, ocean scientific research priorities have not only diversified, but are also weighed against highly demanding, multifaceted, and sometimes even conflicting missions?

This working paper provides a perspective on major trends in the epistemological and institutional history of global and European ocean science between 1980-2020. It does so by way of scientometric methods (quantitative data analysis pertaining to scientific publications), using Web of Science (WoS) data. Scholars have studied sub-topics within ocean science using scientometrics, such as trends in global ocean power generation (Chen et al., 2021), trends in macroalgal biomass research as a source of biofuel feedstock (Coelho, Barbosa, and Souza, 2014), research on the interactions between marine fish and plastic debris (Santos de Moura and Vianna, 2020), research about arsenic bioaccumulation in marine ecosystems (Li, Zhong, and Zhang, 2020), or research on estuary pollution (Sun, Wang, and Ho, 2012). In addition, Elango and Rajendran (2012) have studied collaboration patterns in marine science, and Charles (2017) focused on key geographic centres of ocean science knowledge production. To our knowledge, no study thus far mapped institutional and epistemological trends in global and European ocean science to date.

As section 2 will discuss in more detail, the term ocean science is mobilized in different ways by different actors involved (e.g. policy makers, scientists), and - depending on the context - certain aspects are highlighted at the expense of others. What we ourselves offer in this report, too, is not comprehensive nor definitive. Rather than assuming that ocean science can be 'properly' delineated, this working paper takes as a starting point that the boundaries within and around ocean science can be drawn in diverse ways. Within the constraints afforded by scientometric analysis and the WoS database, we aim to cast the net widely by taking ocean science to include any research that relates to oceans, marine and coastal ecosystems from diverse disciplines, including natural, social, biomedical, physical sciences and engineering.

The report is structured as follows. Section 2 discusses the challenges associated with scientometrically and conceptually delineating ocean science. To highlight the normativity and partiality of field delineation, we analyse two ocean science field delineations throughout the working paper pertaining to global (section 4) and European 5) ocean science. We explore global and European ocean science through analysing the two scientometric ocean science field delineations in three main ways. First, we study key topics in ocean science between 1980-2020 using term co-occurrence networks maps of terms in the abstracts and titles of relevant papers. Section 4.2 explores the development of research topics in global ocean science, and section 5.2 explores the development of research topics in European ocean science. Second, we study changes the number of ocean science papers top journals in global and European ocean science publish over the four decades. Section 4.3 studies top journals in global ocean science, and section 5.3 studies top journals in European ocean science. Third, we study changes in top ocean science institutions and map their thematic focus. Section 4.4 studies top institutions in global ocean science and section 5.4 studies top institutions in European ocean science. Section 6 concludes the report by summarising its key findings. Finally, section 7 discusses future research.

2 Delineating and Studying Ocean Science

Scientometrically delineating scientific fields - collecting data about a set of publications that relate to the scientific field - such as ocean science is challenging conceptually as well as technically because they often lack clear boundaries. As we discuss below, delineating ocean science is challenging epistemologically (e.g. what does and does not count as ocean science knowledge?), sociologically (e.g. who does and does not participate in ocean science knowledge creation, and who has the authority to decide?) and technically (e.g. how should we identify papers which do and do not belong to ocean science?). To highlight the partiality and normativity of delineations, this report analyses two ocean science 'scientometric field delineations'.

2.1 What is Ocean Science?

Scientists from different disciplines and policy makers might differ in how they define the purpose and relevance, as well as internal and external coordination and boundaries of 'ocean science'. Current policy documents, such as the UN's recent report about global ocean science (UN, 2019) discuss ocean science as a systems science; a (preferably) globally coordinated, societally relevant, interdisciplinary science which responds to current global challenges.Some recent, high-profile, outward-facing initiatives by scientists seem to take a similar integrative, transdisciplinary, systems perspective (WIOMSA, 2021). Among the researchers involved in ocean science, there is a widespread sense that marine ecosystem degradation, changes in atmospheric conditions, and human intrusions are conjoined global problems. At the same time, some experts have also expressed concern about effects of increasing specialization and competition in the field (Boero, 2021).

Scientometrically delineating ocean science necessitates defining a set of search parameters (e.g. keyword search, a list of relevant journals or a combination) that allows us to collect relevant papers. These search criteria hinge on our definition of ocean science. As the Introduction discussed, we define ocean science as all research that relates to oceans, seas, marine and coastal environments as well as fisheries for two main reasons. First, we consider oceans to inextricably linked to land and water ecosystems as well as economic and leisure activities (cf. SIWI, 2020). This makes it challenging to scientometrically delineate the field because of the lack of clear boundaries between ocean science and non-ocean science. Second, the FluidKnowledge project explores the way (e)valuation and science-policy dialogues shape research agendas in various branches of ocean science, including coastal and fisheries modelling, deep sea research and the marine social sciences. The project is particularly interested in how scientists and policy makers value and define the boundaries of ocean science. Thus, we aim for our analyses to be as inclusive as possible, and explore and capture the diversity of ocean science. The relationship between ocean science and fisheries research deserves a special mention. Although policy actors such as the UN consider fisheries research a part of 'ocean science', not all ocean scientists do so. We included fisheries research in our definition of ocean science for two main reasons: because of our attempt to identify ocean science as broadly as possible considering human activities which impact it, and because of the fisheries related sub-project that comprises FluidKnowledge.

2.2 Who does Ocean Science?

Ocean science is conducted globally at academic and non-academic, commercial as well as governmental (research) institutions. Ocean science is a multi-stakeholder science, and ocean science related policy, infrastructure and collaboration requires multi-stakeholder dialogues. This report uses scientometric data, which primarily captures data about ocean science papers published by scientists affiliated with academic institutions. We understand the partiality of this perspective, and we hope that the interactive version of the science maps included in this report will facilitate discussions about the characteristics and limitations of ocean science as depicted in this report, contributing to multi-stakeholder dialogues.

2.3 How do we Identify Ocean Science Papers?

In order to study ocean science using scientometrics, we need to identify or delineate a set of relevant papers. Delineating entities (e.g. people, institutions and scientific publications) for research purposes is a key challenge in social network analysis, bibliometrics, scientometrics and information retrieval (IR). The latter three have developed computational and statistical techniques to delineate scientometric data, such as publications pertaining to scientific disciplines. Field delineation approaches differ in three main ways (cf. (Zitt, 2015; Zitt, 2020):

1. Whether they delimit the field using 'a priori' or 'a posteriori' criteria
2. How they validate results
    - goal of validation: 'thick' exploration of field boundaries (e.g. Marres and Rijcke, 2020) or accurate recall based on a preconceived definition of the field
    - when they validate methods / findings during the field delineation process
    - the validation method: e.g. expert or other human judgement or automated / statistical metrics
3. For hybrid approaches, the sequence in which they combine approaches

To contextualise our field delineation approach, and to highlight the contingency of our findings on these decisions, we briefly discuss considerations for delineating ocean science with respect to the first two points below. We omit a discussion about the sequence of methods in hybrid field delineation because we do not use a hybrid field delineation method.

2.3.1 A Priori and a Posteriori Field Delineation Approaches

Zitt (2015) differentiates between 'a priori' and 'a posteriori' field delineation methods. 'A priori' approaches - historically more popular in IR - delimit the field using a set of criteria, which hinge on "a preconceived breakdown of the domain" (p. 2226) and well defined expectations, translated into queries which yield a set of publications. For example, relevant publications may be identified using keyword queries, selecting key actors, or selections based on existing classifications (e.g. journal classifications) (Zitt, 2020) potentially combined statistical cutoff criteria, such as Bradford's law. Queries often are iterated and adjusted.

In contrast, 'a posteriori' approaches more characteristic of bibliometrics are informed by statistical induction, where bibliometric data is first mapped, and the field is delineated based on clusters present in the map. We discuss three notable uses of 'a posteriori' field delineation approaches. Firstly, many classifications used in scientometrics rely on bibliometric network analysis. Historically journal level classifications have been the most popular, many of which use bibliometric analysis of citation networks, along with assessing journals' title and scope (Muñoz-Écija, Vargas-Quesada, and Chinchilla Rodríguez, 2019). (Zitt, 2015) More recently Waltman and Eck (2012) proposed a publication level classification based on direct citation relations and Boyack et al. (2011) (cited by Milanez, Noyons, and Faria, 2016) clustered biomedical publications using the text-based similarity between papers based on of keywords extracted from titles and abstracts. Secondly, scientometric maps can be used to 'zoom in' on areas of interest. Thirdly, scientometric maps can help explore the neighbourhood of 'seed' literature identified beforehand. As part of this process, the (a priori) expectations of researchers about the research field can be "projected a posteriori on a wider science landscape" (p. 2227). Clustering methods render larger scale maps readable Zitt (2015).

This paper uses one 'a priori' field delineation method: a lexical query where we identified ocean science papers based on the presence of keywords in the abstracts and titles of papers. In addition, we use a query which relies on journal classification system and thus relies on prior 'a posteriori' field delineation methods. In particular, we delineate ocean science by collecting data about papers published in journals associated with ocean science relevant Web of Science subject categories. Section 3.1 discusses the technicalities of our field delineation methods in more detail, and sections 4.1 and 5.1 compare the field delineations.

2.3.2 Validating Field Delineation

The Goal of Field Delineation

Mapping and field delineation is inherently political (Zitt, 2015; Marres and Rijcke, 2020) and is informed by epistemological and ethical commitments. Scholars who delineate scientific fields may wish to explore how different maps highlight different aspects (Wen et al., 2017), eliciting scholars' opinion about field boundaries (Marres and Rijcke, 2020) or aim for accurately delineating fields of research based on established definitions of the studied fields (e.g. Milanez, Noyons, and Faria, 2016; Muñoz-Écija, Vargas-Quesada, and Chinchilla Rodríguez, 2019).

This working paper delineates ocean science in two ways, in the hope that the analyses it presents highlight different aspects of ocean science. We hope the analyses we present can serve as a basis for discussions about the past, present and future of ocean science.

Validation Methods

According to Zitt (2015), an advantage of a posteriori methods is that validation can consist of comparing the delineated field with the broader landscape, which can be less "demanding" (p. 2227) than defining a good lexical query a priori. In addition, a posteriori approaches can reduce "the risk of silence or noise on entire subdomains, at the scale(s) of observation picked" (p. 2227).

Expert judgement is often used for validation, for example to help evaluate final results (e.g. Muñoz-Écija, Vargas-Quesada, and Chinchilla Rodríguez, 2019) or to evaluate researchers' lexical queries (e.g. Milanez, Noyons, and Faria, 2016; Zitt, 2015). According to Zitt (2015) "experts' panels often show specialization biases, giving a poor collective a priori mental map of the domain, especially for multidisciplinary or controversial topics" (p. 2227).

Rather than assuming that ocean science can be 'properly' delineated, this working paper assumes that the boundaries of ocean science can be drawn in diverse ways. Like (Zitt, 2015) we assume that experts can help delineate ocean science from the perspective of their specialisation and professional experiences. However, in contrast to (Zitt, 2015), we do not consider this a negative 'bias'. Rather, we posit that this shows the inherent multivalence and interdisciplinarity of ocean science. We assume that arriving to a single 'validated' definition of ocean science would unavoidably favour certain perspectives. Data analyses could embody and reify such normative choices and foreclose opportunities for dialogue. Given that we aim to provide analyses that can spark discussions, instead of validating our field delineation a priori or a posteriori, we aimed for as simple a field delineation method as possible that we can easily articulate, and that readers of this report can thus debate. We detail our methodological choices in section 3.1.

2.4 Whose Ocean Science Does This Working Paper Study?

In sum, this report analyses a broad set of papers related to ocean science. Although our field delineations are inclusive, they also inevitably omit relevant research and include research that some might consider to lie outside of the boundaries of ocean science. This is the case with all field delineations. We hope that this report and the interactive data visualisations therein can foster dialogues about what ocean science could and should be in the coming decade. We also trust that, by providing multiple visualisations, we forefront the partial nature of all mappings.

3 Methodology

This section discusses our field delineation and data analysis methodology. Section 3.1 discusses our field delineation methods. Section 3.2 reflects on the limitations of this project's focus on major data trends using raw counts of the occurrence of data points, and our efforts to offset some of these limitations. Section 3.3 reflects on the way we operationalised temporal analysis. Section 3.4 discusses the term co-occurrence map methodology we use to explore epistemological trends in ocean science, with a focus on online interactive maps and overlay maps colored according to diverse variables. Section 3.5 discusses our methods to study trends in key ocean science journals using bar charts. Finally, section 3.6 discusses our approach to studying key institutions using both bar charts, co-authorship networks and term maps.

3.1 Three Ocean Science Field Delineations

We initially created three ocean science field delineations: a lexical field delineation that identified papers by searching for terms in their abstracts and titles, and two journal based searchers that identified papers published in specific ocean science related journals. We discuss each field delineation in detail below, starting with the journal based field delineations.

For the journal based delineations we selected papers published in ocean science related journals. We identified 'ocean science' relevant journals using WoS' Subject Categories (SCs). WoS assigns one or more SCs for each journal selected into the database. WoS' 254 Subject Categories are also mapped onto five broad research areas. We selected journals whose SCs include one of the following terms: '*ocean*', '*marine*' or '*fish*', We decided to search ocean, marine and fisheries research related journals alike based on the considerations about the breadth of ocean science discussed in the Introduction and in section 2.1.

We identified 5 ocean science related SCs using the above search:

1. Engineering, Marine
2. Engineering, Ocean
3. Fisheries

4. Marine & Freshwater Biology
5. Oceanography

As each journal is assigned one or more SCs, we had to decide whether to include all journals associated with the above SCs, or journals *only* associated with these SCs. Using the former - broader - criteria (referred to as the *broad journal field delineation* hereafter), our search matched 665.354 papers. Using the latter - narrower - criteria (referred to as the *narrow journal field delineation* hereafter), our search matched 207.798 papers. This report only analyses papers in the broad journal field delineation, and omits the analysis of the narrow journal field delineation for two main reasons. First, as section 4.1 will discuss, the narrow journal search overlaps with both the broad journal field delineation and the lexical field delineation. Second, as section 2.1 discussed, for the purposes of FluidKnowledge, we prefer inclusive field delineations over narrower ones.

With the lexical field delineation we identified ocean science related papers by searching for a list of terms in their abstracts and titles. We tried to identify relevant search terms in two main ways. First, we selected noun phrases present in the titles and abstracts of papers identified through journal based delineation. We tried to select a set of ocean science related noun phrases by combining algorithmic and manual criteria. We tried to manually evaluate the ocean science relevance of the top 1500 most relatively frequent noun phrases in the abstracts and titles of papers identified through journal based selection. We defined relative frequency as their frequency in our paper set divided by their frequency in the whole of WoS. However, we encountered the following challenges:

1. manually evaluating noun phrases' ocean science relevance was very time consuming;
2. the need to select top relatively frequent noun phrases for each of the five Subject Categories so that our noun phrases do not favour one or the other which adds labour, and
3. most importantly, any systematic 'biases' (omissions or over-representation) present in the journal based delineation would be reinforced by the noun phrases this selection process yields, which have high relative frequency in this set of papers. We found it difficult to evaluate the biases this method introduces.

To ensure that the field delineations are independent of each other, we designed an independent lexical field delineation method - using terms other than those highly frequent in papers in the journal based delineation. We designed lexical field delineation below (see the code depicted in Listing 1) based on the insight that ocean science lends itself to spatial delineation: ocean science studies ecological processes and human activities that take place in oceans, seas, marine environments, estuaries and coasts. This approach is also similar to the Aurora University Network's lexical field delineation which delineates papers related to the UN's Sustainable Development Goal 14 (Aurora Universities Network, 2020). We selected the list of 'sea' related terms based on Mark Costello's marine research glossary (Costello, 2019). Furthermore, we added aquaculture and fisheries related terms based on the considerations outlined in section 2.1. We also ensured our search omits a few semantically unrelated but similar terms, such as 'blue ocean' (related to blue ocean strategy or leadership, a management studies related concept), 'coaster*' and 'coasting*' - which include the term 'coast' - 'customariness', 'ultramarine*' and 'mariner*' - which include 'marine*'. We identified these terms using TheFreeDictionary. The lexical field delineation matched 1.270.879 papers.

```
DROP TABLE #ocean_data_1
SELECT *
```

```
INTO [#ocean_data_1]
FROM [database]
WHERE CONTAINS((title, abstract, keyword, keyword_plus), '"*ocean*" OR "fishery*
    " OR "fisheries*"  OR "aquacultur*" OR sea OR "seawater*" OR "seafloor*"  OR
    "seashore*"  OR "seashell*" OR "seamount*"  OR "seabed*" OR "seaweed*" OR "
    seagrass*" OR "deep-sea*"  OR "sea-hill*" OR "seahill*" OR "seas" OR "
    undersea*" OR "seascape*" OR "seaward*" OR "seabottom*" OR "seafood*" OR "
    coast*" OR "marine*" OR "coral reef*" OR estuary OR estuaries OR "blue
    economy" OR "maritime economy" OR "ocean economy" OR "marine economy" OR "
    blue growth" OR "marine social science"')
AND NOT CONTAINS ((title, abstract, keyword, keyword_plus), '"blue ocean*" OR "
    coaster*" OR "coasting*" OR customariness OR "ultramarine*" OR "mariner*"')
```

Listing 1: Lexical field delineation search string

Finally, we mapped each of the three field delineations on the CWTS map of science which classifies scientific papers published since 2000 using over 4000 publication clusters (*microclusters*, for short). The CWTS classification categorises the microclusters into five broad research areas: biomedical and health sciences; life and earth sciences; mathematical and computer science; physical science and engineering; and social sciences and humanities. Section 4.2 outlines the difference in the number of microclusters field delineations match above custom defined thresholds as a function of these five broad disciplinary categories. For the lexical field delineation, we selected clusters with at least 100 or 1% of matched papers. For the broad and narrow journal field delineations we included microclusters with at least 50 or 1% of matched papers.

