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Environmental Evidence

SYSTEMATIC MAP PROTOCOL

Open Access

Identifying and addressing the anthropogenic drivers of global change in the North Sea: a systematic map protocol

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Abstract

Background: Anthropogenic pressures on marine ecosystems have increased over the last 75 years and are expected to intensify in the future with potentially dramatic cascading consequences for human societies. It is therefore crucial to rebuild marine life-support systems and aim for future healthy ecosystems. Nowadays, there is a reasonable understanding of the impacts of human pressure on marine ecosystems; but no studies have drawn an integrative retrospective analysis of the marine research on the topic. A systematic consolidation of the literature is therefore needed to clearly describe the scientific knowledge clusters and gaps as well as to promote a new era of integrative marine science and management. We focus on the five direct anthropogenic drivers of biodiversity loss defined by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES): (1) climate change; (2) direct exploitation; (3) pollution; (4) biological invasions; and (5) sea-use change. Our systematic map's regional focus lies on the North Sea, which is among the most impacted marine ecosystems around the globe. The goal of the present study is to produce the first comprehensive overview of how marine research on anthropogenic drivers in the North Sea has grown and changed over the past 75 years. Ultimately, this systematic map will highlight the most urgent challenges facing the North Sea research domain.

Methods: The search will be restricted to peer-reviewed articles, reviews, meta-analyses, book chapters, book reviews, proceeding papers and grey literature using the most relevant search engines for literature published between 1945 and 2020. All authors will participate in the adjustment of the search in order to consider all relevant studies analyzing the effect of the direct anthropogenic drivers on the North Sea marine ecosystem. The references will be screened for relevance according to a predefined set of eligibility/ineligibility criteria by a pool of six trained reviewers. At stage one, each abstract and title will be independently screened by two reviewers. At stage two, potentially relevant references will be screened in full text by two independent reviewers. Subsequently, we will extract a suite of descriptive meta-data and basic information of the relevant references using the SysRev platform. The systematic map database composed will provide the foundation for an interactive geographical evidence map. Moreover, we will summarize our findings with cross-validation plots, heat maps, descriptive statistics, and a publicly

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available narrative synthesis. The aim of our visualization tools is to ensure that our findings are easily understandable by a broad audience.

Keywords: Climate change, Direct exploitation, Pollution, Biological invasions, Sea-use change, Anthropocene, Marine ecosystem, Research gap, Research trend, Evidence-based

Background

The Global Ocean, across all levels of ecosystem structure and functioning, is now largely altered by human activities [1–4], with around 65% of ocean surface having experienced increasing cumulative impacts over the last decades [1, 5–7]. No more than 13.2% of the world's ocean is now classified as marine wilderness [8]. Over the last 75 years, as demographic pressure and economic activity increased in coastal areas, anthropogenic pressures on marine ecosystems have grown and accumulated to affect almost directly or indirectly all the oceans, their biodiversity, resilience and functionality, leading to severe negative consequences for the supply of multiple ecosystem services and human well-being [4, 9–12]. The Millennium Ecosystem Assessment (MEA) [13], and more recently the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) [14], identified five main human-induced drivers that directly and unequivocally influence ecosystem processes. For several decades, direct exploitation of fish and seafood was the main driver with the largest relative impact on marine ecosystems and biodiversity while sea-use and coastal land changes was the second [14]. Three other anthropogenic drivers of ecosystem changes, namely human-driven climate change, pollution and invasive alien species are considered as more-recent threats with the potential to become the major drivers of global biodiversity loss in the coming years [14–16]. In particular, climate change is expected to outpace other important drivers of biodiversity loss in the coming decades [14, 17–19]. Hence, marine ecosystems are expected to change dramatically over the next decades [14, 20–23], jeopardizing the many benefits that healthy oceans supply to human society [24].

