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ORIGINAL RESEARCH

Measuring consideration of aquatic ecosystems in national biodiversity conservation planning through text analysis

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Abstract

Broadening understanding and consideration of biodiversity across aquatic systems is critical to ensure their resilience. Globally, the Convention on Biological Diversity (CBD) sets objectives for conservation of biodiversity and sustainable exploitation of biological resources. Nationally, the broad plan for delivery of these three aims is articulated in National Biodiversity Strategies and Action Plans (NBSAPs), which contextualize globally agreed goals to local needs. Here, we use text analysis to investigate the focus of 182 national biodiversity plans that cover actions to achieve the CBD 2010–2020 framework, focussing on marine and freshwater ecosystems and their contrast with terrestrial ecosystems. The approach was validated by correlating intervention-related content measured by text analysis with corresponding interventions inferred from manual reading of the NBSAPs. Our analysis reveals variations in focus between terrestrial and aquatic systems that differ across country types and groups (e.g., inland, coast, or island country groupings, and continents), with significant country-level residual effects. Additionally, differential weightings in the focus of plans relating to environmental status, stressors, or interventions are identified. This study demonstrates the utility of text-analysis tools, and how their use could assist better alignment of national biodiversity strategies and NBSAPs to the 2022–2030 'Biodiversity Plan', to achieve more holistic and better-aligned approaches for conserving biodiversity towards the CBD's 2050 vision.

Keywords Water · Habitat · Governance · Policy · Text mining

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Introduction

The ocean is crucial to regulating the Earth's climate and is home to a diverse range of interconnected ecosystems that support almost every animal phylum, as well as the largest vertebrate biomass on Earth: fish (May 1994; Bar-On et al. 2018; Dobush et al. 2022). Meanwhile, a quarter of freshwater fauna are currently threatened by extinction (Sayer et al. 2025). Aquatic food production both in freshwater and marine farming environments is increasing and has outpaced population growth since 1960. Its value is unquestionable: Approximately 10 % of the world's population depends on fisheries and aquaculture for their livelihoods, and a further 4.3 billion people are reliant on fish for 15 % of their animal protein (Naylor et al. 2021; FAO 2024). Nevertheless, resilience of freshwater and marine ecosystems is being eroded by unsustainable levels of anthropogenic pressures, ranging from ocean warming and acidification to more localized threats of overfishing and pollution, which all have cumulative impact on productivity (Gallo et al. 2017; Halpern et al. 2019; Dobush et al. 2022). As warnings on climate change increase, along with impacts on biodiversity, time constraints for delivery of effective interventions make urgent issues even more pressing.

As both marine and freshwater environments often span international boundaries and provide common resources, it is critical that national conservation strategies reflect a globally agreed consensus. Increased economic development and international trade exacerbate biodiversity loss, imposing cumulative effects across these poorly understood ecosystems (Mattison and Norris 2005; Molnar et al. 2008). It behoves the global community to come together to learn from shared experience and broad scientific progress, to spur collective prioritization and action. As societal awareness of the stresses on aquatic systems grows, and the social-environmental ramifications become ever more visible, actions focused on marine and freshwater systems should not be underrepresented in national conservation strategies or marginalized in global conservation fora (Gallo et al. 2017; Dobush et al. 2022; Friedman et al. 2022). Yet, out of the 17 Sustainable Development Goals (SDGs) outlined by the United Nations (UN) 2030 Agenda in 2015, Goal 14—Life Below Water—remains the least funded with less than 5 % of the required level to achieve UN targets (WEF 2022; Nature 2023).

Following the expiry of the Convention on Biological Diversity's (CBD) previous decadal plan for people and nature – the "Strategic Plan for Biodiversity 2011–2020", with its 20 "Aichi Biodiversity Targets" (CBD 2010; below, Aichi targets) – the later "Kunming–Montreal Global Biodiversity Framework" (GBF) was agreed in December 2022 (GBF; CBD 2022). At national level, efforts to achieve Global Biodiversity Framework objectives are planned and documented through the preparation of "National Biodiversity Strategies and Action Plans" (NBSAPs), which guide each nation's focus on biodiversity conservation (see Articles 3, 6, 20 and 21 of the CBD). Planning reflects the overall goals and targets of the GBF, accounting for specific national circumstances and local priorities for biodiversity conservation. Parties are now required to transition their NBSAPs to reflect the vision of the GBF.