3.2 Studying key trends

This working paper explores key trends analysing the paper sets associated with the broad journal field delineation and the lexical field delineation. We identify key trends mainly based on counting the raw (and not normalised) occurrence of terms, journals and institutions. We depict such counts in two main ways: bar charts and weighted network maps. Focusing on data points that occur often obscures smaller data patterns (cf. Foucault Welles, 2016); variations and terms, institutions and journals that occur less often but may play a key role according to other metrics or evaluation criteria, such as network metrics, normalised metrics or qualitative indicators. We hope to offset the limitations of focusing on the most prominent terms, institutions and journals in three main ways. First, we include a relatively large number of journals and institutions (50) in our analyses. While this makes some data visualisations challenging to read, especially in print, we hope it helps paint a more inclusive picture about key institutional and epistemological trends in ocean science. Second, we provide interactive term maps using VOSviewer online, which readers can use to look up terms that occur less often and explore the network structure. Third, for European analyses we provide term maps that depict the research focus of the 10 European countries that publish the highest number of ocean science papers, beyond the top 4 countries the screenshots in this report explores.

3.3 Depicting Temporality: Studying the history of ocean science

This working paper explores key epistemological and institutional trends in ocean science 1980-2020. Given the focus on temporal analysis, this section reflects on our methodological choices with respect to how we operationalize time using the raw occurrence of data points discussed in section 3.2. First, we depict change over time by characterising each decade 1980-2020. We considered depicting temporal patterns for each decades in three ways:

1. characterising decades with the most frequent terms, institutions and journals at the time;

2. characterising decades according the occurrence of terms, journals and institutions that occur the most in the past decade (2010-2020);
3. characterising decades according the occurrence of terms, journals and institutions that occur the most in the data overall (1980-2020).

The first option would help understand each decade of ocean science in terms of the top institutions during that time period irrespective of other decades. The second and third options help trace the changing occurrence of terms, journals and institutions that occur frequently in the 'present'. The second option defines the 'present' as the most recent time period, whilst the third option defines 'present' as the current, 'overall' state of the field. These both enable tracing the epistemological and institutional "history of the present" in line with the aims of the FluidKnowledge project. This report presents analyses using the third option: we depict changes in the occurrence of terms, journals and institutions that occur frequently in the period 1980-2020. In particular, we depict bar charts for each decade using faceted bar charts, and temporal changes for term co-occurrence networks using overlay colors discussed in section 3.4.2 which signify relative occurrence of terms in each decade. Whilst these visualisation methods provide baselines against which temporal changes can be interpreted, they highlights consistency across the decades, and can obscure differences and changes.

3.4 Term Co-occurrence Network Maps

This section discusses the term co-occurrence network methodology. We create term co-occurrence maps using random samples of 25000 papers for global and European ocean science for each field delineation. We mapped a random sample to reduce computing requirements. We extracted terms from the abstract and title of papers.

We used the VOSviewer 1.6.17 software (Eck and Waltman, 2010) to create the term co-occurrence network maps (term maps, for short) presented in sections 4.2, 5.2 and 5.4. VOSviewer allows filtering terms based on two main metrics: the number of times they occur and their 'relevance score'. The latter helps exclude 'generic' terms which occur in all papers in the dataset, such as 'study', 'paper', 'result' etc. VOSviewer calculates the relevance score by comparing the distribution of each noun phrase over all noun phrases with the overall distribution of co-occurrences over noun phrases. The method assumes that for 'general' noun phrases the two distributions are similar. In contrast, terms with high relevance score co-occur with a subset of all noun phrases more often, thus, the two distributions differ (Eck and Waltman, n.d.).

We map terms that occur at least 10 times in the title and abstract of papers, and those that fall in the top 60% in terms of relevance score. Thus, our maps capture popular and specific terms, thus depicting larger trends.

3.4.1 Interactive Term Co-Occurrence Network Maps

As section 2.4 discussed, we hope this report can foster discussions about the present and future of ocean science. Thus, although we discuss the term maps, we note that our interpretation is only one of possible insights the maps can facilitate. Readers will likely reach different insights when exploring them, depending on their interests and expertise. Thus, we encourage readers to explore the interactive term maps that we share using the VOSviewer online software. The static screenshots included in this report mainly serve illustrative purposes. To aid the interactive exploration of maps, we provide a link to the interactive version of each term map.

3.4.2 Overlay Term Co-Occurrence Network Maps

VOSviewer allows coloring terms in term co-occurrence network maps according to specific variables, such as average publication time, which are called 'overlay' maps. This report uses three types of overlay maps: temporal, country, and institutional overlay maps. In the temporal overlay maps presented in section 4.2.1 and provided for the interactive term maps in sections 4.2 and 5.2, we color terms according to their average occurrence in each decade (ranging from 0 to 1 for each decade. A term for a decade takes value 0 if the term does not occur in a decade at all, and takes value 1 if the term only occurs in that specific decade. Thus, we can map the relative occurrence of terms in specific decades, which lands a perspective on temporal epistemological shifts. Country overlay maps presented in section 5.2.1 use the same calculation method to depict the extent to which terms are used in papers published by scholars affiliated with institutions in European countries. Finally, institution overlay maps presented in sections 4.4 and 5.4 depict the relative occurrence of terms in papers affiliated with sets of institutions that pertain to the same cluster on the institution co-authorship networks discussed in section 3.6.2 and presented in sections 4.4 and 5.4. Similar to the term maps for global and European ocean science, the institutional term maps analyse a random sample of 25.000 papers published by top European and global institutions for each field delineation.

3.5 Journal Analyses

We map the top journals in global and European ocean science across the three ocean science fields using bar charts that depict publication counts. For each field delineation and for both global and European ocean science, we create faceted bar charts that depict the number of ocean science papers published in the top 50 journals across four decades: 1980-1989, 1990-1999, 2000-2009 and 2010-2020.

3.6 Institutional Analyses

We study the top institutions in global and European ocean science across the two ocean science field delineations in three ways: using publication counts, institution co-authorship networks and term maps that depict the relative research focus of institution clusters. While the institutional term maps are presented alongside the bar charts depicting the changing occurrence of institutions across the decades, the two types of analyses can be challenging to interpret with respect to each other due to the difference in their unit of analysis. Whilst the bar charts depict counts of individual institutions, the network maps depict the relative thematic focus of clusters of institutions. Thus, we encourage readers to use the bar charts to trace the changing publication count of top institutions and the term maps to study the relative thematic focus of cluster of institutions. We present each of these analyses in detail below.

3.6.1 Institution Publication Counts

For each field delineation and for both global and European ocean science, we create faceted bar charts that depict the number of ocean science papers published by scholars the top 50 institutions across four decades: 1980-1989, 1990-1999, 2000-2009 and 2010-2020. We map the changing publication count of the 50 institutions that published most ocean science papers between 1980-2020. This analysis provides and overview of the changing importance of institutions that publish most ocean science papers, suggesting shifts in research focus.

3.6.2 Institution Co-authorship Networks

We conduct co-authorship network analysis to depict the relationship between the top institutions in European and global ocean science. Two institutions share co-author ties the extent to which papers scientists affiliated with them co-publish papers.

We calculated co-authorship relations based on the normalisation method based on Waltman, Eck, and Noyons (2010) (cf. Waltman and Eck, 2012). To create non-directed institution co-authorship networks, we calculated the normalised co-authorship relationship $r_{ij} = r_{ji}$ between institutions i and j by calculating the mean of the raw co-authorship measure $b_{ij} = b_{ji}$ described by Equation 1

$$b_{ij} = b_{ji} = \sum_{k=1}^{N} a_{ki} a_{kj} (1 - \delta_{ij}) \tag{1}$$

where a_{ki} is an edge that indicates institution i authoring paper k; a_{kj} is an edge that indicates institution j authoring paper k - the product yielding a value bigger than 0 when institutions i and j co-author a; and δ_{ij} is the Kronecker delta function

$$\delta_{ij} = \begin{cases} 0 & \text{if } i \neq j \quad (2) \\ 1 & \text{if } i = j \quad (3) \end{cases}$$

The *(1-δ_{ij})* factor in Equation 1 ensures the exclusion of edges calculating co-authorship between identical institutions. Next, we normalised the raw co-authorship coupling values by dividing them by the sum relatedness of pairs of institutions i and j with all institutions, given by Equation (4)

$$r_{ij} = r_{ji} = \left(\frac{b_{ij}}{\sum_k b_{ik}} + \frac{b_{ji}}{\sum_k b_{jk}}\right) * \frac{1}{2} \tag{4}$$

where k stands for all institutions (all nodes in the network). With this method, the relatedness of institutions is calculated with respect to the sum of their connections. Thus, two institutions can be strongly connected even if they share relatively little connections with other institutions.

3.6.3 Institution Term Maps

As section 3.4.2 discussed, we created term maps using a random sample of 25.000 papers authored by scholars affiliated with the top institutions highlighted by the term maps. We create overlay maps which depict the relative research focus of institution clusters identified through the co-authorship analysis in section 3.6.2. The interactive co-author maps and interactive term maps can be used in tandem to explore differences in research focus. By clicking on institutions in the co-authorship map, we can access the numeric id of the cluster they pertain to. Subsequently we can select the corresponding cluster on the term map overlay.

The report proceeds with analysing epistemological and institutional trends in global and European ocean science.

4 Global Ocean Science

4.1 Delineations of Global Ocean Science

Figure 1 depicts the difference in the three field delineation methods - the lexical, broad journal and narrow journal field delineations - discussed in section 3.1 as a function of the broad disciplinary categories of the CWTS microclusters they match. The figure shows that the narrow journal field delineation is contained in the other two field delineations. As the dark blue bars on the figure show, the lexical and broad journal field delineations overlap to the great extent. However, only the lexical field delineation, on the other hand, matches a large proportion (83%) of social science and humanities microclusters, and a relatively large proportion of the physical sciences and engigeering mircolusters (55%) and the biomedical and health sciences mircoclusters (50%). This suggests important differences between the field delineations. As discussed in section 3.1, the report will analyse the lexical and broad journal ocean science field delineations.

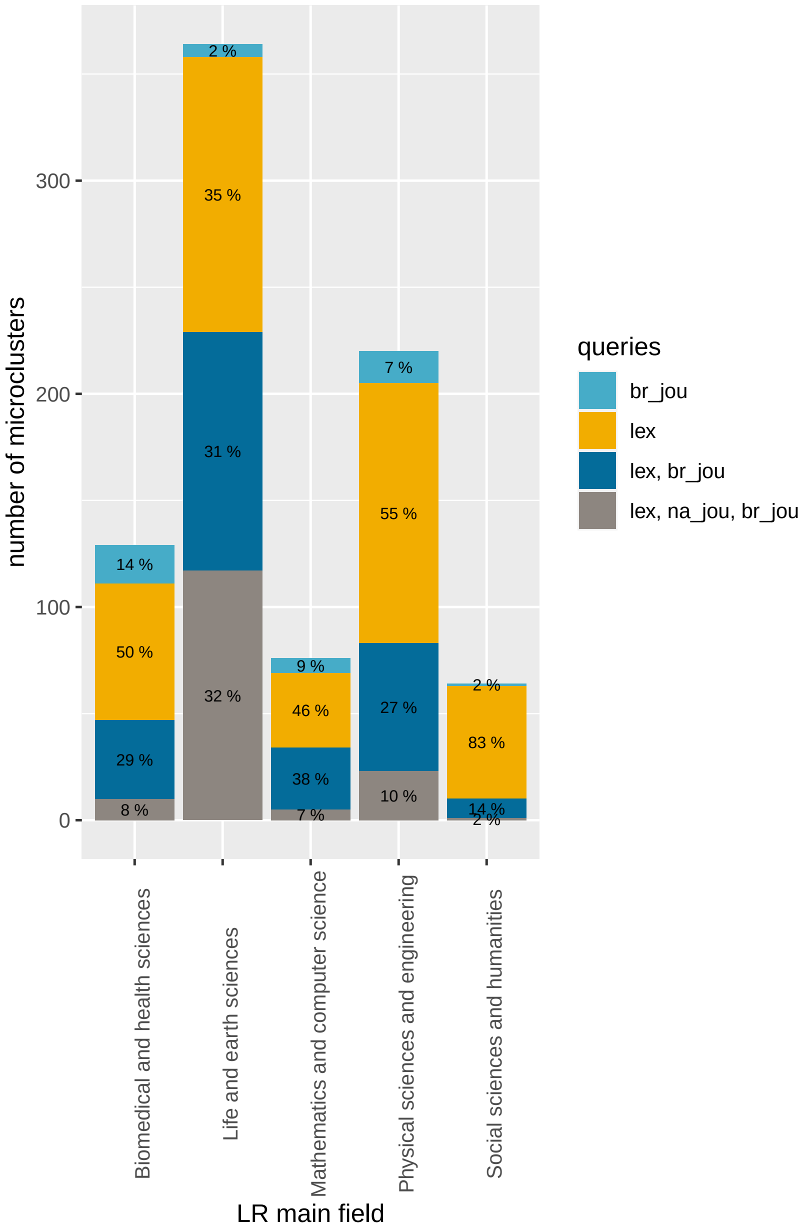


Figure 1: Comparison of field delineations

4.2 Key Research Topics in Global Ocean Science

This section explores key research topics in global and European ocean science and their change over time using the co-occurrence networks of terms from the abstract and title of papers pertaining to two scientometric ocean science fields: ocean science delineated by lexical field delineation and the broad journal based search. As section 3.4 outlined, the maps depict research topics and their changes in global ocean science using a random sample of 25000 papers from each scientometric field.

Figure 2 depicts the research topics and their changes depicted by the lexical ocean science field. The interactive map is available on this link.

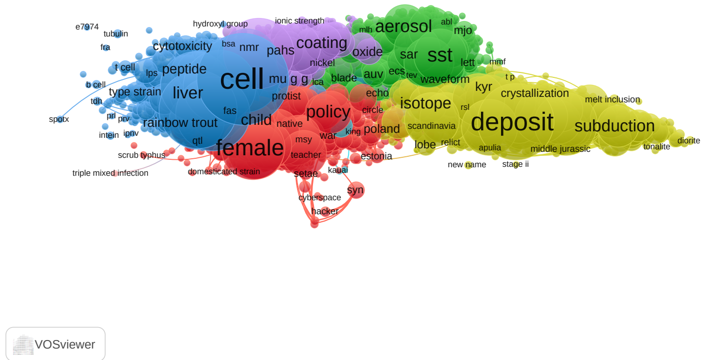


Figure 2: Term map: lexical field delineation, Global ocean science, 1980-2020

Figure 3 depicts the research topics and their changes depicted by the broad journal ocean science field. The interactive map is available on this link.

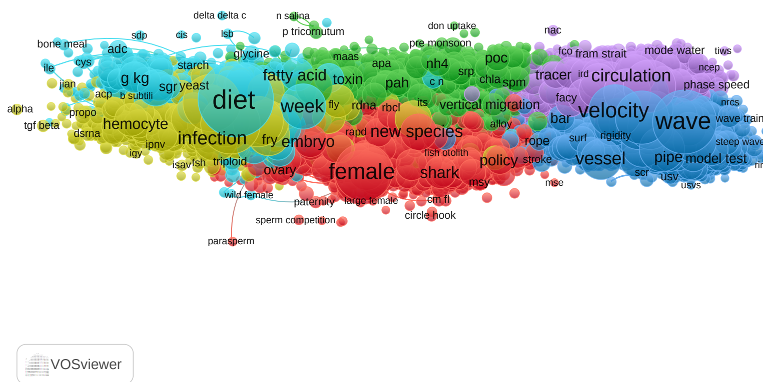


Figure 3: Term map: broad journal field delineation, Global ocean science, 1980-2020

We also illustrate the density of terms in the above two term maps, to help explore similarities and differences in the popularity of terms in different clusters or parts of the term maps.

Figure 4 depicts the density of terms on the lexical term map depicted on figure 2.

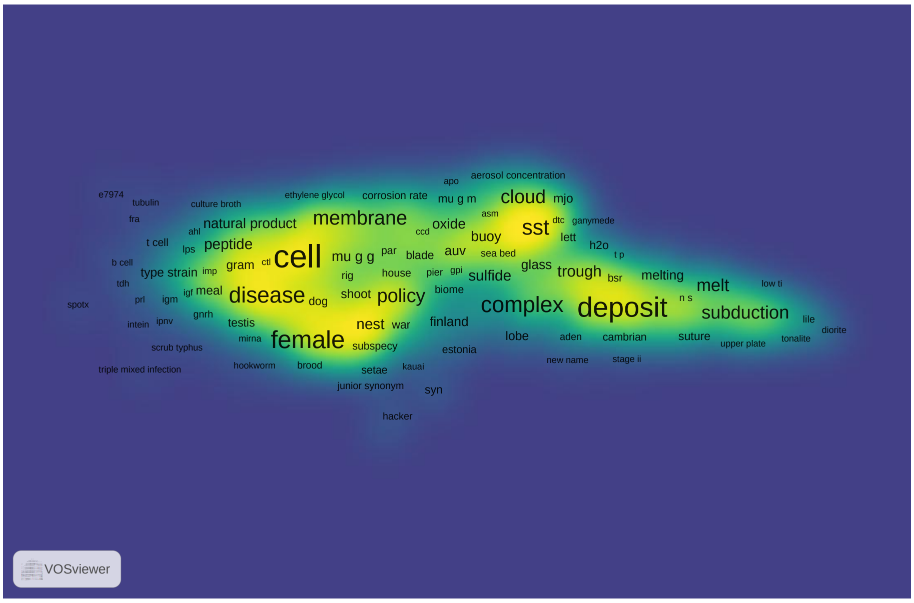


Figure 4: Term map depicting the density of terms: lexical field delineation, Global ocean science, 1980-2020

Figure 5 depicts the density of terms on the broad journal term map depicted on figure 3.