There is an urgent need to understand the spatiotemporal impacts of the direct (e.g., fishing, sea-use change, climate change) and indirect (e.g., human population growth, per capita income, technological advances) drivers of change in marine ecosystems in order to maintain or restore key ecosystem functions and associated services as well as project future impacts [25, 26]. This is necessary especially if we want (i) to achieve the Sustainable Development Goal 14 (SDG 14) of the United Nations ("conserve and sustainably use the oceans, seas and marine resources for sustainable development") and other associated SDGs [27], (ii) reach the new biodiversity goals and targets of the post-2020 global biodiversity framework [16] and (iii) progress towards an effective science-based and integrated ocean management system [28]. With these prospects, it is crucial to draw retrospective evaluations of marine research on anthropogenic drivers in order to provide a solid scientific base for marine management decisions. As a consequence, we need to clearly identify knowledge clusters and gaps before entering into a new era of science and management in view of the upcoming United Nations Decade of Ocean Science for Sustainable Development 2021–2030 and its dual goals of generating scientific knowledge and informing policies in support of the 2030 Agenda [29–32]. In addition, research efforts on different anthropogenic drivers in the marine realm can appear not well aligned with their assessed and predicted impacts [33]. At global scale, climate change was, for instance, the most researched driver of biodiversity loss of the past decade (representing ca. 50% of published articles on drivers); while a relatively low research effort was invested into the drivers' pollution or habitat change (representing ca. 7.5% and 10% of published papers on drivers, respectively) [33]. Hence, research efforts seem disproportionate among anthropogenic drivers and their realignment will improve the information of policy goals [33].

All these statements hold particularly true for the North Sea, an archetypal shelf sea located in the Northeast Atlantic Ocean which ranked amongst the most human-influenced marine ecosystems in the World's oceans [6, 34, 35]. The North Sea is considered a hot spot of climate change [36, 37]. Likely because it is characterized by a strong human footprint, it is also an exceptionally well-studied and data-rich ecosystem, monitored by several countries organized in OSPAR (Convention for the Protection of the Marine Environment of the North-East Atlantic) and ICES (International Council for the Exploration of the Sea) [34, 38, 39]. Surrounded by approximately 184 Mio inhabitants the North Sea is influenced by multiple anthropogenic pressures; many are still increasing, especially in coastal areas with over 500 inhabitants per km^2 [40, 41].

Despite its status as a hotspot of global change and being one of the most intensively investigated seas of the world [38, 42], no previous studies have analyzed and synthetized how and what kind of marine research was conducted on global change drivers in the North Sea. Moreover, no studies have analyzed how research is connected and correlated with the magnitude and the trend of these drivers in the North Sea. Ecological synthesis, particularly systematic maps analyzing the scope and extent of specific scientific literature, are nevertheless paramount to enhance ecological knowledge, to identify knowledge gaps and to organize ecological information for decision-makers, especially in the North Sea [32, 38, 43]. Synthesizing and mapping a general state of scientific research on anthropogenic drivers represents a necessary step toward achieving UN Decade of Ocean Science for Sustainable Development, guiding stakeholders (from scientists to policy makers) towards new scientific and funding horizons and highlighting future scientific challenges facing the North Sea.

Objectives of the review

The main objective of our systematic map is to provide a comprehensive overview of the available knowledge and methods used to assess the historic, current, and projected impacts of the five direct drivers of marine ecosystem change in the North Sea by applying an ecosystem approach, i.e., looking at the main physicochemical and biological components of the system. These five direct drivers are: climate change, direct exploitation of fish and seafood (i.e., fishing), biological invasions, sea-use change and pollution. The aim of this study is to map past and current research efforts for the different anthropogenic drivers of biodiversity loss and ecosystem changes. Spanning more than 70 years of historical context, this paper will draw a holistic picture of how marine research on anthropogenic drivers in the North Sea has grown and changed. Our attention will be focused on the ecological component of the North Sea socio-ecological system. The socio-economic impacts of global change (i.e., on human well-being) as well as the indirect anthropogenic drivers (e.g., economic, demographic, governance, technological and cultural drivers) will be outside the scope of our mapping exercise. This systematic map will highlight the future conceptual and methodological scientific challenges facing the North Sea.