Despite good intentions for delivery of the CBD's last decadal framework, a lack of investment (Evans 2021; Xu et al. 2021), national capacity (Dobush et al. 2022), and ability to integrate approaches across authorities (Contestabile 2021) were identified as barriers to progress in implementation of the Strategic Plan. Indeed, a previous review of conservation planning (Evans 2021) suggested that the focus and definition of strategies was varied and did not always align well with either local conservation needs or the overarching goals and targets of the CBD. Furthermore, nations were tasked with crafting biodiversity plans towards national needs and the goals of the Kunming–Montreal GBF in advance of CBD Conference of Parties meeting held in late 2024 (CBD Article 6). However, only 22 % of countries submitted NBSAPs at the meeting dubbed “the implementation CoP”. This reveals that alignment of national conservation planning with the GBF remains challenging for states. Progress appears to be patchy, with greater progress for some Aichi targets than others (Buchanan et al. 2020).

Aside from progress indicators, another approach to assessing progress is to scrutinise policy documents (here, NBSAPs) for their content. Here, we use text analysis to investigate the focus of NBSAPs in terms of content that addresses aquatic (marine and freshwater waters) as opposed to terrestrial systems, to examine potential policy gaps and the balance of attention to different conservation priorities. We also address how variation between NBSAPs is explained by country-level covariates such as geographical location or GDP. Text analysis approaches are particularly beneficial for large numbers of documents, and were previously applied at high level to NBSAPs by Uetake et al. (2019). In particular, we pay attention to keywords related to potential interventions, and how approaches vary across different regional and country contexts and requirements.

Methods

Data sources

Between June and November 2022, published NBSAP reports available from the Convention on Biodiversity website (CBD 2024) were downloaded. Where necessary, reports were translated into English using the translation tool in Microsoft Word (Office 365 Version 2508), for example, from French, Spanish, Arabic, and Hebrew. In most cases, Word was able to translate without problems, but eight (4% of the total plans) could not be translated because for example Word could not recognize the original language or the NBSAPs were presented as scanned documents, precluding text extraction. These NBSAPs were excluded from further analysis. In the United Kingdom, separate NBSAPs exist for England, Scotland, Wales, and Northern Ireland, whilst some countries had not yet published a NBSAP at the time of study.

Data for country areas, population sizes, gross domestic product (GDP, nominal, USD), and GDP per capita were obtained from the World Bank database (World Bank 2024), using the most recent data for each country. For GDP, the most recent data up to 2022 was used as it was more consistently complete up to this year. In five cases (Eritrea, North Korea, South Sudan, Venezuela, Yemen), recent GDP statistics were unavailable, and GDP for Cook Islands and Nieu were supplemented from the CIA World Factbook (CIA 2024). Coastline lengths were also derived from the CIA World Factbook (CIA 2024), specifically including the Caspian Sea. UK-level data were used for all four component-countries of the UK. NBSAPs were classified into seven geographical regions (Africa, Americas, Asia, Commonwealth of Independent States (CIS) and region, Europe, Middle East, Oceania), and three territory types: island, coast (including Australia) or inland (coastline length was zero). The NBSAPs included in the analysis can be found in Table S1 in the Electronic Supplementary Material.

NBSAP processing

Data cleaning and analysis on the resulting 182 analysed NBSAPs was performed using custom code in the R statistical environment (R Core Team 2023; Fig. 1). Text from each NBSAP was converted into a single text file to identify and count individual words. To compile a case-insensitive dictionary of words of intellectual interest across the NBSAPs,