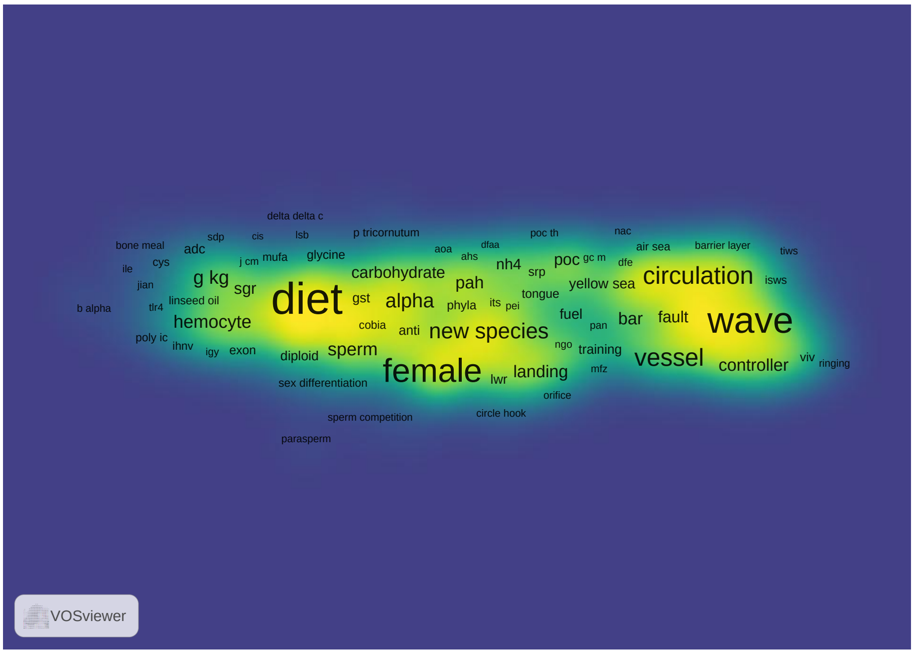


Figure 5: Term map depicting the density of terms: broad journal field delineation, Global ocean science, 1980-2020

Reading maps from left to right helps explore similarities and differences in the perspective the field delineations offer on key topic areas in global ocean science. A structural difference between the networks is the number of term clusters: while the term map of the lexical field delineation in figure 2 depicts five term clusters, the term map of the broad journal field delineation in figure 3 depicts six term clusters. Nevertheless, as discussed below - exploring both maps from left to right - the clusters and their positions highlight a number of similarities between the maps.

The dark blue cluster on the left side of the lexical field delineation term map in figure 2 as well as the light blue and yellow clusters on the left side of the broad journal field delineation term map in figure 3 depict terms associated with fish physiology, pathology and genetics, featuring terms such as gene, infection, cell and immunity. The pathology and resilience of fish is a key concern due to the importance of fishing for global economy. In contrast to the lexical term map, the light blue cluster on the broad journal term map contains more terms about diet: including 'fish feed' and human fish fish consumption (e.g. fish meal).

Next we discuss the red clusters on both maps on the (centre) bottom of the maps. These clusters share similarities, and contain terms associated with fish reproduction (e.g. female, maturity, genetic diversity, offspring, spawning and egg) and resilience, including to predators (e.g. sharks, as depicted by the broad journal map) and fishing (e.g. both maps include the term policy). This cluster also contains terms associated with fisheries markets and their regulation. Terms associated with fishing and fisheries management, such as landing and fishermen seem more more prominent on the broad journal map (on the right side of the red cluster).

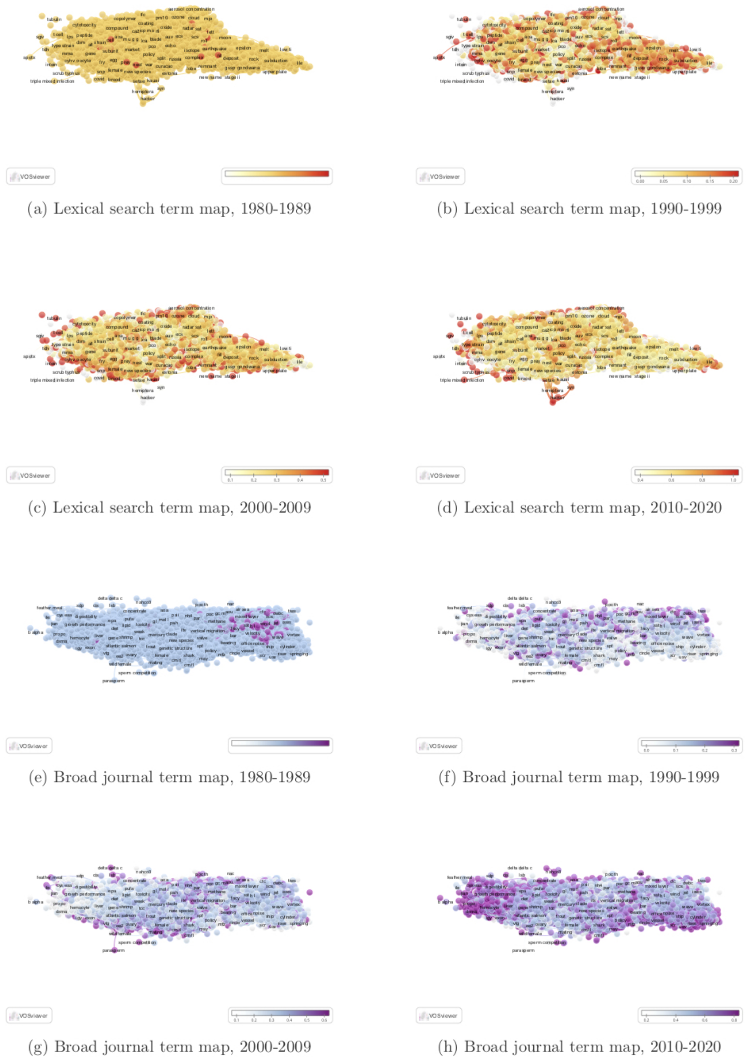
We continue with discussing the (centre) top part of the term maps: the purple cluster on the lexical term map on figure 2, and the green cluster on the broad journal term map on figure 3. Both clusters contain terms associated with the toxicity of ocean ecosystems and relevant methods to study it. For example, the purple cluster in the lexical term map includes terms such as wastewater, residue, microplastics and spectrometry. The green cluster on the on broad journal map features toxin terms such as wastewater and mercury, as well as terms (including molecules) related to ocean nitrification (related to ocean acidification).

We continue with discussing the top right part of the maps: the green cluster in the lexical field delineation term map on figure 2 and the purple cluster on the broad journal term map on figure 3. Both clusters contain terms associated with physical oceanography, including studies of water currents and movement, sea level, sea surface temperature (sst) as well as relevant research and data collection methods, such as satellite on the lexical term map and parametrization on the broad journal term map.

Finally, we discuss the bottom right cluster on both maps: the yellow cluster on the lexical term map on figure 2 and the dark blue cluster on the broad journal term map on figure 3. Both clusters contain terms associated with studying the dynamics of ocean water, including tsunamis and earthquakes. However, we also note differences between the clusters. First, while the yellow cluster on the lexical term map extends relatively far away from the rest of the term map - and shares relatively little overlap with the other clusters - the dark blue cluster on the broad journal map is more closely linked to the purple cluster above it, which focuses on physical oceanography. The semantics of the terms reflect the clusters' position. While the yellow cluster on the lexical term map mainly focus on ocean geochemistry, the dark blue terms on the broad journal term map depict terms associated with physical oceanography (e.g. wave, velocity) and associated research methods (e.g. sensor, simulation, error). In addition, the dark blue cluster on the broad journal term map also contain terms associated with ocean infrastructure, including ships and underwater infrastructure (e.g. pipes). Altogether, the blue cluster on the broad journal term map seems to put a larger emphasis on human uses of ocean environments compared to the yellow cluster on the lexical term map.

4.2.1 Temporal Shifts in Research Topics

Next, we analyse the shifts in ocean science topics across four decades 1098-2020. Figure 6 depicts the shifts in research topics using VOSviewer overlays using both the lexical field delineation and broad journal field delineation. The interactive versions of these visualisations are available using the interactive lexical field delineation term map and the interactive broad journal field delineation term map respectively.



(a) Lexical search term map, 1980-1989

(b) Lexical search term map, 1990-1999

(c) Lexical search term map, 2000-2009

(d) Lexical search term map, 2010-2020

(e) Broad journal term map, 1980-1989

(f) Broad journal term map, 1990-1999

(g) Broad journal term map, 2000-2009

(h) Broad journal term map, 2010-2020

Figure 6: Shifts on global ocean science research topics 1980-2020, lexical and broad journal field delineations

The temporal maps of both field delineations suggest a relative shift in focus from topics depicted on the rights side of the maps to topics depicted on the left side of the maps, albeit the shift is more noticeable in the broad journal field delineation map depicted in subfigures e)-h) in figure 6.

In the lexical field delineation term maps (depicted by subfigures a) - d) in figure 6), we note the relative prevalence of terms on the right side of the map (associated with the yellow cluster depicting terms related to ocean geochemistry in figure 2) between 1990-1989, compared to ocean science since 1990. Between 1990-2000, terms in the bottom left and centre top of the map became relatively more prevalent, associated with research on ocean toxicity as well as fish reproduction and pathology. In the past decade (2010-2020) terms on the top right and centre top of the map became relatively more prominent, corresponding to research on ocean toxicity as well a fish physiology and genetics.

Subfigures e) - h) in figure 6 corresponding to the broad journal field delineation term map suggest a relative shift in research focus to fish physiology, genetics and growth on the left side of the map (corresponding to the yellow and light blue clusters on figure 3); research on fisheries management and policy on the bottom centre or bottom right of the map (corresponding to part of the red cluster on figure 3); and physical oceanography studies of water movement and ocean infrastructure depicted on the bottom right of the map (corresponding to part of the dark blue cluster on figure 3) over time. Subfigure h) suggests that these topics are relatively more popular between 2010-2020 than before. Comparatively, as subfigure f) shows, between 1990-1999, research around fisheries management and physical oceanography (depicted in the bottom centre and bottom right of the map) received less attention compared to the rest of the map. Subfigure g) suggests that between 2000-2009 global ocean science delineated by the broad journal field delineation prioritised fish reproduction (in the bottom left of the map and ocean toxicity (in the top centre and top right of the map).

4.3 Key Journals: Global Ocean Science

This section explores shifts in global ocean science research topics by studying changes in the number of ocean science papers published in the top 50 most frequent journals across four decades 1980-2020. As section 3.5 outlined, while we discuss the epistemological history of global ocean science through the changing popularity of the 50 journals that have published most ocean science papers between 1980-2020, section 8.1.1 includes visualisations about the changing popularity of the 50 journals that published most ocean science papers in the past decade (2010-2020).

This section discusses shifts in global ocean science research topics through changes in the number of papers published in the 50 journals that have published most ocean science papers between 1980-2020 in the two ocean science field delineations: the one delineated by lexical field delineation and the other delineated by broad journal field delineation. As figure 7 depicts, there is relatively little overlap between the 50 journals between the lexical and broad journal ocean science field delineations.

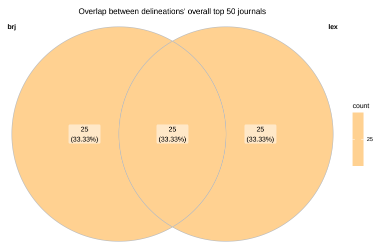
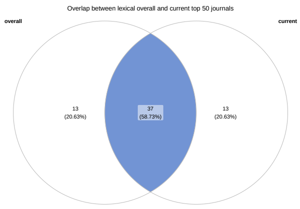


Figure 7: Venn global journals overall

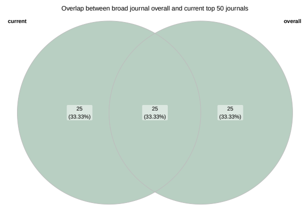
The figures below depict the overlap of the top 50 current visualisations with the overall top 50 visualisations discussed in section 4.3. As figure 8a shows, there is a fair overlap between the overall and current journal for the lexical field: 37 out of 50 journals are shared between the two lists. In contrast, as figure 8b shows, there is only 25 common current and overall top journal for the broad journal field's top 50 journals.
Institutions only included in both the lexical and broad journal global top 50 are:

Institutions only included in the lexical global top 50 are CNRS - National Institute for Earth Sciences & Astronomy (INSU), Columbia University, Japan Agency for Marine-Earth Science & Technology (JAMSTEC), Max Planck Society, NERC Natural Environment Research Council, UK Research & Innovation (UKRI), United States Department of Energy (DOE), Universite Paris Saclay, University of Colorado System, University of London, University of Queensland, and University of Texas System.

Institutions only included in the broad journal global top 50 are Chinese Academy of Fishery Sciences, Consejo Nacional de Investigaciones Cientificas y Tecnicas (CONICET), Fisheries Research Agency - Japan, Institute of Marine Research - Norway, Institute of Oceanology, CAS, James Cook University, Shirshov Institute of Oceanology, Texas AM University College Station, Universidade de Lisboa, Universidade de Sao Paulo, University of Bergen, and the



(a) Venn diagram: overlap between the global lexical field delineation overall and current top journals



(b) Venn diagram: overlap between the global broad journal field delineation overall and current top journals

Figure 8: Overlap between top journals in global ocean science for the lexical and broad journal field delineations

University of Tasmania.

Figure 9 depicts the overall top 50 journals in the lexical global ocean science field and changes in the number of ocean science papers they publish across four decades.

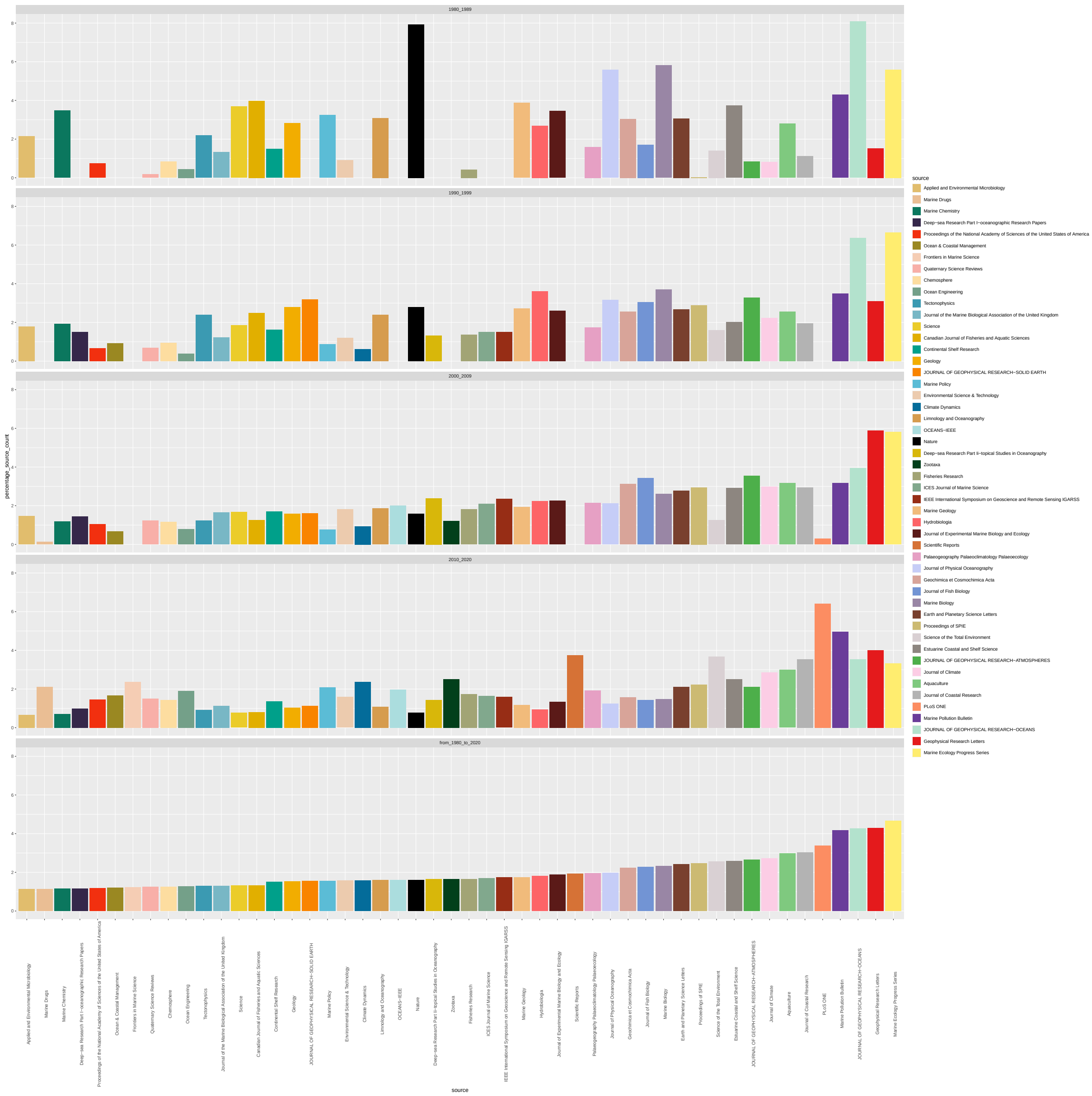


Figure 9: lexical field delineation, global ocean science, overall top 50 journals and their changing importance over time

We highlight a few trends the figure suggests. We first explore it from left to right, exploring journals that publish decreasing proportion of ocean science papers. We see decreasing proportion of papers published across the decades in a number of journals, including Marine Chemistry; Science; the Canadian Journal of Fisheries and Aquatic Sciences; Nature; Marine Geology; Hydrobiologia; the Journal of Physical Oceanography; Marine Biology and the Journal of Geophysical Research-Oceans. This suggests that a relatively decreasing proportion of ocean science scholarship is published in the big interdisciplinary journals Science and Nature. On the other hand - this time exploring the visual roughly from right to left - two interdisciplinary journals: Scientific Reports and PLOS One become key publication venues for ocean science in the past decade (2010-2020). The journals Science of the Total Environment; Zootaxa; Climate Dynamics; Ocean Engineering; Frontiers in Marine Science (the latter only appeared in the past decade); and Marine Drugs also publish an increasing proportion of ocean science papers. Finally, we note that in the past decade (2010-2020) the journal Marine Policy is regaining its relative popularity, after being popular in 1980-1989 and loosing relative popularity 1990-2010.

Figure 10 depicts the overall top 50 journals in the broad journal global ocean science field and changes in the number of ocean science papers they publish across four decades.