Primary question

The primary overarching research question of this study is: How did the research interest in anthropogenic drivers of marine ecosystem changes develop over the past 75 years (1945–2020) regarding the North Sea?

Population

All biotic (plant and animal species but excluding humans) and abiotic (e.g., sediment, seawater properties) components of the North Sea marine ecosystem (i.e., ICES divisions IVa, IVb and IVc) will be included.

Exposure(s)/intervention(s)

The five direct anthropogenic drivers of global ecosystem changes will be considered as the exposures (Table 1).

All management and mitigation measures and/or restoration initiatives dedicated to reduce or compensate one of the direct anthropogenic drivers and associated impacts will be considered as relevant interventions as soon as their consequences for the North Sea ecosystem are analyzed.

Comparator

Studies will not be required stricto sensu to have a comparator.

Outcome(s)

There are no predefined outcomes. All outcomes will be potentially relevant as soon as they are related to the population studied, including but not restricted to physics/biogeochemistry (e.g., sea surface temperature, nitrogen/phosphorus ratio), biology/physiology (e.g., metabolic rate) and ecology (e.g., ecosystem structure and functioning). Changes in nature's contribution to people as defined by the IPBES global assessment report (e.g., habitat creation and maintenance, regulation of acidification, food provisioning, learning and inspiration) [14] will be also considered as outcomes.

Table 1 The five direct anthropogenic drivers of ecosystem changes, according to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services

Direct anthropogenic drivers	Type of effects
Climate change	Seawater warming, acidification, deoxygenation
Direct exploitation	Overfishing, habitat degradation
Pollution	Eutrophication, chemical pollutants
Biological invasions	Non-native species introduction
Sea-use change	Habitat degradation/loss

Secondary questions

A set of secondary research questions will complete the analysis:

- Which direct drivers have been neglected by "modern" (since 1940's) marine science? (Knowledge gaps)
- What is the proportion of research dedicated towards testing responses to observed or anticipated impacts?
- Facing global change, which changes in nature's contribution to people are least studied?
- Is there a relationship among advances in applied methodologies, conceptual frameworks and acknowledged gaps in knowledge?
- Are ecological shifts in the North Sea reflected in funded research programs and topics?
- What are the main future avenues of research in marine science?

Methods

In general, the method used to generate the systematic map will follow as precisely as possible the Collaboration for Environmental Evidence (CEE) Guidelines and Standards for Evidence Synthesis in Environmental Management [44]. In addition, the paper will conform to RepOrting standards for Systematic Evidence Syntheses (ROSES, Additional file 1) [45].

Searching for articles

Scoping

Our research strategy is designed in order to retrieve a broad range of articles covering the topic of direct anthropogenic drivers in the North Sea between 1945 and 2020. A scoping exercise in Web of Science (WoS) Core Collection was conducted to build a relevant search string, using terms describing the five direct anthropogenic drivers analyzed in this study. Our first search string was partly elaborated from the ones defined in Mazor et al. [33] who identified a short list of keywords for each direct anthropogenic driver based on a keyword frequencies analysis over a large set of 48,234 peer-reviewed articles exploring research trends on direct anthropogenic drivers of biodiversity loss at the global scale. A test list of 50 relevant scientific articles, which encompassed literature on the five direct anthropogenic drivers of ecosystem change, was defined by all authors (see Additional file 2) to develop the search string and compare the comprehensiveness of searches against each other [46]. Keywords were extracted along with further relevant words from the title and abstract of these papers, identified by the review team. The keywords were grouped into terms and a thesaurus dictionary [47] was used to identify appropriate synonyms. Generality of the search was increased by adding synonyms, while specificity was increased by substituting broad terms for specific alternatives.