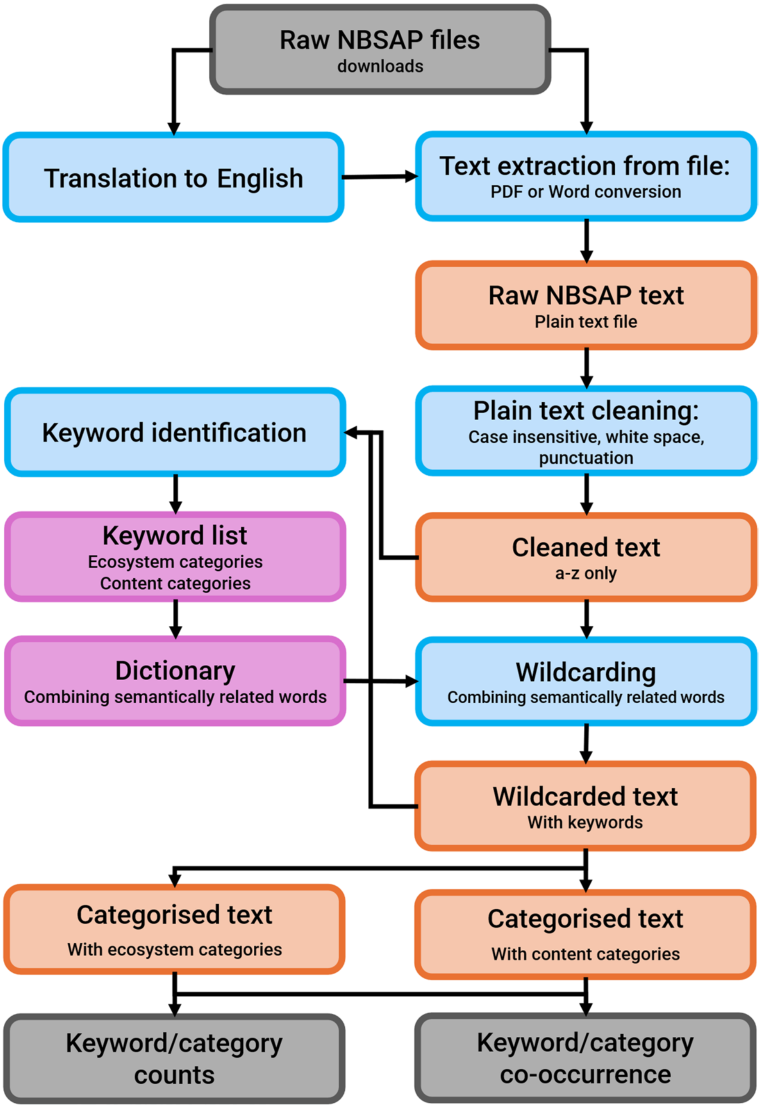

Fig. 1 Flowchart of the textual analysis of the National Biodiversity Strategies and Action Plans (NBSAPs)

all files were first pre-processed by converting to lower case, replacing all non-alphabetical characters with spaces, and dividing into words at word boundaries. Words were then ordered by number of occurrences, combining singular and plural forms, and, restricted to those words that occurred at least five times per NBSAP on average. Definite and indefinite articles, prepositions, possessives and other non-descriptive or irrelevant words were excluded from this tabulation.

Our study used a simple text analysis approach, and we did not assess pragmatic meaning of words in their individual context; however, a "wildcarding" approach (partial matches of words according to a pattern of letters) was applied that allowed some limited semantic processing to carry out tasks such as merging synonyms, combining plurals with their singular forms, coping with spelling variants (e.g., "-ize" and "-ise"), and removing grammatical inflections such as verb endings. This was applied using Regular Expressions (Regex) to the pre-processed files using custom wildcards. Wildcard "*****" was used to match 0 string of characters. For example, "administ*", "council*", "ministr*", and "federa*" were all combined to "administration". The more restrictive wildcard "+" was used to match 0 or 1 of any character, such as for plurals of the form "bird+". The wildcard "?" was used to match any single character, such as variants in words such as "mobili?e". Wildcarding used a "dictionary" table consisting of a list of *replace–search pattern* pairs applied in table order to each text (see example in Table S2), where the *search pattern* is the original wildcard pattern and the *replace* the replacement word for further analysis. A choice was made as to what extent hyponyms—specific terms within a broader category—should be merged with their hypernym (e.g., "reservoir" with "lake"), and a conservative approach was taken here to avoid excess loss of information.

The subset of processed words of intellectual interest constituted our *keywords*, which below are indicated in bold. The dictionary and keywords were drafted by initial word-counting of raw text and subjective choice of terms of interest, followed by refinement for error checking and to minimize side effects, especially for distinct words with similar spelling. For example, **government** and **governance** were treated separately. A second pass after wildcarding identified additional keywords with at least five occurrences. The words included within the wildcarding process are detailed within the Electronic Supplementary Material.