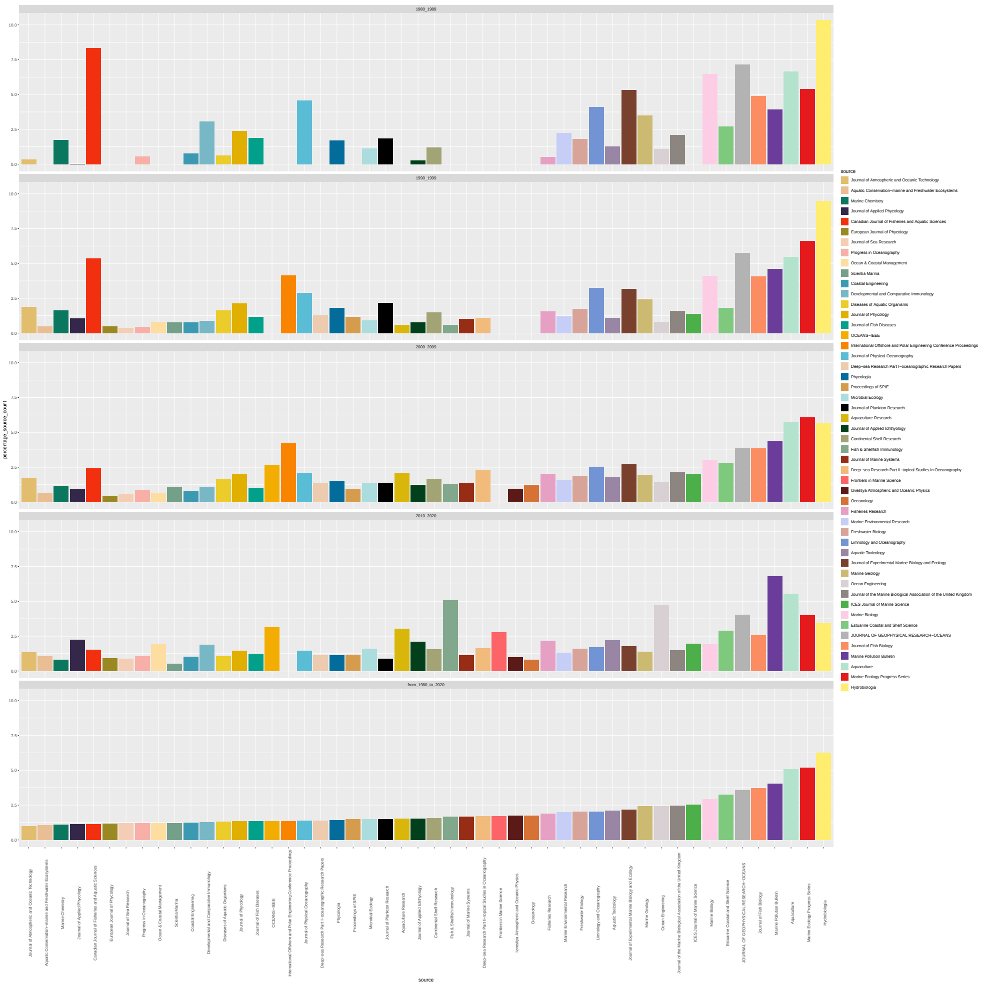


Figure 10: broad journal field delineation, global ocean science, overall top 50 journals and their changing importance over time

We highlight a few trends the figure suggests. We first explore it from left to right, exploring journals that publish decreasing proportion of ocean science papers. We see decreasing proportion of papers published across the decades in a number of journals, including the Canadian Journal of Fisheries and Aquatic Sciences (a significant decrease); the Journal of Physical Oceanography; Limnology and Oceanography; the Journal of Experimental Marine Biology and Ecology; Marine Biology; Estuarine Coastal and Shelf Science; Marine Geology; the Journal of Geophysical Research - Oceans; the Journal of Fish Biology; and Hydrobiologia. On the other hand - this time exploring the visual roughly from right to left - a number of journals become increasingly important publication venues over time. These include Ocean Engineering; Frontiers in Marine Science (which only appeared in the past decade, 2010-2020); a number of fish science related journals including Fish Shellfish Immunology; Aquaculture Research; and the Journal of Applied Ichthyology; as well as OCEANS IEEE; Ocean Coastal Management; and the Journal of Applied Phycology (research on algae). Finally, we note that in the past decade (2010-2020) the journal Developmental and Comparative Immunology is regaining its relative popularity, after being popular in 1980-1989 and loosing relative popularity 1990-2010.

Altogether, whilst the lexical field delineation highlighted the significant role of interdisciplinary journals, such as Nature, Science, Plos One and Scientific Letters (and for the latter two the growing proportion of ocean science papers they publish) and climate (system) related publication venues (including the Science of the Total Environment and Climate Dynamics); as well as and the growing importance of biomedical research associated with oceans through the journal Marine Drugs, the broad journal delineation highlighted the growing importance of journals associated with fisheries and algae related research.

The two delineations also highlighted common trends. First, the decreasing proportion of ocean science papers published in the Canadian Journal of Fisheries and Aquatic Sciences; Marine Geology; and the Journal of Geophysical Research-Oceans. Second, the growing importance of Frontiers in Marine Science since its appearance in the past decade. Third, the relative growth in ocean engineering related publication venues (Ocean Engineering in the lexical field, and Oceans - IEEE in the broad journal field). Finally, both the lexical and broad journal field delineations highlighted the importance of marine social science venues: Ocean Coastal Management (broad journal field) and Marine Policy (lexical field delineation field).

4.4 Key Institutions: Global Ocean Science

This section discusses the changing proportion of papers published by top institutions in the lexical and broad journal field delineations. Figure 11 depicts the overlap between the top 50 global institutions in the lexical and broad journal field delineations. We note a relatively strong overlap between the two sets of institutions: 38 out of 50 are included in both.

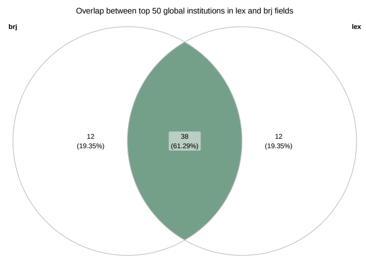


Figure 11: Overlap between the global top 50 institutions in the lexical and broad journal field delineations

Institutions included in both visualisations are the Alfred Wegener Institute, Helmholtz Centre for Polar & Marine Research, Centre National de la Recherche Scientifique (CNRS), Chinese Academy of Sciences, Commonwealth Scientific Industrial Research Organisation (CSIRO), Consejo Superior de Investigaciones Cientificas (CSIC), Consiglio Nazionale delle Ricerche (CNR), Fisheries & Oceans Canada, Helmholtz Association, Hokkaido University, Ifremer, Institut de Recherche pour le Developpement (IRD), NERC National Oceanography Centre, National Aeronautics & Space Administration (NASA), National Oceanic Atmospheric Admin (NOAA) - USA, Ocean University of China, Oregon State University, Russian Academy of Sciences, Sorbonne Universite, State University System of Florida, Texas AM University System, United States Department of Defense, United States Department of the Interior, United States Geological Survey, United States Navy, University System of Georgia, University System of Maryland, University of British Columbia, University of California San Diego, University of California System, University of Chinese Academy of Sciences, 'CAS', University of Hawaii System, University of North Carolina, University of Southampton, University of Tokyo, University of Washington, University of Washington Seattle, Utrecht University, and the Woods Hole Oceanographic Institution.

Institutions included only in the global top 50 lexical field are the CNRS - National Institute for Earth Sciences & Astronomy (INSU), Columbia University, Japan Agency for Marine-Earth Science & Technology (JAMSTEC), Max Planck Society', 'NERC Natural Environment Research Council, UK Research & Innovation (UKRI), United States Department of Energy (DOE), Universite Paris Saclay, University of Colorado System, University of London, University of Queensland, and University of Texas System.

Institutions included only in the global top 50 broad journal field are the Chinese Academy of Fishery Sciences, Consejo Nacional de Investigaciones Cientificas y Tecnicas (CONICET), Fisheries Research Agency - Japan, Institute of Marine Research - Norway, Institute of Oceanology, CAS, James Cook University, Shirshov Institute of Oceanology, Texas A&M

University College Station, Universidade de Lisboa, Universidade de Sao Paulo, University of Bergen, and University of Tasmania.

Figure 12 depicts the changing proportion of papers published by the 50 institutions with most ocean science papers in the lexical ocean science field.

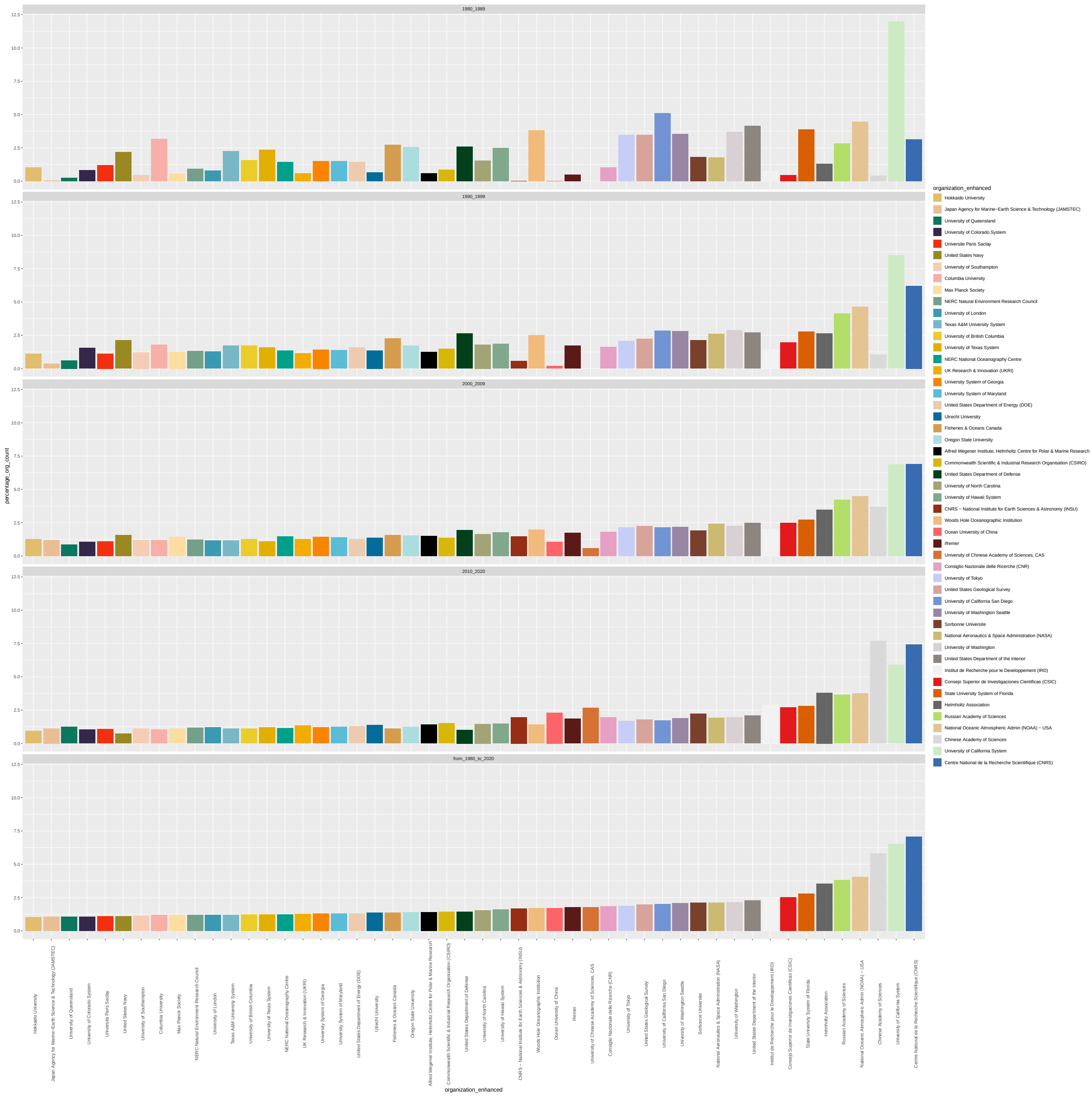


Figure 12: lexical field delineation, global ocean science, overall top 50 institutions and their changing importance over time

Figure 13 depicts the co-authorship network, and the interactive co-author map is available on this link.

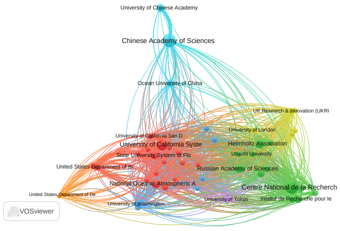


Figure 13: lexical field delineation, global ocean science, overall top 50 institutions co-author network

The interactive term map which illustrates the comparative research focus of lexical global top institution clusters in the co-authorship network in figure 13 is available on this link. The term clusters depicted on this map resemble the clusters in the global ocean science term maps.

Figure 14 depicts the changing proportion of papers published by the 50 institutions with most ocean science papers in the broad journal ocean science field.

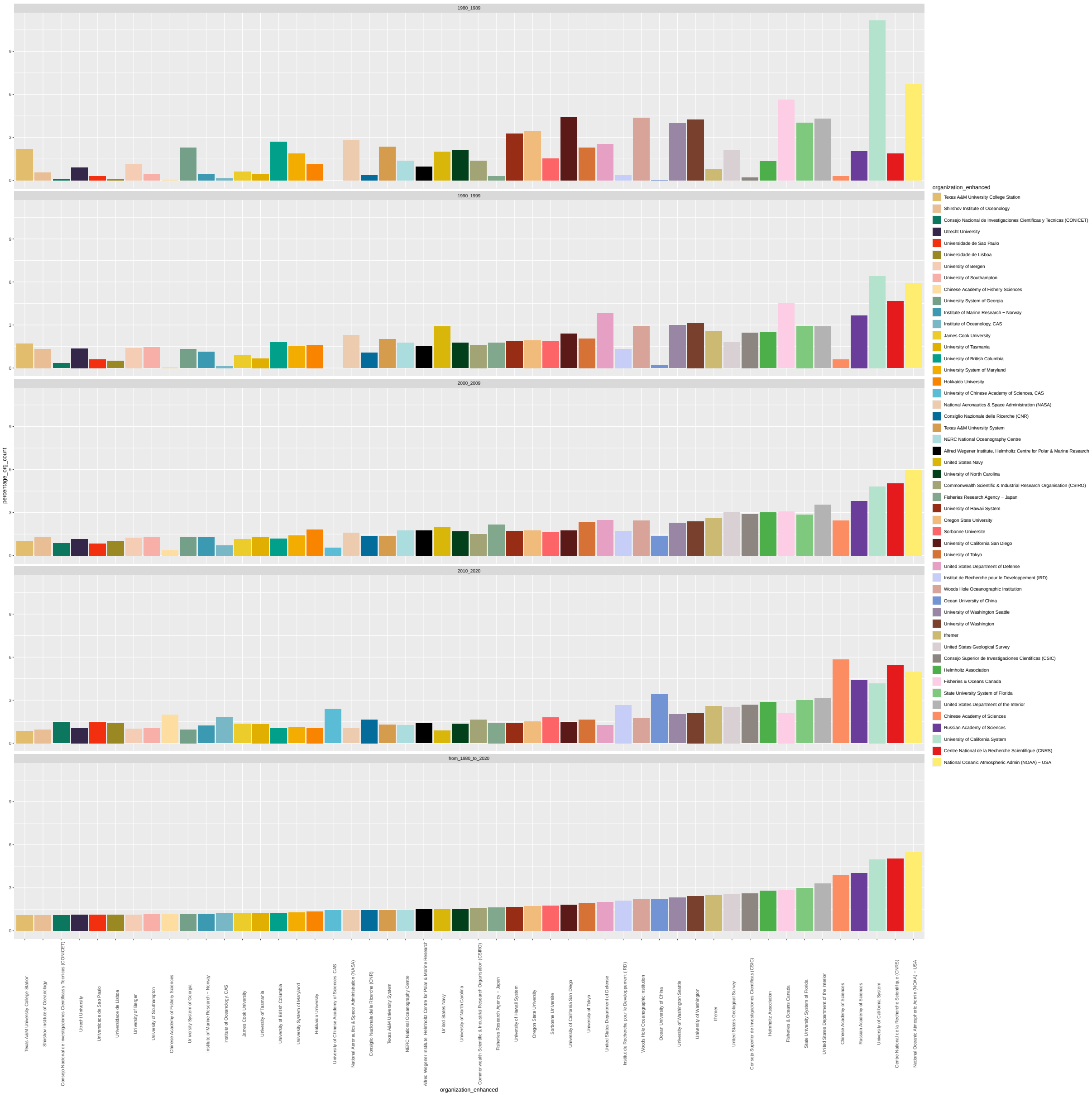


Figure 14: broad journal field delineation, global ocean science, overall top 50 institutions and their changing importance over time

Figure 15 depicts the co-authorship network, and the interactive co-author map is available on this link.

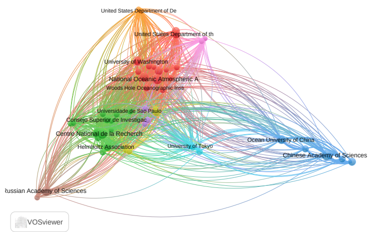


Figure 15: broad journal field delineation, global ocean science, overall top 50 institutions co-author network

The interactive term map which illustrates the comparative research focus of global broad journal top institution clusters in the co-authorship network in figure 15 is available on this link.

Due to the strong overlap between the lexical and broad journal top 50 global institutions, we proceed with analysing institutional trends based on the lexical field delineations. We first note a few institutions that publish decreasing proportion of ocean science papers in the lexical field over time. Exploring figure 12 from left to right, these include the United States Navy, Columbia University, Texas AM University System, University of British Columbia, University of Texas System, Fisheries Oceans Canada, Oregon State University, United States Department of Defense, University of Hawaii System. The Woods Hole Oceanographic Institution's ocean science paper count decreases steeply. In addition, the United States Geological Survey, University of California San Diego, United States Department of the Interior also publish decreasing proportion of ocean science papers over time. Although the University of California System publishes relatively decreasing paper counts, it remains a central institution.