Search terms

The search terms consist of relevant keywords to study human-nature relationships and were discussed through several rounds among all authors. We listed the terms accordingly to the five major direct anthropogenic drivers defined by the IPBES in its last global assessment report [14]: (1) climate change, (2) invasive species, (3) sea-use change, (4) direct exploitation and (5) pollution (including eutrophication). The final and best combination of search terms is as follows:

TS=("climat*" NEAR/3 "chang*" OR "global warming" OR "carbon dioxide" OR "CO2" OR "acidification" OR "deoxygen*" OR "oxygen" NEAR/3 "loss" OR "decreas*" NEAR/3 "oxygen" OR "reduc*" NEAR/3 "oxygen" OR "sea surface temperature*" OR "marine warming" OR "climate warming" OR "ocean warming" OR "temperature*" NEAR/3 "chang*" OR "seawater warming" OR "sea water warming" OR "rising temperature*" OR "greenhouse" OR "green house" OR "invasi*" OR "alien" OR "introduc*" NEAR/3 "species" OR "non-native" OR "nonnative" OR "endangered" OR "biodiversity" OR "biological diversity" OR "unsustainabl*" OR "abundance" NEAR/3 "change*" OR "distribution" NEAR/3 "change*" OR "habitat*" NEAR/3 "chang*" OR "habitat*" NEAR/3 "loss" OR "fragmentation" OR "habitat*" NEAR/3 "qualit*" OR "habitat*" NEAR/3 "fragment*" OR "habitat*" NEAR/3 "modif*" OR "habitat*" NEAR/3 "degrad*" OR "habitat*" NEAR/3 "decline" OR "habitat*" NEAR/3 "destabili*" OR "habitat*" NEAR/3 "destruction" OR "habitat*" NEAR/3 "destroy*" OR "ecosystem*" NEAR/3 "degrad*" OR "ecosystem*" NEAR/3 "destruction" OR "ecosystem*" NEAR/3 "declin*" OR "ecosystem*" NEAR/3 "qualit*" OR "ecosystem*" NEAR/3 "fragment*" OR "ecosystem*" NEAR/3 "chang*" OR "landscape" NEAR/3 "chang*" OR "sea-use chang*" OR "offshore" NEAR/3 "wind farm*" OR "offshore" NEAR/3 "wind park*" OR "OWF*" OR "overfish*" OR "overexploit*" OR "overharvest*" OR "overhunt*" OR "over hunt*" OR "over fish*" OR "over exploit*" OR "over harvest*" OR "exploit*" OR "fishing" OR "fisheries" OR "fishery" OR "pollut*" OR "eutrophicat*" OR "trophic amplification" OR "noise*" NEAR/3 "impact*" OR "noise*" NEAR/3 "increas*" OR "noise level*" OR "light level*" OR "light" NEAR/3 "impact*" OR "light" NEAR/3 "increas*" OR "nitrogen*" NEAR/3 "increas*" OR "nitrogen*" NEAR/3 "impact*" OR "nutrient*" NEAR/3 "loading" OR "ecotoxic*" OR "environment*" NEAR/3 "toxic*" OR "ecologic*" NEAR/3 "toxic*" OR "environment*" NEAR/3 "toxic*" OR "heavy metal*" OR "oil spill*" OR "oil leak*" OR "runoff" OR "run off" OR "microplastic*" OR "micro plastic*" OR "contamina*" OR "water qualit*" OR "cruise ship*" OR "trawl*" OR "dredging" OR "drilling" OR "dumping" OR "deglaciat*" OR "anthropogenic*" OR "human induced" OR "human driven" OR "human stressor*" OR "human pressure*" OR "human* impact*")