Keyword categories

The significance and subsequent categorisation of words posed challenges. **Water**, for example, has different significance from different perspectives. This prompted our choice to provide two levels of descriptor category, the first related to ecosystems and the second "content" category more broadly associated with common perception and application. Keywords were characterized into 12 *ecosystem categories* contrasting aquatic systems of interest and broad terrestrial environments: water, freshwater, lake, river, marine, coastal, terrestrial, urban, forest, arid, grassland, and mountain. Choice of categories was based on keyword frequency to reflect the full range of ecosystems for comparison, not just aquatic ones. Some words referred to water but could not be allocated to a particular water type (e.g., **fish**); likewise, some terrestrial words could not be allocated to a particular ecosystem (e.g., **soil**). These categories were more broadly grouped as "all freshwater" (freshwater + lake + river), "all saltwater" (marine + coastal), and "all water" (the above + "water").

"Wetlands" are extremely diverse types of ecosystems that may span freshwater or marine environments. For the purpose of our analysis, we considered that the occurrence of "wetlands" referred exclusively to "freshwater" ecosystems, thus wetland keywords are grouped there on the figures below, whilst mangroves and saltmarshes are considered below as "coastal" ecosystems.

The second categorisation was made into 11 *content categories* to assess the perceptions of how different species or ecosystems were being impacted and how interventions and policy were related to the status of those ecosystems or species, as follows: bio-descriptor (e.g., **biodiversity**, **natural**), species group, resource, environment, status, stressor, geographical, sector, intervention, policy-maker, and social. **Water** was categorised in the "resource" content category. Further keywords of specific interest for spatial interventions in conservation were also identified based on a typology of area-based fisheries management measures (Himes-Cornell et al. 2022).

Relationships between descriptive statistics of the NBSAPs (e.g., keyword frequency, total text length, and text length of keywords only) and independent variables introduced above (e.g., national population size or coast length) were analysed using general linear models, with transformations applied to reduce skew in residuals. We used the square root of document length, and log-transformed population and geographical variables, with 1 km added to coastline length and 0.0001 km^{-1} to coastline per unit area to avoid $\log 0$. Covariates were included in the models first, followed by territory type and geographical region, to address variables more likely to be causally associated. The proportions of keywords in each category across countries was analysed using unscaled principal components analysis (PCA) using the *FactoMineR* package (Lê et al. 2008), followed by fitting of general linear models to components as above.

Co-occurrence of terminology within a single NBSAP

Word frequencies provide a basic assessment of the focus of NBSAPS but do not describe the context in which words occur. Therefore, to better understand the framing of different keywords and categories within them, we determined which specific pairs of words or categories of words were associated with each other (appeared close together in the text). For each NBSAP in turn, the positions (word numbers starting from the beginning of the document) of each keyword were identified. Adapting approaches of Lund and Burgess (1996), measures of lexical co-occurrence were based on these lists of positions. This could be a single list checked for co-occurrence against itself, as explained in the maths below, or co-occurrence between words in two lists (e.g., ecosystem and content keyword categories). A matrix $\mathbf{D}$ of keywords was calculated, representing the count of keyword pairs (p, q) that met a specified criterion for closeness in the text. We used co-occurrence within a rectangular window of radius $w = 250$ to approximate typical paragraph sizes. Where $\mathbf{a}_{i,j}$ represents the jth position of occurrence of word i, $\boldsymbol{n}_i$ is the number of occurrences of word i, and $d(x)$ is the distance indicator function, this matrix is calculated as

$$\mathbf{D}_{p,q} = \sum\nolimits_{u=1}^{\boldsymbol{n}_p} \sum\nolimits_{v=1}^{\boldsymbol{n}_q} d\left(\mathbf{a}_{p,u} - \mathbf{a}_{q,v}\right)$$

$$d(x|w) = \begin{cases} 1, & 0 \leq |x| \leq w \\ 0, & x = 0;\ |x| > w \end{cases}$$

.