We note the decreasing proportion of papers published by the United States Navy and the United States Department of the Interior depicted in the orange cluster (cluster 7) of the co-authorship network in figure 13. Exploring the interactive term map, we observe that these two institutions mainly focus on physical oceanography research about water movement and sea surface temperature. In addition, a number of institutions with diminishing proportion of ocean science papers, such as the Woods Hole Oceanographic Institution, the University of Hawaii System and the University of California San Diego are depicted in the red cluster (cluster 1) of the co-author network in figure 13. Exploring the interactive term map, we observe that these two institutions mainly focus on physical oceanography research about water movement and sea surface temperature, and fisheries (policy) research. Future research could explore the overall proportion of papers published by institutions in this cluster.

Next, we note the institutions that publish growing proportion of ocean science papers over time, exploring figure 12 from right to left. These institutions include the Centre National de la Recherche Scientifique (CNRS), the Chinese Academy of Sciences, the Helmholtz Association, the Institut de Recherche pour le Developpement (IRD), Consejo Superior de Investigaciones Cientificas (CSIC), Ocean University of China, University of Chinese Academy of Sciences, CAS; and CNRS National Institute for Earth Sciences Astronomy (INSU).

We note the growing proportion of papers published by Chinese ocean science institutions depicted in the bright blue cluster (cluster 6) of the co-authorship network in figure 13. Exploring the interactive term map, we observe that the research focus of these institutions include most ocean science research topics. We also explore the growing proportion of ocean science papers published by French institutions depicted in the green cluster (cluster 2) of the co-authorship network in figure 13. Exploring the interactive term map, we observe that the research focus of these institutions is also dispersed on the term map, albeit with relatively less focus on fisheries policy and physical oceanographic studies of water movement and sea surface temperature.

5 European Ocean Science

This section presents European Ocean Science.

5.1 Three Delineations of European Ocean Science

Figures 16 - 18 depict the paper count of European countries across the three field delineations. As the figures show, the lexical and broad journal field delineations rank European countries' ocean science paper production relatively similarly.

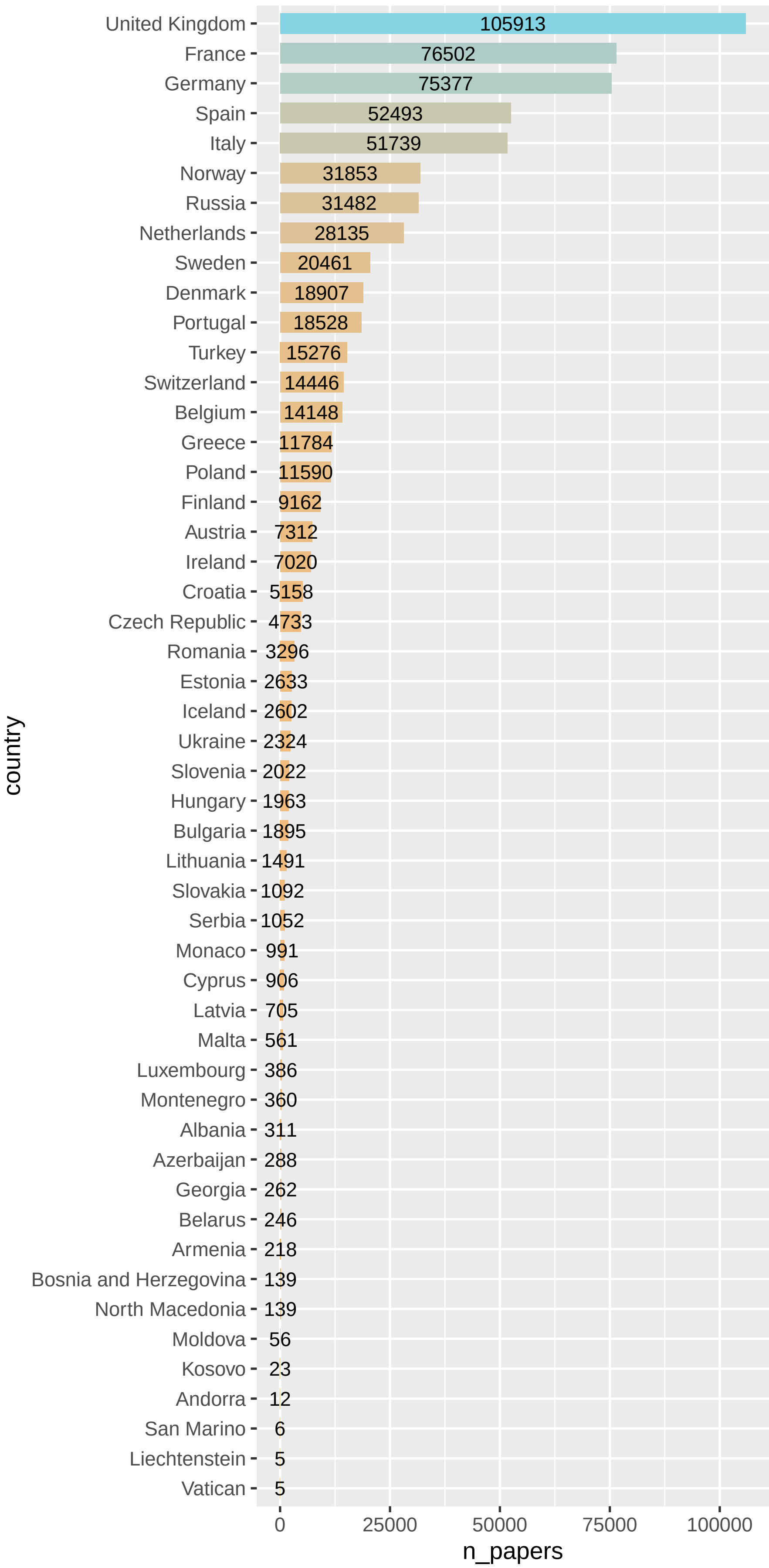


Figure 16: lexical field delineation, paper count of European countries

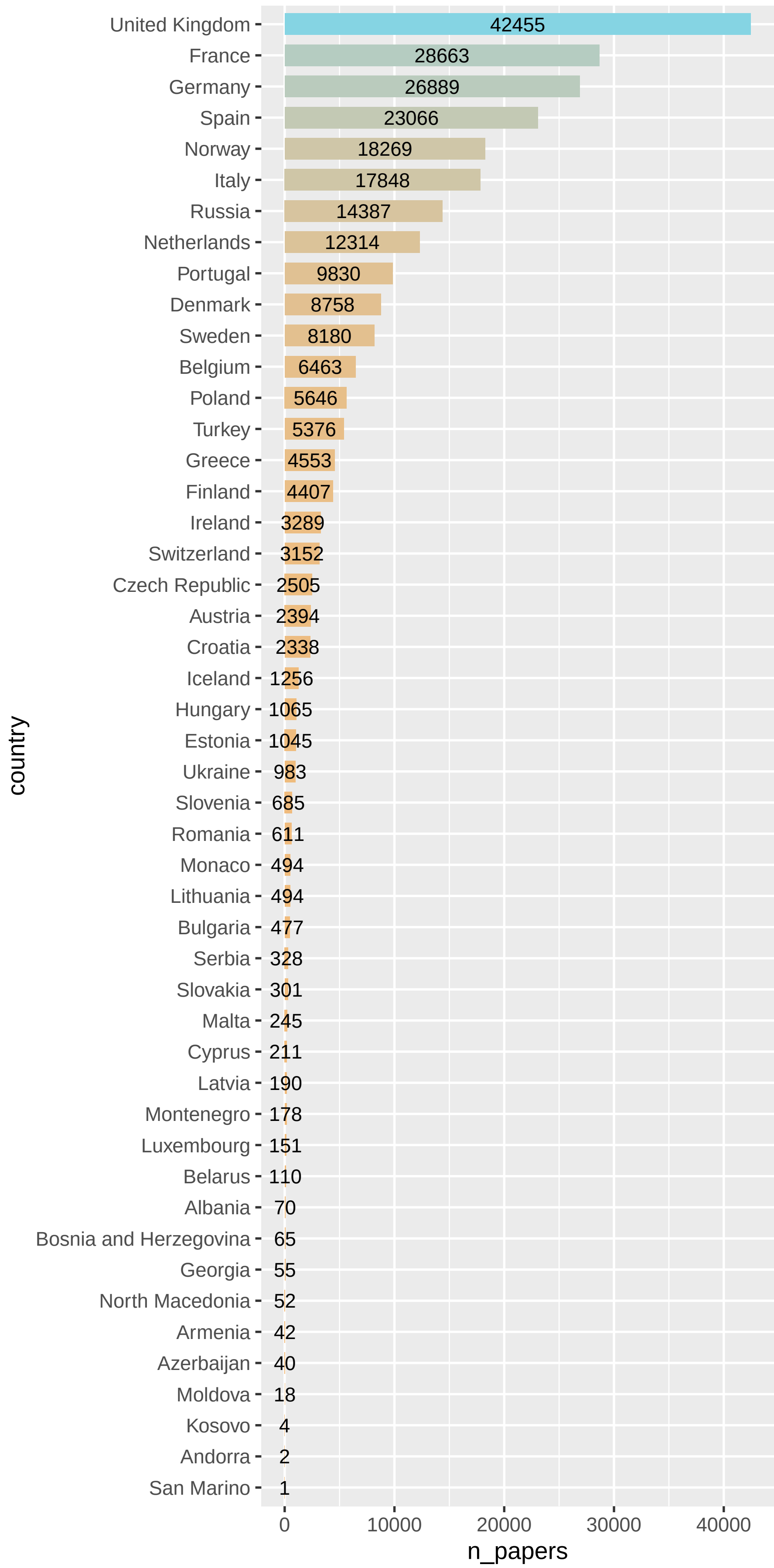


Figure 17: broad journal field delineation, paper count of European countries

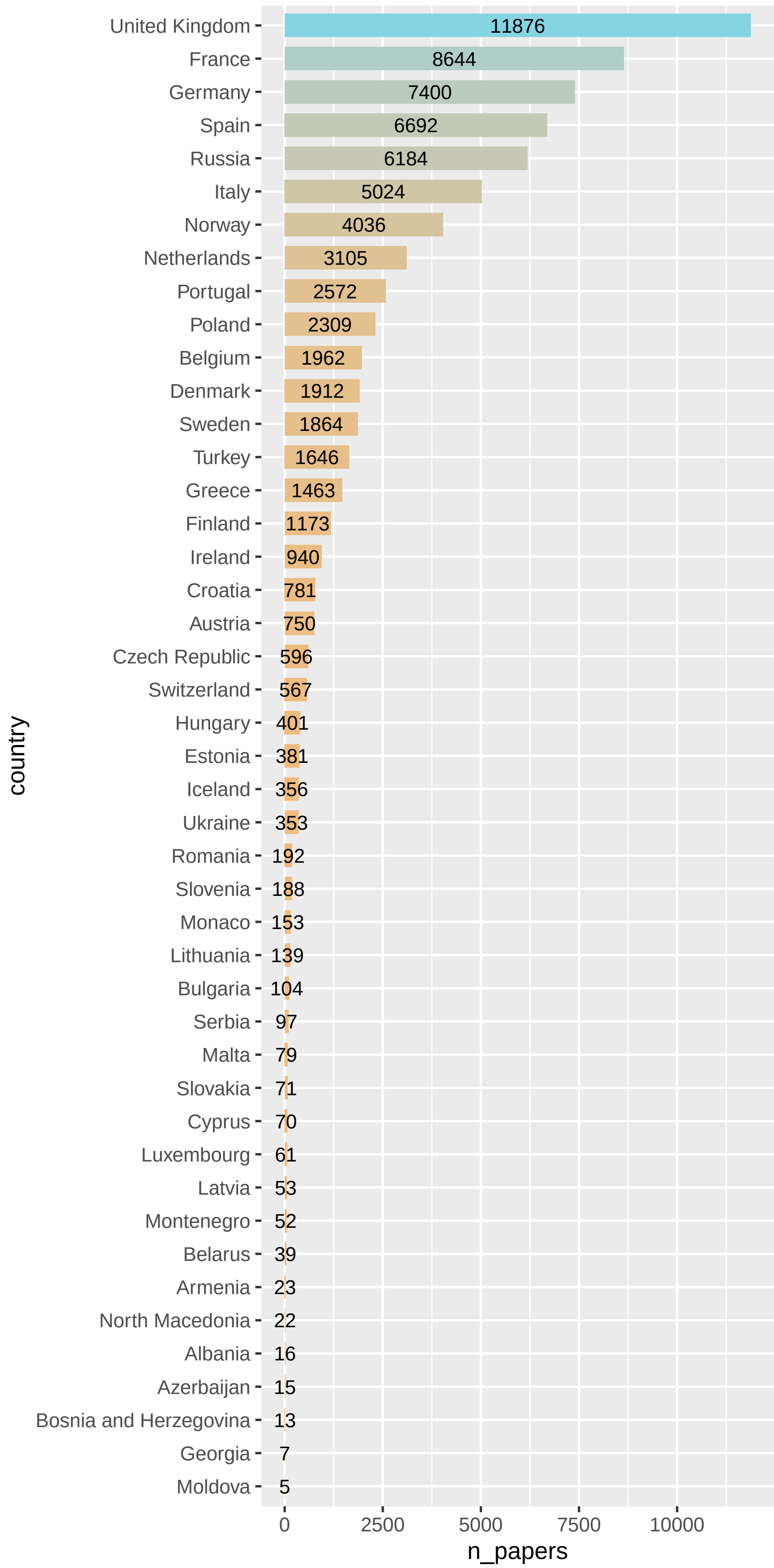


Figure 18: Narrow journal search, paper count of European countries

5.2 European Ocean Science Research Topics

The maps in this section depict research topics and their changes in European ocean science using a random sample of 25000 papers from each scientometric field. We depict the topical focus of European countries with most ocean science papers published.

Figure 19 depicts the research topics and their changes depicted by the lexical ocean science field. The interactive map is available on this link.

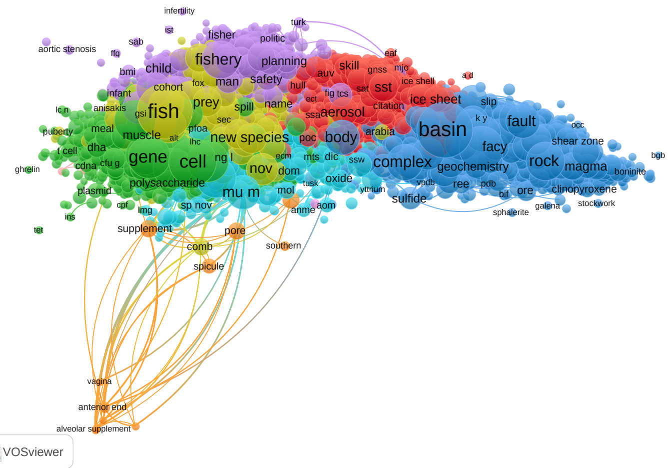


Figure 19: Term map: lexical field delineation, European ocean science, 1980-2020

Figure 20 depicts the research topics and their changes depicted by the broad journal ocean science field. The interactive map is available on this link.

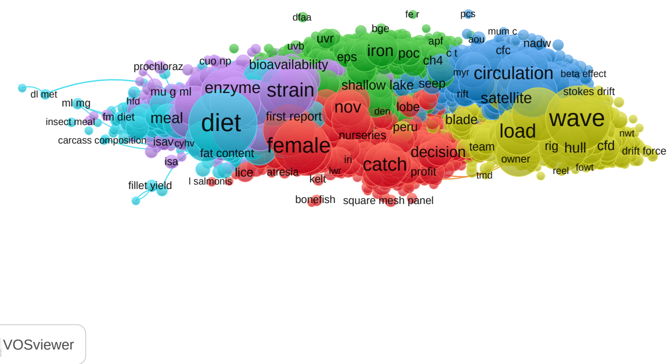


Figure 20: Term map: broad journal field delineation, European ocean science, 1980-2020

We first note similarities between the European term map of the broad ocean science field depicted by figure 20 and the global ocean science term maps discussed in section 4.2, in particular, the global ocean science term map produced with the broad journal delineation depicted by figure 3. Similar to the global map, the left side of the European broad journal term map features a cluster (in light blue) with terms related to fish feed and fish diet, and a cluster (in purple) featuring terms related to fish genetics, physiology and pathology. Also similar to the global term maps, the red cluster on the bottom centre of figure 20 contains terms related to fish reproduction and fisheries management. Further, similar to the global ocean science term ma, the upper green cluster on the European broad journal term map contains terms related to ocean biochemistry and toxicity, the upper right cluster (in blue) contains terms similar to the upper right cluster of the global term map on figure 20 (in purple) about physical oceanography, water movement and sea surface temperature. Finally, similar to the global broad journal term map, the bottom right cluster of the European broad journal term in yellow map contains terms related to ocean infrastructure and their study.