AND

TS=("North Sea" OR "Brent Group" OR "Sleipner Vest Field" OR "Sleipner Field" OR "Maar Bank" OR "Pobie Bank" OR "Forty Mile Ground" OR "Viking Bank" OR "Viking Graben" OR "Little Halibut Bank" OR "Smith Bank" OR "Moray Firth" OR "Buchan Deep" OR "Fladen Ground" OR "Utsira high" OR "Utsira Formation" OR "Ling Bank" OR "Revet" OR "Norvegian Trench" OR "Eigersunds Bank" OR "Little Fisher Bank" OR "Great Fisher Bank" OR "Fisher Banks" OR "Jutland Bank" OR "Jutland Coastal Current" OR "Horns Rev" OR "Long Forties" OR "Scalp Bank" OR "Devil's Hole" OR "Firth of Forth" OR "Farn Deeps" OR "Dogger Bank" OR "Silverpit Crater" OR "Outer Silver Pit" OR "Inner Silver Pit" OR "Silver Pit" OR "Norfolk Banks" OR "The Wash" OR "Southern Bight" OR "Broad Fourteens" OR "Frisian Front" OR "Cleaver Bank" OR "Oyster Ground" OR "German Bight" OR "German Bight Water" OR "Heligoland Bight" OR "Wadden Sea" OR "Strait of Dover" OR "Central Graben" OR "Snorre Field" OR "Wee Bankie" OR "North Sea Canal" OR "Fair Isle Current" OR "Norwegian Trench" OR "Hild Field" OR "Tern Field" OR "Middelkerke Bank" OR "Fulmar Formation" OR "Ninian Field" OR "Frigg Field" OR "Statfjord Field" OR "Statfjord Formation" OR "Gullfaks Field" OR "Pomeranian Bight" OR "Norwegian Deep" OR "Broad Fourteens Basin" OR "North Sea Flemish Banks" OR "Norwegian Channel" OR "Ekofisk Field" OR "North West Hutton Field" OR "Leman Field" OR "Aberdeen Bank" OR "Plaice Box" OR "Troll Field" OR "Mellum I.").

Note that the * (asterisk) acts as a wildcard, so a string such as invasi* would for instance represent invasive, invasiveness and invasion. NEAR/x acts as a proximity operator to find records where the terms joined by the operator are within a specified number of words of each other (3 words in our case). Moreover, to consider differences in search syntax between WoS, Scopus and PubMed "TS" in WoS is replaced by "TITLE-ABS-KEY" in Scopus and by "[Title/Abstract]" in the search string in PubMed.

Comprehensiveness of search

The comprehensiveness of each search attempt in WoS was tested against its ability to return the test-list of benchmark articles (completed February 15th, 2021). The search terms were searched in the field code "Topic" which includes the title, abstract and the publication's keywords and "keywords Plus"; a set of keywords generated by WoS through an automatic computer algorithm which identifies words or phrases that appear frequently in titles of an article's references [48]. Despite the limited effectiveness of "Keywords Plus" [49] this searching process ensures for a large number of article entries. The search string was adjusted to capture more than 95% of the papers considered as particularly relevant. In this sense, the main sub-regional seas and ecological sites within the North Sea (e.g., Wadden Sea or Dogger Bank) were explicitly added as search terms.

The final search string will be used to search publication databases, search engines and grey-literature repositories for articles published over the period 1945–2020.

Searches will be performed using exclusively English search terms. Studies published in other languages (i.e., French, German, Italian and Spanish) but identified via the English search strings will be screened for inclusion. Searches will be made for peer-reviewed primary articles, reviews, meta-analysis, book chapters, book reviews, proceeding papers and grey literature.

Publication databases to search

Searches will be carried out using the following databases and platforms:

- Web of Science Core Collection on the Web of Science platform (Clarivate) using the access rights provided from the University of Hamburg. The search covered SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI and CCR-EXPANDED.
- Scopus (Elsevier) using the access rights of the Royal Netherlands Institute for Sea Research.
- PubMed (https://pubmed.ncbi.nlm.nih.gov/). PubMed is an open access meta-database developed by the National Center for Biotechnology Information (NCBI).
- AquaDocs (https://aquadocs.org/). AquaDocs is an open access repository of the UNESCO/IOC International Oceanographic Data and Information Exchange (IODE) and the International Marine and Aquatic Sciences Libraries and Information Centers (IAMSLIC) with support from the FAO Aquatic Sciences and Fisheries Abstracts.