To produce an average matrix across a group of NBSAPs, N individual country matrices were averaged, but were first scaled to unit weight to avoid longer documents being higher weighted in the average.

$$\bar{\mathbf{D}} = \frac{1}{N}\sum\nolimits_{u=1}^{N}\frac{\mathbf{D}_u}{\sum \mathbf{D}_u}$$

Manning and Schütze (1999) noted measures of co-occurrence such as *pointwise mutual information* are sensitive with rare events, and most words in a document will not co-occur frequently. Our aim was to identify co-occurrence of words which differ from random chance in magnitude, but without ascribing undue importance to rare word combinations which occur only as chance events. Thus, we used weighted [information theoretic] *mutual information* to robustly detect interesting co-occurrences that are both prominent and frequent, which is related to the Kullback–Leibler divergence. This is not a significance-testing approach: rather, the measure balances the deviation of the number of co-occurrences from random expectation against how often it occurs. First, the expected value of $\mathbf{D}$, $E(\mathbf{D})$ was calculated as

$$E(\mathbf{D})_{p,q} = \sum\nolimits_{u=1}^{n}\mathbf{D}_{u,q} \times \sum\nolimits_{v=1}^{n}\mathbf{D}_{p,u} / \sum \mathbf{D}$$

.

where n is the number of keywords. From this, a *feature matrix* was generated, whose elements indicated notable levels of co-occurrence or non-co-occurrence between pairs of words when further from zero:

$$\mathbf{F}_{p,q} = \frac{\mathbf{D}_{p,q}}{\sum \mathbf{D}}\log\left(\frac{\mathbf{D}_{p,q}}{E(\mathbf{D})_{p,q}}\right)$$

To produce global or sector/regional feature matrices, the N individual country feature matrices were simply averaged, as they were already independent of document length and did not need further normalising. Feature matrices for prominent keyword categories and individual keywords were visualized as heatmaps and also as networks using the R *igraph* and *ggraph* packages (Pedersen 2022; Csárdi et al. 2023), choosing the most prominent co-occurrences to connect keywords.

To assess the relative attention of interventions to potential priority areas, the relationship between "status" keywords (such as **degraded** or **vulnerable**) or "stressors" keywords that co-occurred with "interventions" keywords was examined by linear regression of numbers of their co-occurrences between countries. To avoid potentially misleading *p* values for a large dataset, the figures show 95% confidence intervals for the fit of each category (geographical region or territory type).

Validation

To test the accuracy and appropriateness of our approach, we conducted a validation focussing on human reading of intervention content in NBSAPs, using five documents of medium length chosen to be representative of different regions and territory types. They are anonymised below to avoid attention on individual countries rather than validation. The five NBSAPs were scrutinised to categorise the interventions within them as having been applied to marine, freshwater, forest or other terrestrial environment (excluding urban) ecosystem types. The counts and distributions of interventions from the reading exercise were then compared to the counts of co-occurrences of "intervention" keywords and with "environment" keywords by text analysis, mapping marine interventions to "all saltwater" keywords, freshwater ones to "all freshwater" keywords, forest ones to "forest" keywords, and other terrestrial interventions to "terrestrial" + "mountain" + "arid" + "grassland" keywords.

Results

General differences amongst NBSAPs and their drivers

NBSAPs varied greatly in length and content, from fewer than 2000 words (Liechtenstein) to 185,000 words (Israel). However, document length (word count) did not differ significantly amongst global regions ($p = 0.22$) or territory type (inland *v* coast *v* island; $p = 0.56$). Document length was not associated with coastline length ($p = 0.40$), population density ($p = 0.38$), or gross GDP ($p = 0.17$), but longer NBSAPs were produced by countries that were more populous ($p = 0.002; r^2 = 0.046$), had a larger land area ($p = 0.003$; $r^2 = 0.043$), and a smaller GDP per capita ($p = 0.008$; $r^2 = 0.033$). Nevertheless, in all cases, the adjusted r^2 value was small, and the differences identified explained little of the variation. NBSAPs vary in the proportion of matched content words of interest to document length: Keywords varied from 18% to 46% of overall word count with a mean of 33%. Examples of the word types that can "dilute" keyword content include personal names and lists of species. Repeating the above analyses on keywords alone rather than all words did not alter the significance of any variable.

Analysis of the distribution of keywords across global regions and the three territory types highlights intuitive relationships in conservation planning across ecosystem and content keyword categories (Fig. 2). For example, coastal and marine keywords are particularly pronounced in island countries, and coast countries more than inland countries, whereas terrestrial, urban, forest and grassland keywords are most prominent for inland countries. Less