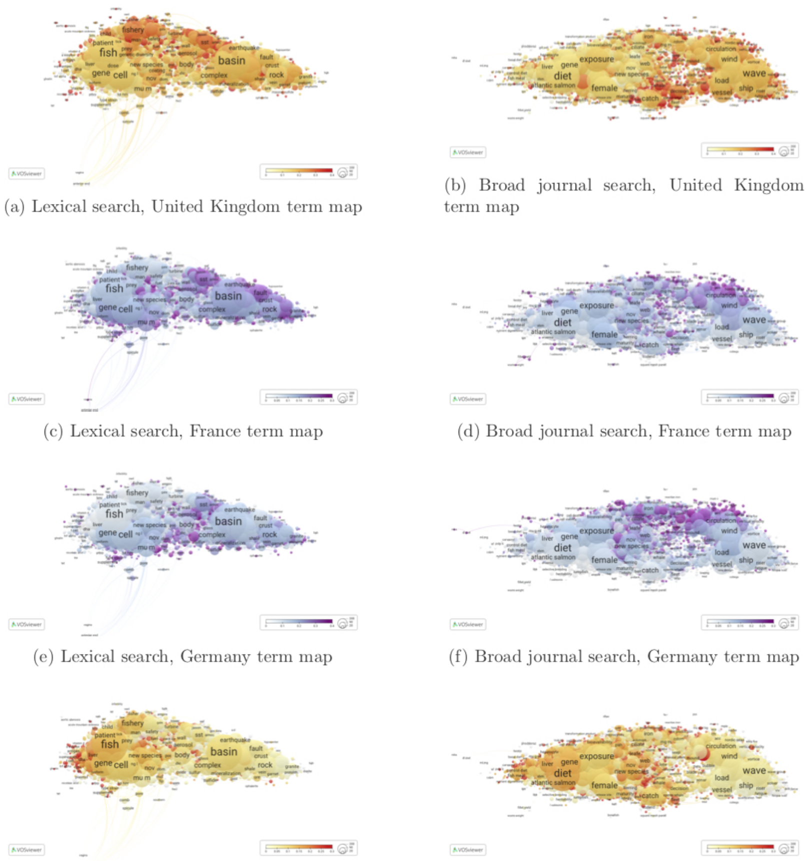
The European term map of the lexical field delineation shares similarities with the global term maps discussed in section 4.2. Similar to the global broad journal term map, the left side of figure 19 - especially the green cluster - contains terms related to research about fish genetics and pathology, also related to aquaculture (e.g. fish fed). The yellow cluster in the lexical European term map - closely overlapping with the green cluster - depicts terms related to the resilience and reproduction (e.g. female) of fish populations or fish stocks against predators (e.g. prey), in terms of their genetic diversity and against fishing (e.g. catch). The purple cluster on the top of the European lexical term map contains terms similar to the red cluster on the global term maps and the European broad journal term map - with terms related to fisheries policy and management -. However, we note two main differences. First, in contrast to the red clusters in the global term maps and the European broad journal map, the purple cluster of the European lexical term map does not contain terms related to fish reproduction (which, in turn, are included in the yellow cluster). Second, terms related to human health (e.g. bmi, patient) are also included in this cluster. Continuing our analysis, the light blue cluster on the European lexical term map contains term related to toxins and ocean biochemistry, mainly included in the red and purple clusters of the global lexical term map. The red cluster on the European lexical term map shares similarities which clusters on the other map related to physical oceanography and the study of sea surface temperature. Finally, the rightmost (dark blue) cluster in the European lexical term map contains terms similar to the right most (yellow) cluster on the global lexical term map about marine geology and geochemistry.

Altogether the two global and two European term maps divide ocean science into similar broad topic areas: fisheries research (including fish reproduction, pathology, genetics and aquaculture - and partially related human biomedical research), marine social science (including fisheries and coastal management), ocean biochemistry, physical oceanography (including studies of sea surface temperature and ocean climate interactions). In addition, the broad journal term maps prominently feature terms related to the study of ocean (and underwater) infrastructures, and the lexical term maps feature more prominently terms related to ocean geology and geochemistry.

Given the similarities among the global and European term maps, we refer the readers to the interactive term maps to explore temporal shifts in European ocean science. Next, we we present term maps which illustrate the varying research focus of European countries.

5.2.1 Country Research Highlights

We present term maps which illustrate the varying research focus of the four European countries who publish the most ocean science papers according to both the lexical and broad journal field delineations: the United Kingdom, France, Germany and Spain.



(a) Lexical search, United Kingdom term map

(b) Broad journal search, United Kingdom term map

(c) Lexical search, France term map

(d) Broad journal search, France term map

(e) Lexical search, Germany term map

(f) Broad journal search, Germany term map

(g) Lexical search, Spain term map

(h) Broad journal search, Spain term map

Figure 21: Term maps: lexical and broad journal field delineation, European countries top 4

Before we analyse the European country maps, note the difference in clusters' position discussed in section 5.2. For example, on the European lexical term map, the cluster related to fisheries and coastal management policy is located on the top part of the map, whereas in the broad journal European term map it is located on the bottom of the term map. Both maps highlight the United Kingdom's relative focus on fisheries and coastal management, ocean biochemistry and physical oceanography. Both maps highlight France's and Germany's relative focus on ocean biochemistry and physical oceanography. Both maps highlight Germany's relative focus on, and Spain's relative focus on fish physiology research. For more details, please explore the interactive visualisations which illustrate the focus of multiple countries - available for the lexical field delineation term map and the the broad journal field delineation term map.

5.3 European Ocean Science Top Journals

This section explores the changing importance of key journals in European ocean science. As section 3.5 outlined, while we discuss the epistemological history of European ocean science through the changing popularity of the 50 journals that have published most European ocean science papers between 1980-2020, section 8.2.1 includes visualisations about the changing popularity of the 50 journals that published most European ocean science papers in the past decade (2010-2020).

Figure 22 depicts the 50 journals that publish the most European ocean science papers in the lexical ocean science field.

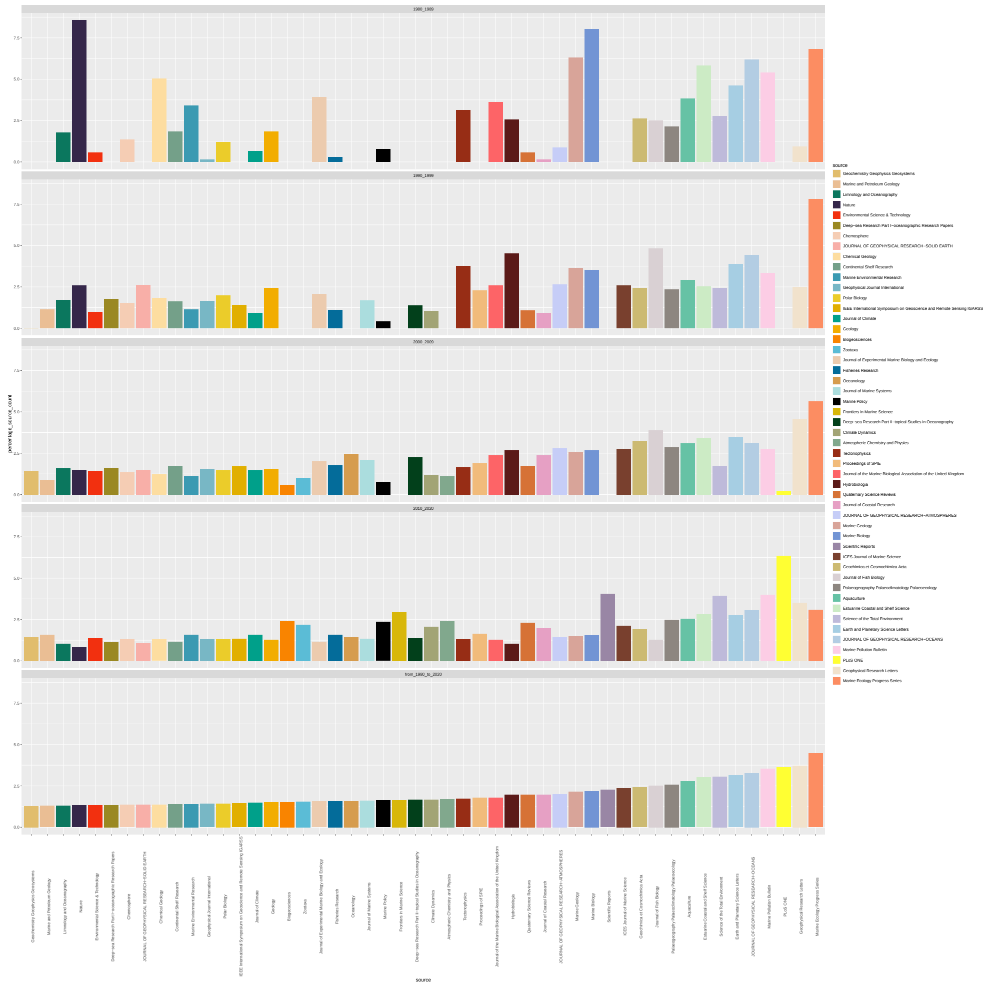


Figure 22: lexical field delineation, Overall top journals in European Ocean science

Figure 22 depicts the 50 journals that publish the most European ocean science papers in the broad journal ocean science field.

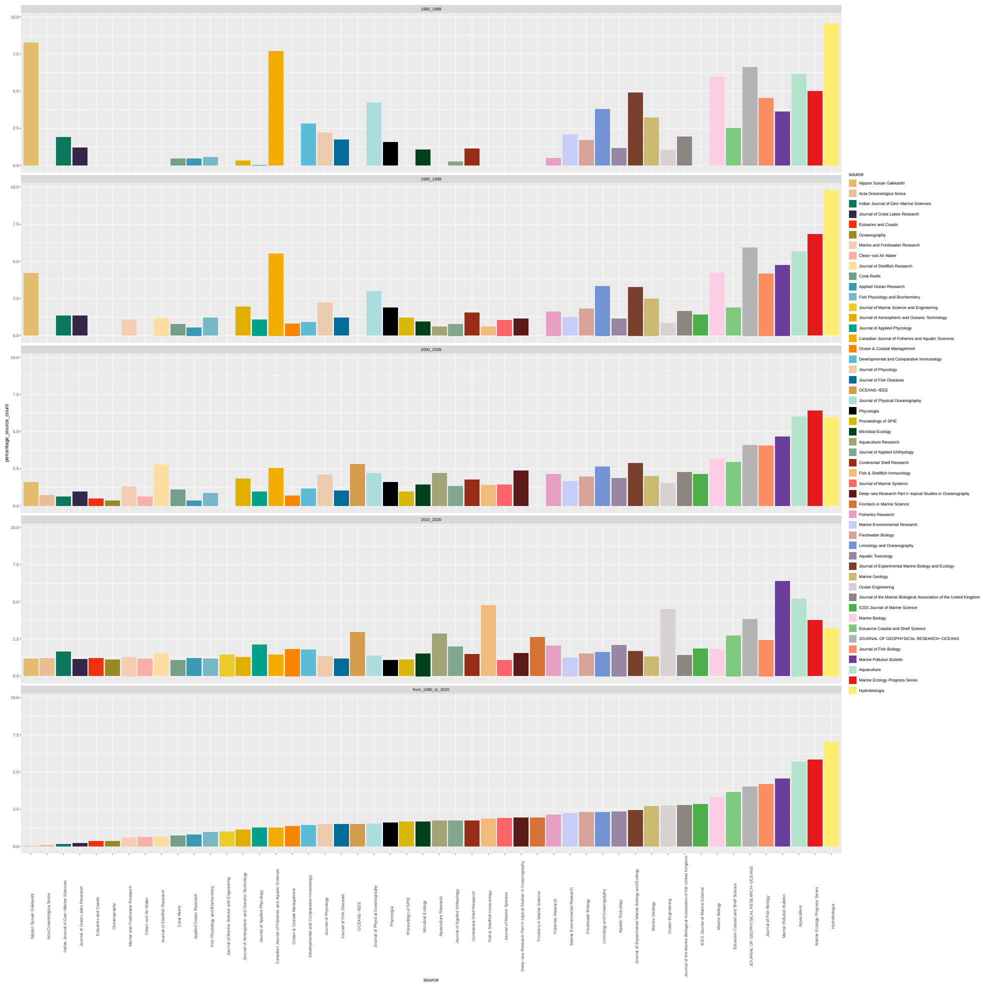


Figure 23: broad journal field delineation, Overall top journals in European Ocean science

First, we highlight a few journals that publish relatively growing proportion of European ocean science papers across time. In the lexical ocean science field, these include Nature, Chemical Geology, Marine Environmental Research, Tectonophysics, Proceedings of SPIE, Journal of the Marine Biological Association of the United Kingdom, Marine Geology, Estuarine Coastal and Shelf Science, JOURNAL OF GEOPHYSICAL RESEARCHOCEANS, and the Marine Ecology Progress Series. In the broad journal field delineation these include Nippon Suisan Gakkaishi (the official journal of Japanese fisheries science), the Canadian Journal of Fisheries and Aquatic Sciences, Journal of Physical Oceanography, JOURNAL OF GEOPHYSICAL RESEARCHOCEANS, and the Journal of Fish Biology. Both analyses highlight the decreasing paper count of the Journal of Experimental Marine Biology and Ecology, and Marine Biology.

Next, we note a few journals that publish relatively growing proportion of European ocean science papers across time. In the lexical ocean science field, these include Geophysical Research Letters, Science of the Total Environment, Scientific Reports, Quaternary Science Reviews, Marine Policy, Biogeosciences, Zootaxa and Frontiers in Marine Science. In the broad journal field delineation these include three physical oceanography journals: Ocean Engineering, OCEANSIEEE and Engineering, Oceanography; two fisheries journals: Journal of Applied Phycology, and Fish Shellfish Immunology; and two journals related to ocean pollution: Cleansoil Air Water and the Marine Pollution Bulletin; as well as the Journal of Marine Science.

5.4 European Ocean Science Top Institutions

This section discusses the changing proportion of papers published by top European institutions in the lexical and broad journal field delineations. Figure 24 depicts the overlap between the top 50 institutions in the European lexical and broad journal field delineations. We note a relatively strong overlap between the two sets of institutions: 39 out of 50 are included in both.

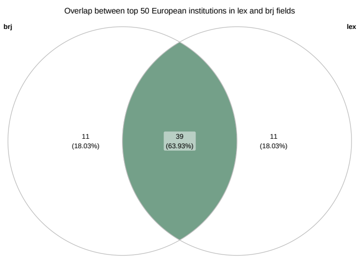


Figure 24: Overlap between the global top 50 institutions in the lexical and broad journal field delineations

Institutions included in both visualisations are Aarhus University, Aix-Marseille Universite, Alfred Wegener Institute, Helmholtz Centre for Polar & Marine Research, CNRS - Institute of Ecology & Environment (INEE), CNRS - National Institute for Earth Sciences & Astronomy (INSU), CSIC - Centro Mediterraneo de Investigaciones Marinas y Ambientales (CMIMA), Centre National de la Recherche Scientifique (CNRS), Consejo Superior de Investigaciones Cientificas (CSIC), Consiglio Nazionale delle Ricerche (CNR), GEOMAR Helmholtz Center for ocean science Kiel, Ghent University, Helmholtz Association, 'INRAE', Ifremer, Institut de Recherche pour le Developpement (IRD), Museum National d'Histoire Naturelle (MNHN), NERC National Oceanography Centre, NERC Natural Environment Research Council, National Oceanic Atmospheric Admin (NOAA) - USA, Norwegian University of Science Technology (NTNU), Royal Netherlands Institute for Sea Research (NIOZ), 'Russian Academy of Sciences, Shirshov Institute of Oceanology, Sorbonne Universite, Technical University of Denmark, UK Research Innovation (UKRI), Universidade de Lisboa, Universite de Montpellier, University of Barcelona, University of Bergen, University of Bremen, University of California System, University of Copenhagen, University of Gothenburg, University of Hamburg, University of Kiel, University of London, University of Southampton, Utrecht University. Note that not all institutions are European because the European lexical and broad journal field delineations include all papers authored by at least one scholar affiliated with a European institution. Top organisations thus can include non-European institutions that often collaborate with European ones.

Top institutions included in only the lexical European field are the CEA, Chinese Academy of Sciences, ETH Zurich, Max Planck Society, Stockholm University, University of Oslo, three French institutions - Universite Paris Saclay, Universite Toulouse III - Paul Sabatier, Universite de Toulouse - and two institutions based in the United Kingdom: University of Cambridge and University of Oxford.

Top institutions included in only the broad journal European field are the CSIC - Instituto de

Ciencias del Mar (ICM), Centre for Environment Fisheries & Aquaculture Science, Hellenic Centre for Marine Research, Institute of Marine Research - Norway, Plymouth Marine Laboratory, Spanish Institute of Oceanography, UiT The Arctic University of Tromso, Universidade do Algarve, Universidade do Porto, University of Plymouth, and Wageningen University Research.

Figure 25 depicts the top 50 institutions in the European lexical ocean science field.

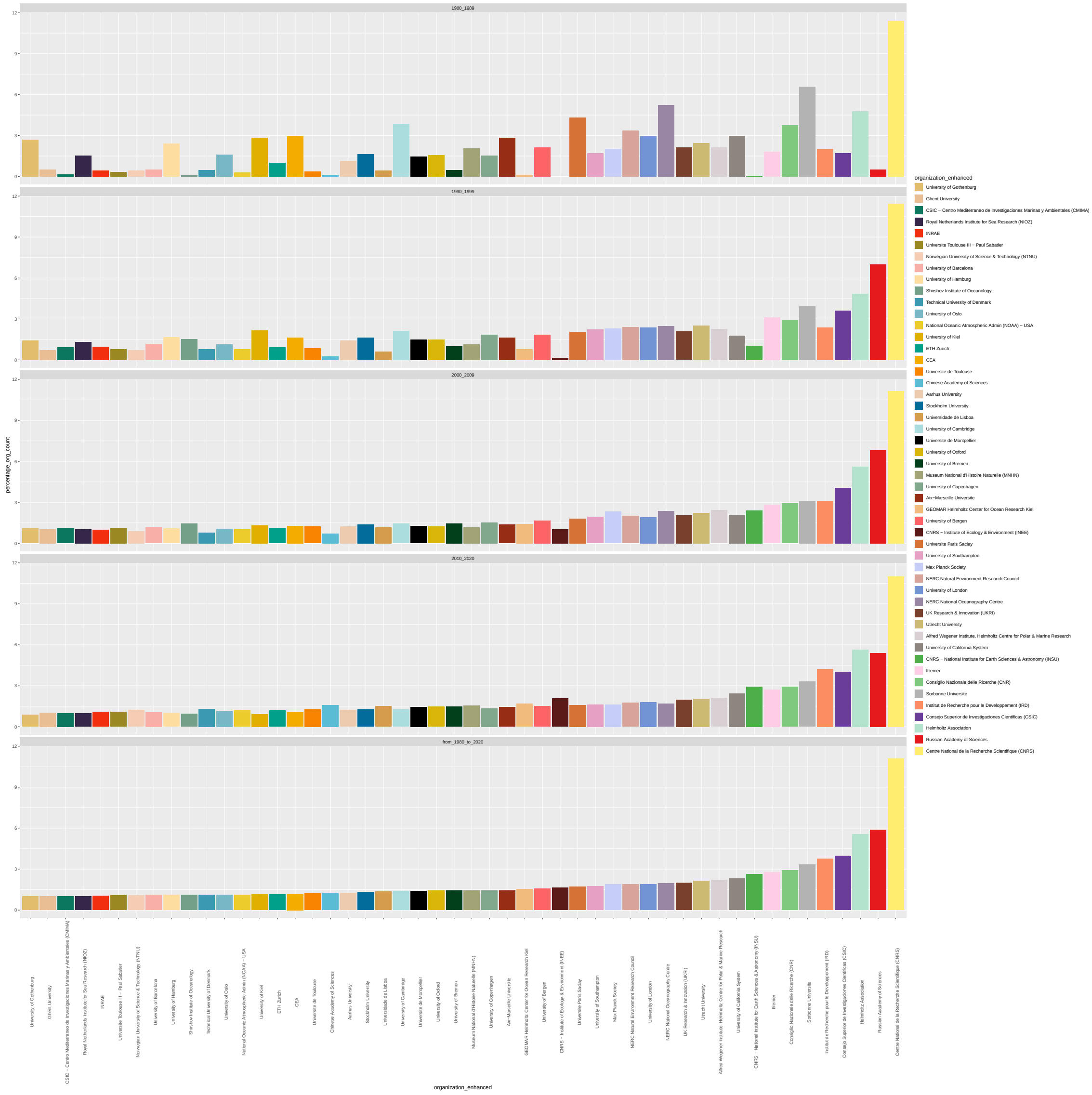


Figure 25: lexical field delineation, overall top institutions in European ocean science

Figure 26 depicts the co-authorship network of European top 50 ocean science institutions in the lexical field delineation field, and the interactive co-author map is available on this link.