Web of Science, Scopus and AquaDocs databases contain the mainstream research outlets in marine ecology, being representative of the disciplines of interest and adequate to map the general research trends, knowledge clusters and gaps needed to fulfill the purpose of the study. The final search performed using the

Table 2 Set of keywords defined for each anthropogenic driver for literature research in Google Scholar. Keywords are adapted from [33]

	Climate change	Direct exploitation	Pollution	Biological invasions	Sea-use change
#1	"Climate change"	Overexploitation	Pollution	"Invasive species"	"Habitat change"
#2	Warming	Overfishing	Eutrophication	"Biological invasion"	"Habitat loss"
#3	"Carbon dioxide"	Overharvesting	"Noise pollution"	Invasive	"Habitat modification"
#4	Acidification	Exploitation	Ecotoxicology	"Alien species"	"Sea-use change"
#5	Change	Overhunting	"oil pollution"	"Non-native species"	Fragmentation

Note that the final combination of each search will be as follow: "North Sea" AND (#1 OR #2 OR #3 OR #4 OR #5)

WoS, Scopus and PubMed databases yielded 10,421, 14,772 and 938 articles, respectively.

Grey literature searches

The search engine Google Scholar (https://scholar.google.com/), via the Publish or Perish software program [50], will be used to identify complementary grey literature (e.g., technical and policy reports). Due to the limitations of Google Scholar, five simplified search strings (i.e., one per direct anthropogenic driver) will be constructed with English terms to translate the search string used for the bibliographic databases described above in a suitable form for Google Scholar (Table 2). The search terms will be inserted in the 'With all the words' box under 'Advanced Search'. The title only will be used to search for literature on Google Scholar. Haddaway et al. 2015 [51], recommended that the search of article titles can focus on the first 300 results. Searches will be conducted per decade (e.g., 1945–1955) and for each of them the first 300 results will be downloaded in order to get all the relevant studies from 1945 and not only the most recent ones among the top 300 results between 1945 and 2020.

To extend the searches on grey literature, the web-based search engines BASE (Bielefeld Academic Search Engine; https://www.base-search.net/) and CORE (https://core.ac.uk/) will be consulted and the first 300 results, over the entire period under review, will be included for screening.

Organizational websites

The following organizational websites will be searched using one of the following terms {"climate change"; "over-exploitation"; "invasive species "; "habitat change", "pollution"} in conjunction with the term "North Sea".

- WWF, World Wildlife Fund [52].
- UNEP-WCMC, United Nations Environment Programme World Conservation Monitoring Centre [53].
- IUCN, International Union for the Conservation of Nature [54].
- IPBES, Intergovernmental Panel on Biodiversity and Ecosystem Services [55].
- CBD, Convention on Biological Diversity [56].
- OSPAR Commission, Convention for the Protection of the Marine Environment of the North-East Atlantic [57].
- ICES, International Council for the Exploration of the Sea [58].
- EEA, European Environment Agency [59].

Supplementary searches

To improve the comprehensiveness of the search, the list of references cited by studies in the test-list of benchmark articles (i.e., 50 key relevant articles) will be included for screening.

Search update

As the original searches will take place in the same year than the production of the systematic map, and because it is a short-term project, no search update will be undertaken as part of this study.

Article screening and study eligibility criteria

Screening process

The screening process will be conducted using SysRev, an online platform for collaborative document reviews and automated data extraction (https://sysrev.com/). The articles will be screened following two sequential levels: a screening of the title and abstract followed by a screening of the full body text. The full-text assessment will take place during the process of data extraction as detailed in the data coding strategy section. At each stage, articles will be compared against the eligibility criteria below. A record will be kept of all studies excluded at the full text screening stage, reporting the reasons for their exclusion.