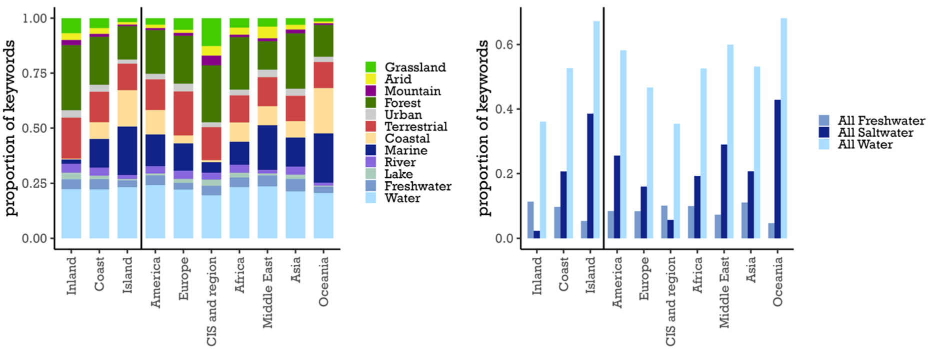

Fig. 2 Proportional occurrence of the twelve ecosystem category keywords among inland, coast, and island territory types (left bars) and seven global regions (right bars)

pronounced was variation in emphasis found amongst territory type for freshwater keywords, although there was a higher occurrence for inland countries. Considering regional patterns, the NBSAPs submitted by countries in Oceania, which comprises island countries (except Australia, designated as coast) had much greater emphasis on marine and especially coastal ecosystems than many other regions. Conversely, countries in the CIS (and region) had much more emphasis on grasslands, mountains and arid areas, with less attention given to marine environments (Fig. 2).

Principal components analysis (PCA) for ecosystem keywords reflects the contrast between oceanic and terrestrial content, with territory types strongly grouped and some separation amongst regions (Fig. 3; Supplementary Fig. S1). Geographical region is significant in several regression analyses of principal components versus country-level explanatory variables, after the other explanatory variables have been accounted for (Supplementary Table S3). This indicates residual differences on a regional level, beyond accounting for geographical or demographic drivers. Together, the PCA results reinforce the suggestion that ecosystem keywords focus around an axis between more marine *versus* more terrestrial content, with secondary components focussed more on dimensions within terrestrial environments.

Variation is seen in the co-occurrence between keyword categories indicating particular keyword associations (Fig. 4). Noticeably, the keyword **sustainability**, associated with the second aim of the Convention (sustainable use) was less frequent and less co-occurring than **protection**. Notably, from a fisheries perspective, association amongst keywords **fish** and **fishing** were few compared to **biodiversity**, **species** and even **forest**. Co-occurrence between **fish** and **fishing** terms with, for example, **protection**, **strategy** or **regulation** were also less frequent.

How are spatial-conservation approaches represented?

In terms of counts of keywords relating to spatial conservation interventions in marine systems, islands and especially coast states show a larger amount of approaches described, and a broader range of intervention than inland states (Fig. 5). Spatial management, including marine protected areas (MPAs) and biosphere reserves, were mentioned the most, with relatively low coverage of keywords connected with the term "other effective area-based conservation measures" (OECMs) or area-based fisheries management interventions. OECMs – a novel descriptor negotiated for Aichi Target 11 to encompass many and diverse

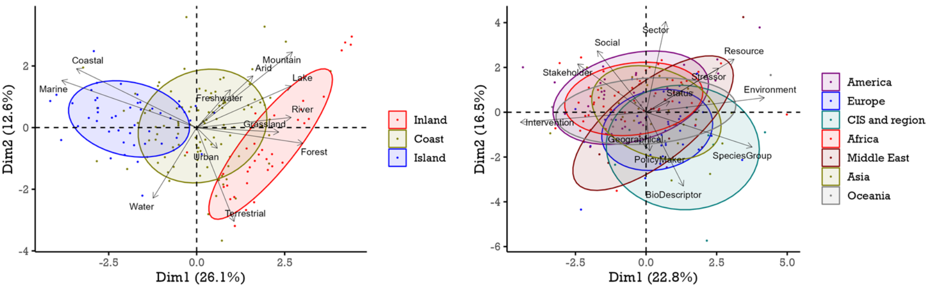

Fig. 3 Principal components analysis biplots of keyword proportions according to ecosystem (left) and content (right) categories. Ellipses show the 68% confidence intervals (equivalent to one standard deviation) for each group of countries