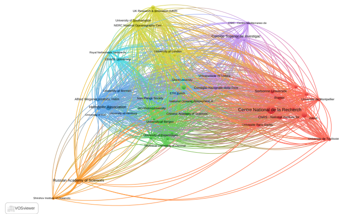


Figure 26: lexical field delineation, European ocean science, overall top 50 institutions co-author network

The interactive term map which illustrates the comparative research focus of institution clusters in the co-authorship network in figure 26 is available on this link.

Figure 27 depicts the top 50 institutions in the European broad journal ocean science field.

Figure 27: broad journal field delineation, overall top institutions in European Ocean science

Figure 28 depicts the co-authorship network of European top 50 ocean science institutions in the broad journal field, and the interactive co-author map is available on this link.

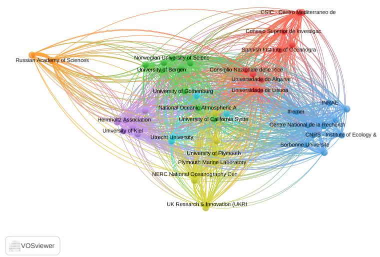


Figure 28: broad journal field delineation, European ocean science, overall top 50 institutions co-author network

The interactive term map which illustrates the comparative research focus of institution clusters in the broad journal European co-authorship network in figure 28 is available on this link.

The broad journal field analysis suggests the that institutions that publish decreasing proportion of ocean science papers over time include University of Kiel, University of London, University of Hamburg, NERC Natural Environment Research Council, UK Research Innovation (UKRI), University of California System, INRAE, University of Bergen, NERC National Oceanography Centre, and Sorbonne Universite.

The broad journal field analysis suggests the that institutions that publish increasing proportion of ocean science papers over time include Institut de Recherche pour le Developpement (IRD), Russian Academy of Sciences, Recherche pour le Developpement (IRD), Ifremer, Consejo Superior de Investigaciones Cientificas (CSIC), Institute of Marine Research Norway, Consiglio Nazionale delle Ricerche (CNR), CNRS Institute of Ecology Environment (INEE), CSIC Instituto de Ciencias del Mar (ICM), CSIC Centro Mediterraneo de Investigaciones Marinas y Ambientales (CMIMA), Norwegian University of Science & Technology (NTNU), Shirshov Institute of Oceanology, CNRS National Institute for Earth Sciences Astronomy (INSU).

Using the interactive map, we note that the Spanish language institutions with growing publication counts in the red cluster (cluster 1) have a relative focus on fisheries research (including fisheries policy), and the Russian Academy of Sciences in the orange cluster (cluster 7) has a relative focus on physical and biochemical oceanography.

6 Conclusion

This report explored epistemological and institutional trends in global and European ocean science in the period 1980-2020. We used two field delineations of ocean science - a lexical and a journal based field delineation - to explore epistemological trends using term co-occurrence networks, as well as institutional trends using bar plots that depict journal counts and bar plots, co-authorship networks and term maps to explore trends in key institutions over time. We hope the report can facilitate discussions about the present and future of European and global ocean science. Thus, the report includes a number of online, interactive network maps that allow readers to explore data visualisations in detail.

We note that the European and global term maps across the lexical and broad journal field delineations cluster ocean science research into similar clusters: genetic, immunological or physiological and social research about fisheries and aquaculture; biochemical oceanography including research about ocean toxicity; physical oceanography and engineering studies including water movement and sea surface temperature. The broad journal field delineation also highlighted research about ocean infrastructures (e.g. ships and underwater pipes) and the lexical field delineation highlighted geological ocean research. We noted differences in the key journals and institutions the lexical and broad journal field delineations highlighted, but several key trends were identified by both field delineations.

7 Future Research

We note four main directions for future research. First, future research could explore the analyses in this report using the third temporal approach section 3.3 discussed: exploring top terms, journals and institutions at each decade independent of core data points in other decades. Second, institutional analyses could study the changing publication count of clusters of institutions, rather than individual institutions, to align the units of analysis explored using bar charts, co-authorship and term maps. Third, future research could explore and map research about specific topic areas within the broad field delineations this paper employed. Finally, to explore how scientists and policy makers value ocean science and imagine its future, future research could discuss data visualisations in this report with experts.

Acknowledgements

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8 Appendix

8.1 Appendix: Global Ocean Science

8.1.1 Current Top Journals, Global Ocean Science

This section discusses shifts in global ocean science research topics through changes in the number of papers published in the 50 journals that have published most ocean science papers in the past decade, 2010-2020. As figure 29 depicts, there is relatively little overlap between the 50 journals between the lexical and broad journal ocean science field delineations: only 20 journals are contained by both analyses.

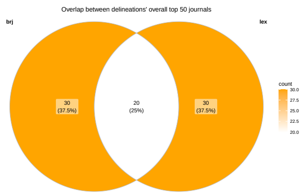

Figure 29: Venn global journals current

Figure 30 depicts the current top 50 journals in the lexical global ocean science field and changes in the number of ocean science papers they publish across four decades.

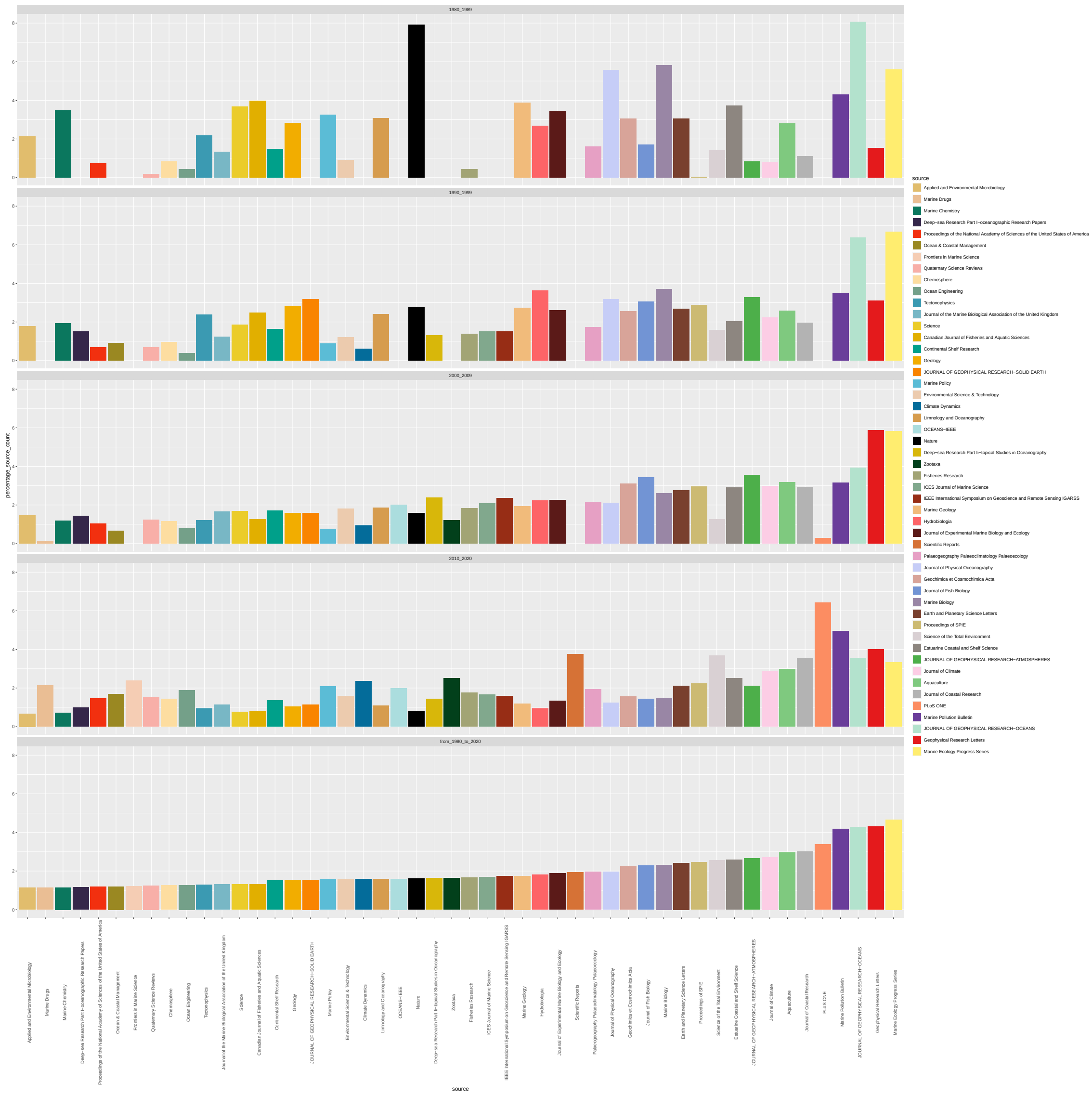

Figure 30: lexical field delineation, global ocean science, currently top 50 journals and their changing importance over time

We highlight a few trends the figure suggests. We first explore it from left to right, exploring journals that publish decreasing proportion of ocean science papers. We see decreasing proportion of papers published across the decades in a number of journals, including Journal of Physical Oceanography (also highlighted by the analysis overall top journals); the Journal of Experimental Marine Biology and Ecology; Continental Shelf Research; Marine Biology (also highlighted by the analysis overall top journals); Geochimica et Cosmochimica Acta; IEEE International Symposium on Geoscience and Remote Sensing IGARSS; Earth and Planetary Science Letters; Estuarine Coastal and Shelf Science; Marine Ecology Progress Series; and the Journal of Geophysical Research-Oceans (also highlighted by the analysis overall top journals). Exploring the visual from left to right, the analysis highlights the growing importance of PLOS One; Proceedings of SPIE; a few publication venues that gained popularity in the lexical ocean science field recently: Atmospheric Chemistry and Physics; Environmental Science and Pollution Research; Remote Sensing; Ocean Engineering; Frontiers in Microbiology; and the IOP Conference SeriesEarth and Environmental Science.

Figure 31 depicts the current top 50 journals in the broad journal global ocean science field and changes in the number of ocean science papers they publish across four decades.

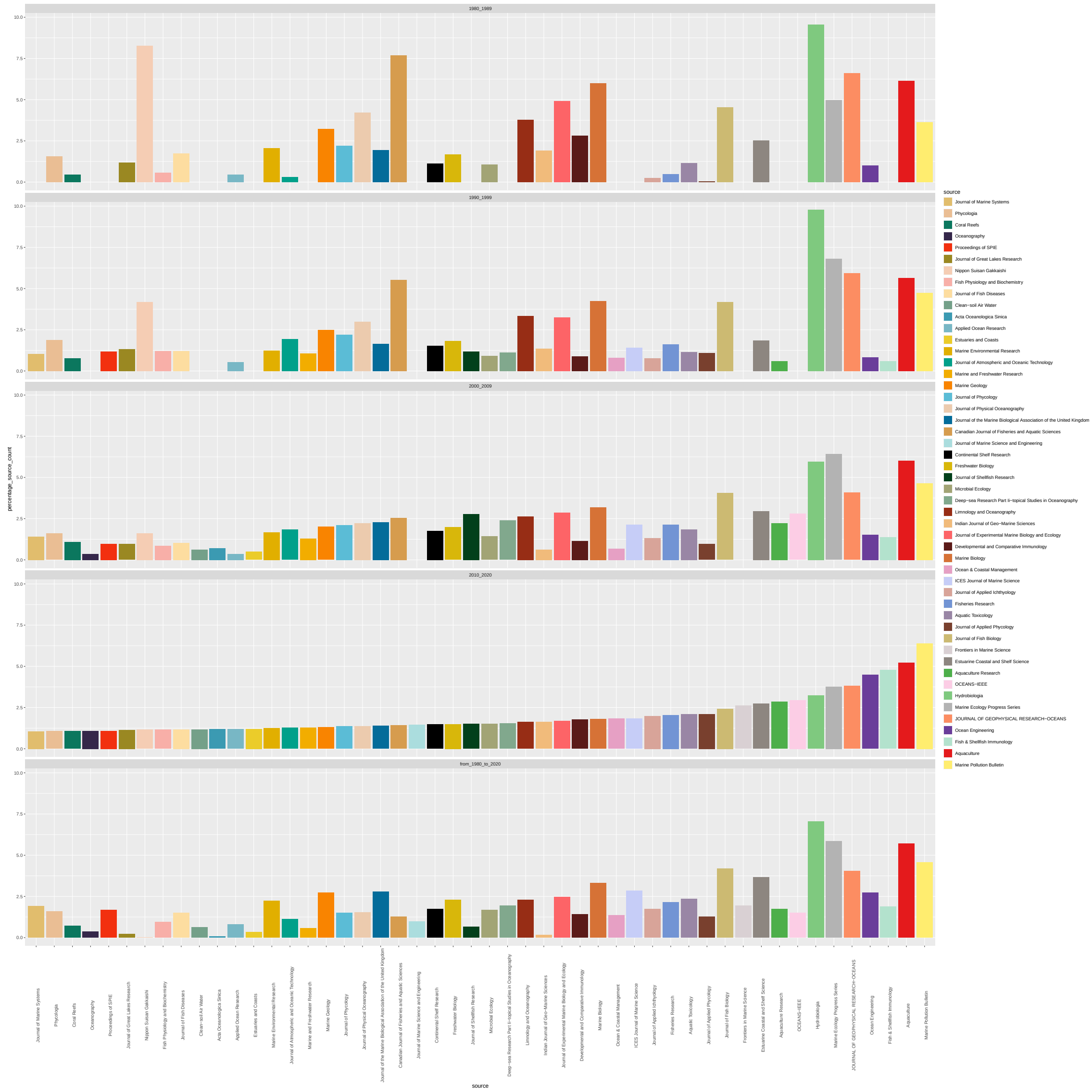

Figure 31: broad journal field delineation, global ocean science, currently top 50 journals and their changing importance over time

We highlight a few trends the figure suggests. We first explore it from left to right, exploring journals that publish decreasing proportion of ocean science papers. We see decreasing proportion of papers published across the decades in a number of journals, including Journal of Physical Oceanography (also highlighted by the analysis overall top journals); the Journal of Experimental Marine Biology and Ecology; Continental Shelf Research; Marine Biology (also highlighted by the analysis overall top journals); Geochimica et Cosmochimica Acta; IEEE International Symposium on Geoscience and Remote Sensing IGARSS; Earth and Planetary Science Letters; Estuarine Coastal and Shelf Science; Marine Ecology Progress Series; and the Journal of Geophysical Research-Oceans (also highlighted by the analysis overall top journals). Exploring the visual from left to right, the analysis highlights the growing importance of PLOS One; Proceedings of SPIE; a few publication venues that gained popularity in the lexical ocean science field recently: Atmospheric Chemistry and Physics; Environmental Science and Pollution Research; Remote Sensing; Ocean Engineering; Frontiers in Microbiology; and the IOP Conference SeriesEarth and Environmental Science.

8.1.2 Current top Institutions

Figure 32 depicts the current top 50 global ocean science institutions according to the lexical field delineation.

Figure 32: Lexical field delineation, global ocean science, current top 50 institutions and their changing importance over time

Figure 33 depicts the current top 50 global ocean science institutions according to the broad journal field delineation.