Consistency checking

The screening will be carried out by only six members of the team with expertise in marine functional ecology and ecosystem responses under global change impacts. Prior to the final search and data extraction the six members will be trained in the screening process and data extraction protocol. They will review more than 30 scientific articles at title and abstract stage consecutively, to ensure consistency. Short meetings, to discuss the inclusion and exclusion criteria will follow these training sessions. After every training session, the Fleiss' kappa (K) parameter will be calculated to ensure consistency among reviewers [60]. This parameter should be equal or greater than 0.6 to represent substantial or nearly perfect agreement. If differences of opinion occur, the training session will be repeated with a new set of articles until the threshold value is reached. Once the inclusion and exclusion criteria will be perfectly understood by all the reviewers, the title and abstract screening will start. Each paper will be reviewed by two reviewers to ensure consistency. If a discrepancy occurs between them, the final decision will be discussed by two additional reviewers. All conflicts will be solved by two additional reviewers. In order to be conservative at this stage, if the qualifying information is not sufficiently detailed to reject or retain a paper with certainty, the given article will be kept for assessment at the next stage. At the second stage, full articles retained in the first screening will be assessed for their eligibility by two reviewers. Once the second stage is completed, the relevant meta-data will be extracted from all articles by two reviewers and all potential conflicts will be solved by two additional reviewers. The coding has been conceived to be as explicit as possible to avoid any kind of interpretation and to minimize potential inconsistencies among reviewers. Furthermore, prior to the coding, all reviewers will train on a subset of papers until a sufficient level of consistency among them is reached (i.e., Fleiss' kappa > 0.6). Reviewers that are authors of papers found during the research process will not review these publications to avoid biases towards these publications. An impartial reviewer will screen these papers at both stages.

Eligibility criteria

In order to be included in the map, an article needs to fulfill each of the following criteria at both stages of the screening process:

- Relevant population(s)
  The study focuses on the North Sea marine ecosystem defined as the ICES divisions IVa, IVb and IVc (including fjords and estuaries if they fall in one the ICES divisions previously mentioned; see map in Additional file 3.), from the coastline to the center of the area. In addition, the study includes the biotope (substrate, sediment, water column) and/or biocenosis components (plants, animals but excluding humans) of the North Sea.
- Relevant exposure(s)/intervention(s)
  The study explicitly considers at least one of the five direct anthropogenic drivers of global change as defined by the MEA [13] and the IPBES [14], namely climate change, direct exploitation (fishing activities), pollution (including eutrophication), biological invasion and sea-use change. A relevant paper is also included if it analyzes management options or mitigation measures related to at least one of the anthropogenic drivers.
- Relevant outcomes
  The study describes, assesses, makes projections of past, current and future impacts of at least one of the five direct anthropogenic drivers of change and/or analyses the biological and/or ecological effects of global change management measures on the North Sea marine ecosystem.
- Relevant study designs
  All study designs will be included with some exceptions detailed below. Experimental and modelling studies as well as studies involving projections and time series analysis will be equally retained. Secondary studies, e.g., meta-analyses, reviews or book chapters, will be marked. Articles must be published between 1945 and 2020, but we will consider all studies assessing the impacts of the direct anthropogenic drivers since the pre-industrial period as considered by the Intergovernmental Panel on Climate Change (IPCC) [61], i.e., from 1850 to 1900. This time period corresponds broadly to the beginning of the "Anthropocene", a period when human forces started to have a large effect on the Earth and became significant geological forces [62, 63].

The following exclusion criteria will be applied:

- Irrelevant areas
  Studies that exclusively focus on areas that are part of the "Greater North Sea" (e.g., English Channel, Kattegat and Skagerrak) but do not fall in one of the ICES divisions IVa, IVb or IVc and studies exclusively outside the North Sea area. Studies not strictly related to the marine environment (e.g., the atmospheric compartment above the North Sea).
- Irrelevant exposure(s)/intervention(s)
  We will make a clear distinction between natural and anthropogenic drivers. Indeed, global change by natural drivers, in contrast with anthropogenic drivers, are unpredictable and cannot be managed and, therefore, can only be described and studied with reference to past events [28]. Hence, climate variability (e.g., seasonal variations, North Atlantic Oscillation) or natural extreme weather events will not be considered in our study, even if it is recognized that they represent major forcing factors for marine ecosystems and that their trends and magnitudes are strongly influenced by human activities. Studies that evaluated the impacts of climate variability without explicitly linking this variability to climate change (i.e., a change driven by human greenhouse gas emissions) will not be included. Articles only presenting carbon capture and storage potential in the North Sea, an engineering solution which aims to reduce CO_2 emissions, without evaluating the potential consequences of carbon sequestration for the environment, will also be considered as irrelevant.
- Irrelevant outcomes
  Studies that only focus on the socio-economic impacts of the direct anthropogenic drivers as well as studies that do not assess the consequences of global change on the marine compartments of the ecosystem (e.g., the atmosphere).
- Irrelevant study design
  Methodological papers describing potentially relevant methods or indicators to analyze the direct anthropogenic drivers themselves or their potential

impacts on the marine ecosystem without explicitly applying them to real case studies in the North Sea.