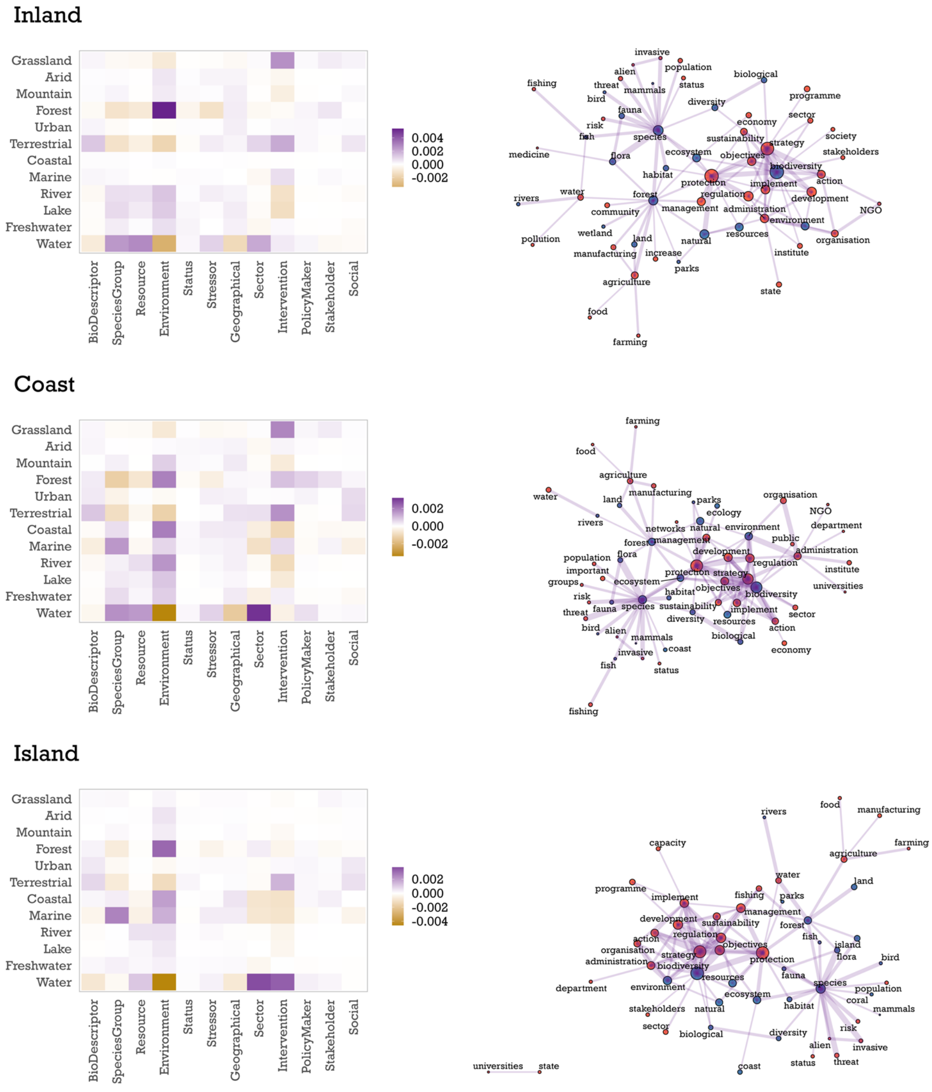

Fig. 4 Co-occurrence of keywords linking strategic actions and ecosystem typology. Heatmaps show co-occurrence between ecosystem keywords (y-axis) and content keywords (x-axis) split by territory type, demonstrating positive (purple, more common) and negative (gold, less common) deviations of keywords from random chance co-occurrence. Keyword-association graphs depict the top 2% of positive associations for the most frequent keywords, where node colour represents biological (blue) and social (red) keyword categories, and node size reflects frequency of the keyword

approaches to biodiversity conservation other than marine protected areas – were rarely mentioned, with a total of 93 occurrences over just 58 of the 182 NBSAPs.