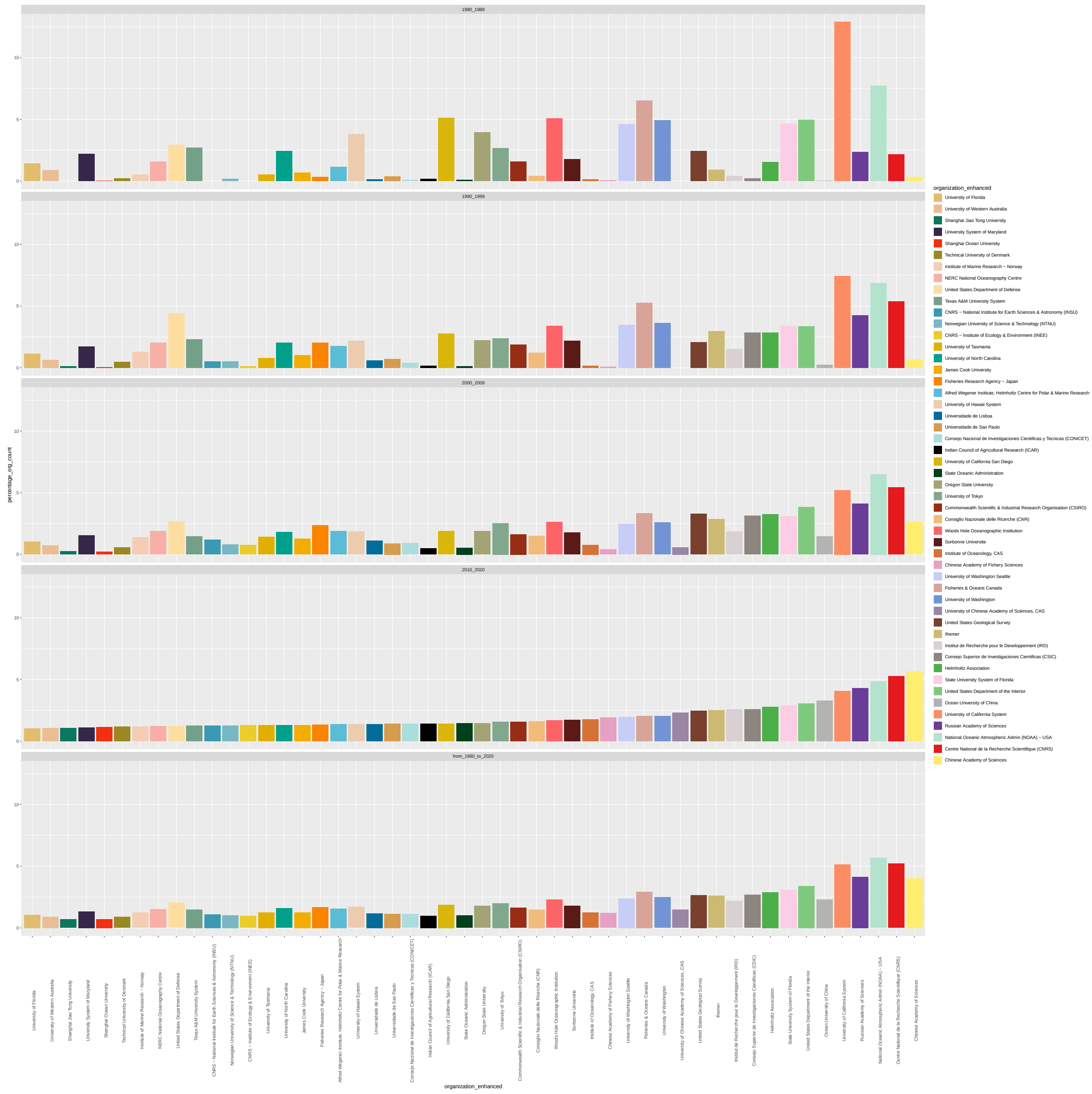

Figure 33: broad journal field delineation, global ocean science, current top 50 institutions and their changing importance over time

8.2 Appendix: European Ocean Science

8.2.1 European Current Top Journals

Figure 34 depicts the current top 50 journals in European ocean science according to the lexical field delineation.

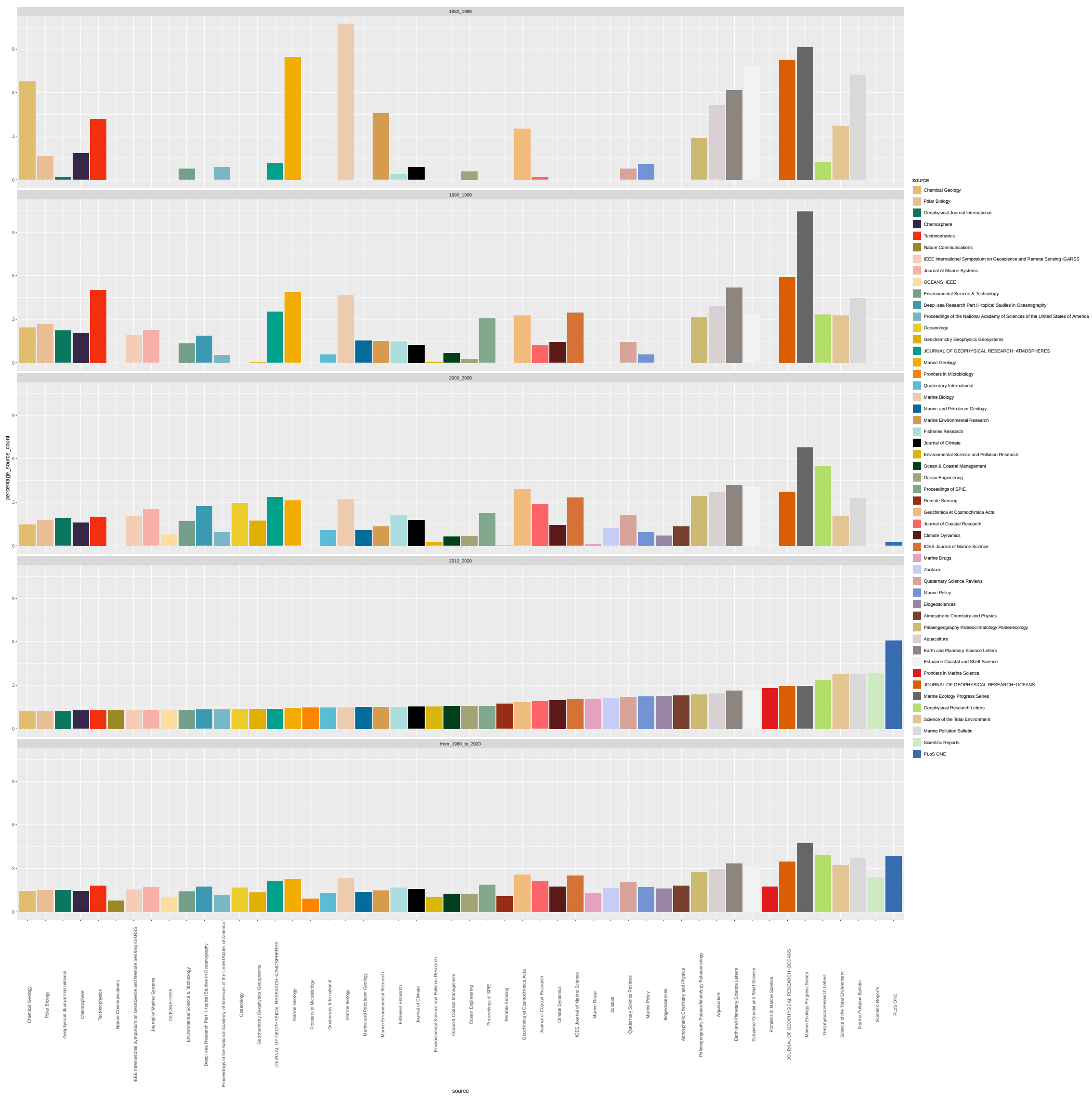

Figure 34: lexical field delineation, Current top journals in European Ocean science

Figure [35](#) depicts the current top 50 journals in European ocean science according to the broad journal field delineation.

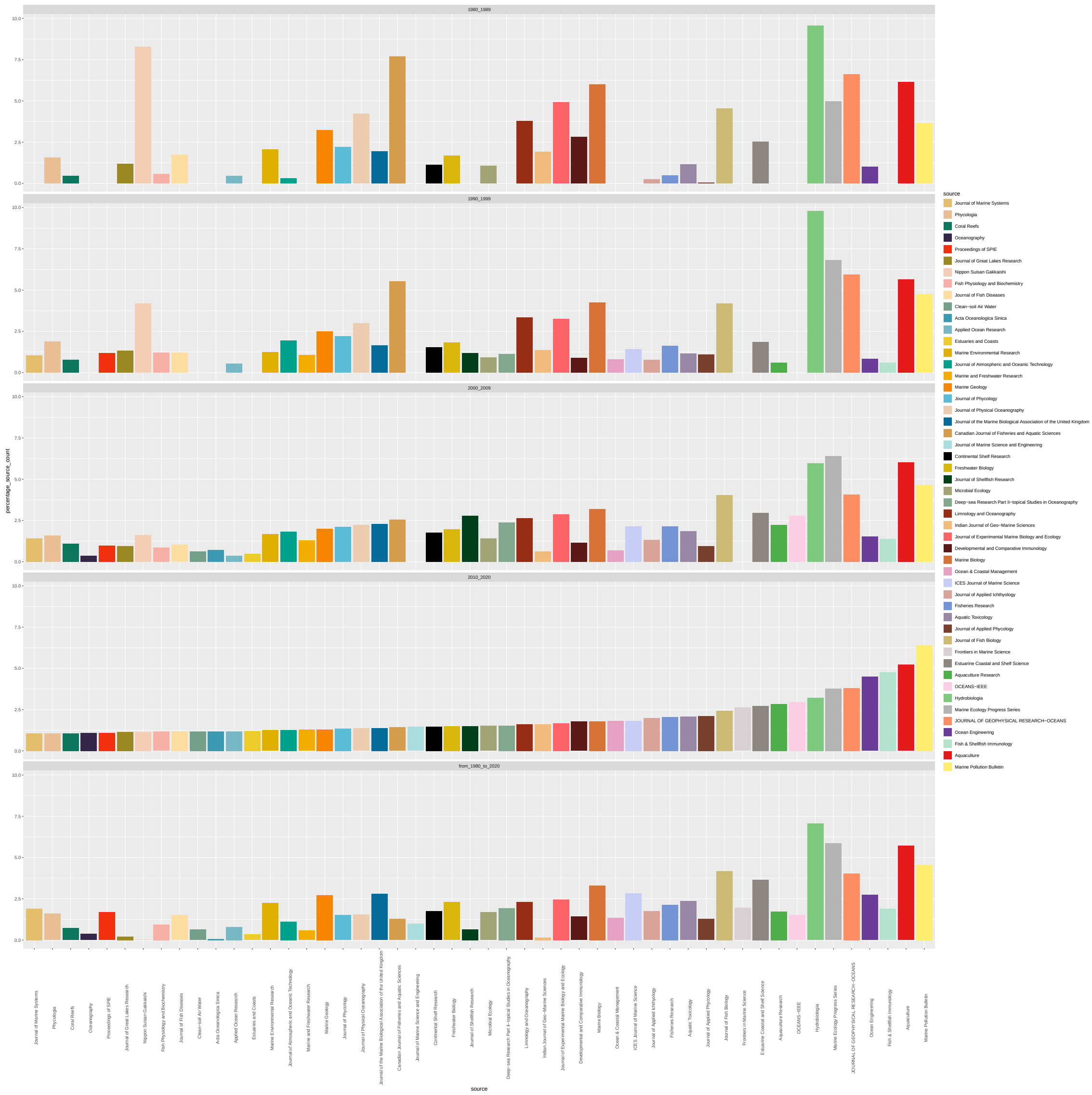

Figure 35: broad journal field delineation, Current top journals in European Ocean science

8.2.2 European Current Top Institutions

Figure 36 depicts the current top 50 institutions in European ocean science according to the lexical field delineation.

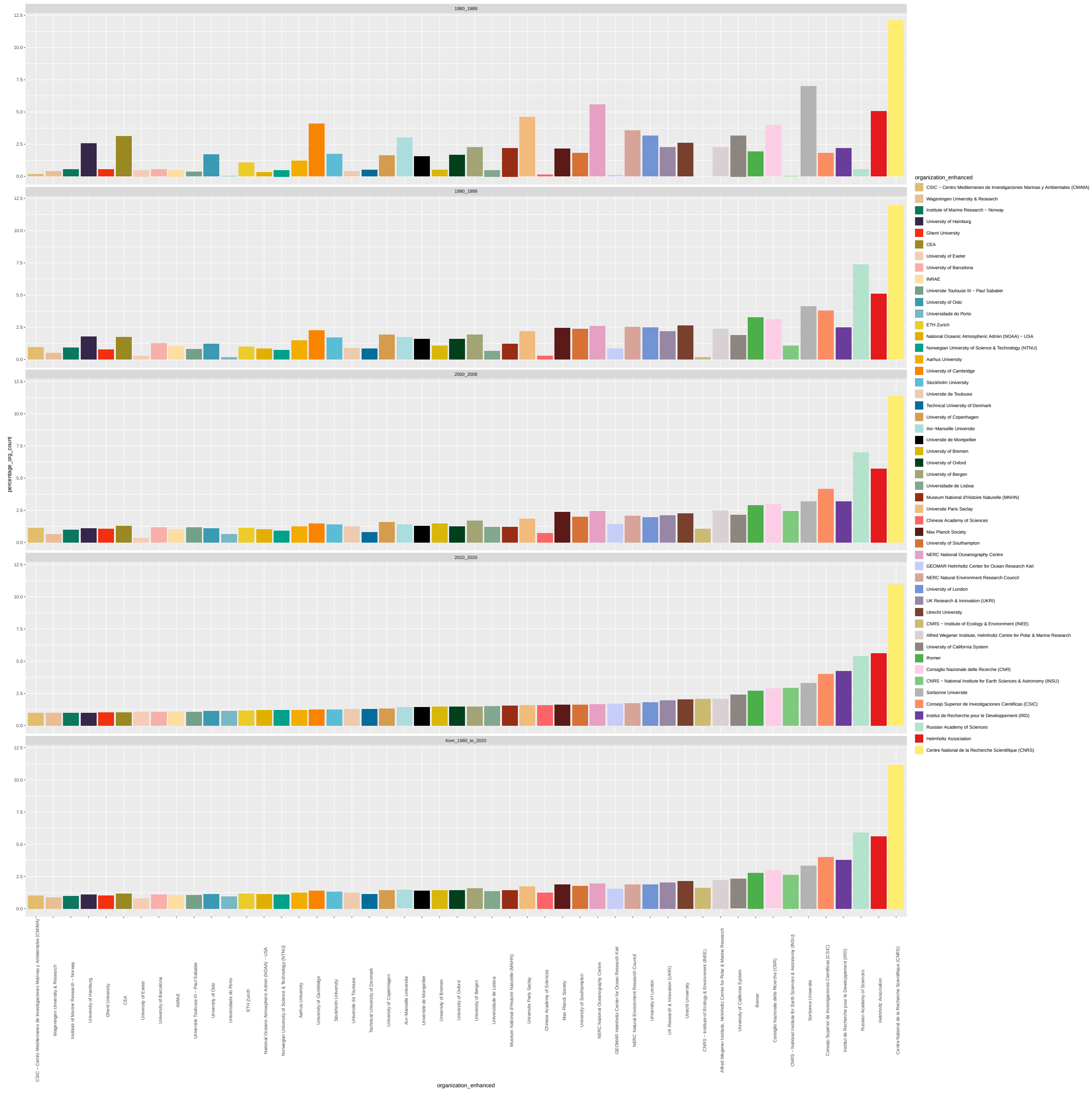

Figure 36: lexical field delineation, Current top institutions in European Ocean science

Figure 37 depicts the current top 50 institutions in European ocean science according to the broad journal field delineation.

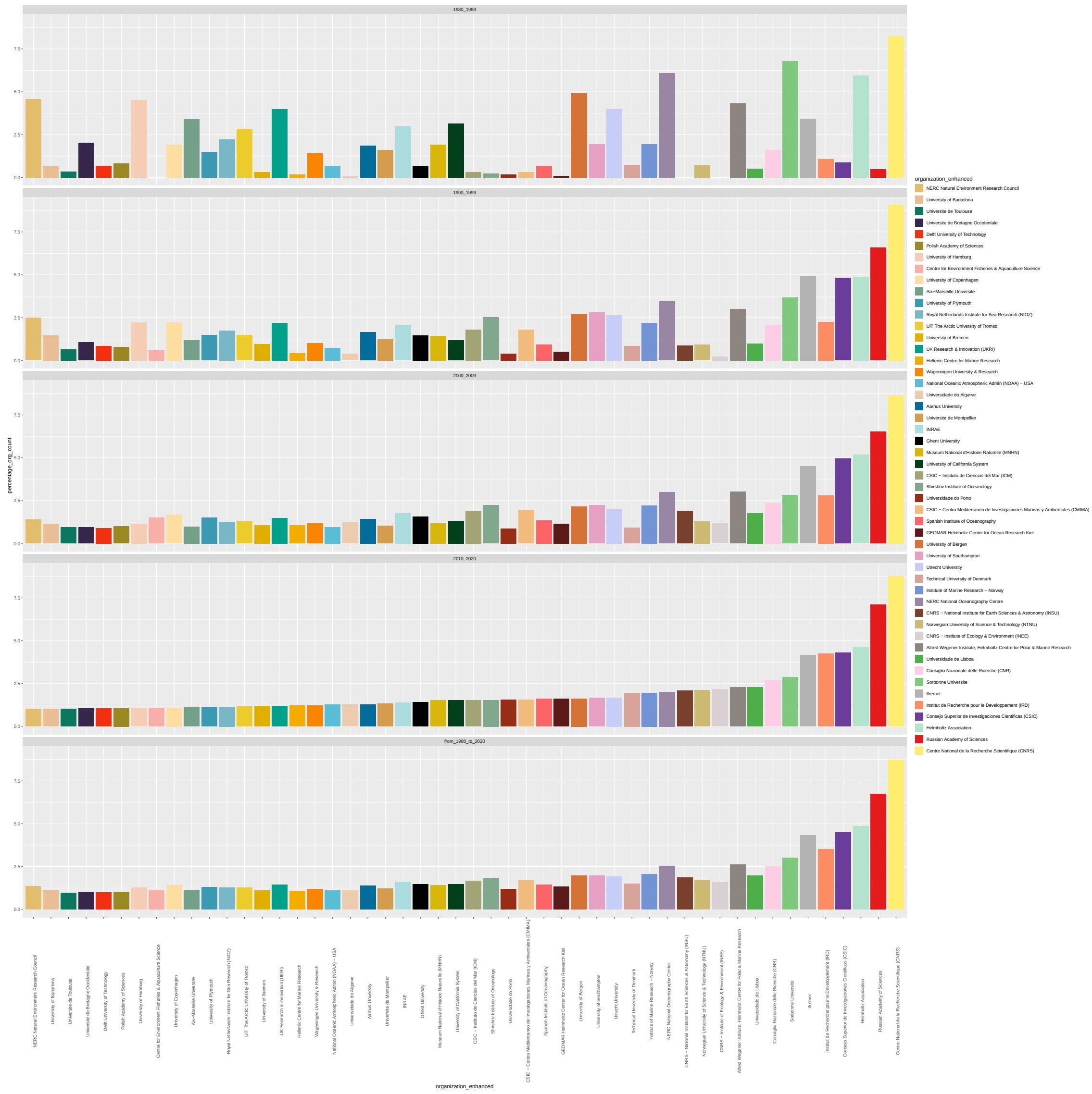

Figure 37: broad journal field delineation, Current top institutions in European Ocean science