All inclusion/exclusion decisions in the full-text stage will be documented and made publicly available together with the literature reference archive and search records.

Study validity assessment

A critical appraisal of study validity will not be performed because the main objective of the systematic map is not to examine the robustness of the study designs. However, information on study designs, (e.g., methodology employed, data types used, duration of the study, which type of driver is analyzed, population studied) will be collected and will allow future assessment of the validity of these methods.

Data coding strategy

For each article, two reviewers will code the full body text and will extract the relevant information (see below). This coding will be performed on the SysRev platform. The results will be extracted as a.csv file, in order to follow a tidy methodology (i.e., each variable forms a column, and each observation forms a row) in the subsequent process in the R environment [64]. Several categories of data will be extracted (Table 3).

Study mapping and presentation

A narrative mapping of all reviewed articles will be provided following the ROSES format [45]. A publicly available systematic map database will be provided detailing all retained scientific articles along with their metadata. Using the new EviAtlas R shiny app [65], a geographic map of all relevant studies will be created and will allow any user to generate key systematic map plots like heat maps or standard descriptive plots (e.g., the number of studies published per year focusing on climate change impacts). This tool will ensure that our systematic map outputs can easily be communicated and understood by a broad audience, including policymakers. Heatmap plots and structured matrices will be produced to identify knowledge gaps and knowledge clusters among the direct anthropogenic drivers, studied populations and locations in the North Sea. In addition, descriptive statistics will be used to summarize quantitative and qualitative trends of the marine research conducted on the studied area.

All the analyses described here will contribute to answer our main question: How did the research interest

Table 3 Categories used for coding studies further described by respective type of data

Category	Type of data
Bibliographic information	(a) Author names (b) Number of authors (c) Countries and lab of authors (d) Publication type (e) Publication source (f) Publication year (g) Number of citations (h) Current impact factor of the journal
Information relating to the inclusion criteria	(a) Population: ecosystem component affected (b) Population: study location (c) Exposure: anthropogenic driver(s) studied (d) Intervention: type of management measures applied/tested (e) Outcome: type of the nature's contribution to people affected (f) Outcome: all other potentially relevant outcomes
Information relating to the study	(a) Study type (e.g., in situ or ex situ study) (b) Type of data (e.g., primary data or meta-analysis) (c) Methodology employed (e.g., experimental or observations) (d) Level of biological organization (e.g., species, community, ecosystem) (e) Study location (e.g., longitude, latitude, ICES division, marine domain, habitat type) (f) Type of pressure associated to the anthropogenic drivers (e.g., habitat degradation, seawater warming) (g) Analyzed impacts[a] (e.g., changes in distribution, changes in abundance) (h) Spatiotemporal dimension of the study (yes or no) (i) Tested responses to drivers (yes or no)
Additional information	(a) Funding (b) Comments

[a] The map team will constitute a list of impacts/effects associated with the direct anthropogenic drivers. Authors will not be contacted in case of missing information

in anthropogenic drivers of marine ecosystem changes develop over the past 75 years (1945–2020) regarding the North Sea?

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13750-021-00234-y.

Additional file 1. ROSES for systematic map protocols. Version 1.0.

Additional file 2. Test list of relevant articles.

Additional file 3. Map of the study area.

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Authors' contributions
All authors conceived and designed the systematic map protocol. FM and RA drafted the manuscript. FM, FP, RA, GB, AB, DA and MS made adjustments to the methodology, including to the inclusion/exclusion criteria that resulted in the final protocol design. All authors read and approved the final manuscript.

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Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Availability of data and materials
Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Competing interests
The authors declare that they have no competing interests.

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