Island states and those in the Oceania region have a particularly high focus on spatial management interventions in marine systems, particularly around marine protected areas (MPAs), and attention across all keywords is notably low in the CIS and surrounding region,

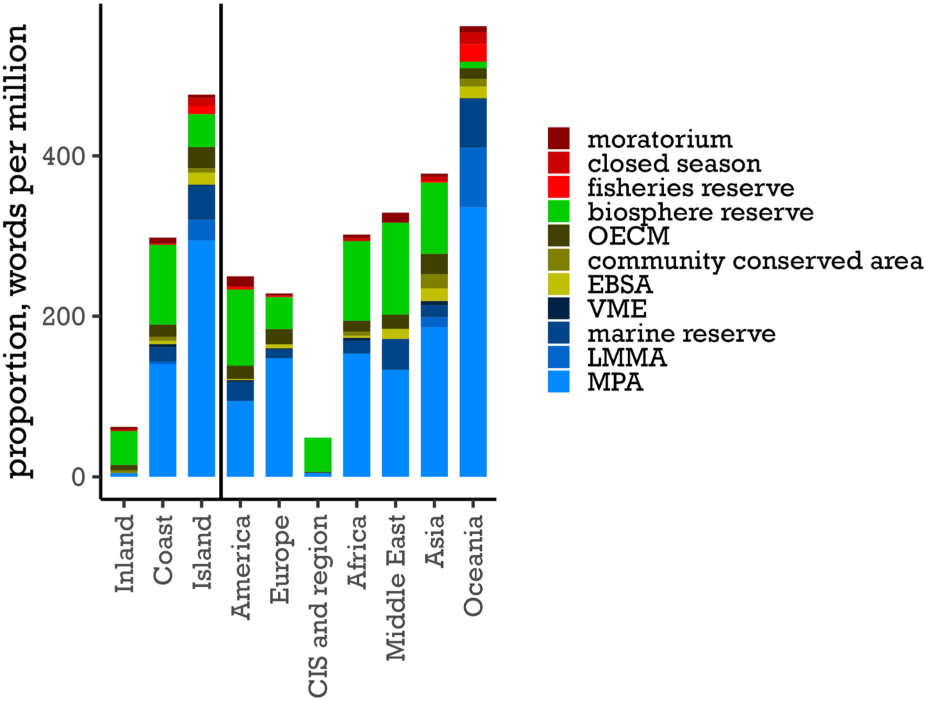

Fig. 5 Frequency of words associated with interventions concerning fisheries management and spatial planning, as a percentage of total words, according to territory type and geographical region. MPA—marine protected area; LMMA—locally managed marine area; EBSA—ecologically or biologically significant marine area; VME—vulnerable marine area; OECM—other effective area-based conservation measure

despite fisheries importance in the Caspian Sea basin and some notable disasters and subsequent rejuvenation efforts such as in the Aral Sea (Plotnikov et al. 2023).

Examining use of status and stressor words in plans

To examine perspective of plans in directing conservation strategies, keywords were categorized separately into ecosystem and content categories prior to creating co-occurrence matrices. The heatmaps and graphs demonstrating ecosystem–content keyword co-occurrence were then created for each territory type and geographical region (Fig. 4 for a simplified view; Fig. S2).

Keywords attributed to contextual aspects such as "stressors" (e.g., **invasive** or **pollution**), "interventions" (e.g., **training**, **budget** or **programme**) and "species group" (e.g., **flora**, **bird** or **coral**), allow examination of the focus of activities documented within NBSAPs. "Environment" content keywords were associated with "forest" and "coastal" ecosystems, while "resource" (e.g., **water** or **stocks**), "species group," and "sector" (e.g., **agriculture** or **manufacturing**) content words associated with "water" and "marine" ecosystems. Here "intervention" keywords were more associated with terrestrial ecosystems (e.g., "terrestrial" and "grassland") than with aquatic environments. Surprisingly, "marine" environments were more strongly associated with “species group” keywords (only for coast and island states) but weakly linked with “intervention” keywords, even in island states.

Categorisation of the keyword **water** as a “resource” resulted in this appearing more strongly in the heatmaps, but it was also heavily related to “sector” keywords, suggesting its use within commercial rather than environment contexts. “Water” ecosystem keywords were also heavily connected to “intervention” keywords, showing that there is considerable attention to water in policy, but it may be from a commercial rather than a biodiversity perspective. There were few specific connections between “freshwater” environments and “policy maker”, “stakeholder” or “social” context keywords. This likely reflects the general smaller number of keyword occurrences in these categories (Fig. S3). In inland and coast countries, “water” content was more strongly linked to content concerning “species groups”, but co-occurrences relating to interventions around “water” were less apparent. Specific references to freshwater (“freshwater”, “lakes” and “rivers”) did co-occur with “environment”, “resources” and “species groups”, but freshwater was not particularly well reflected in terms of linkages to “interventions”.

The network diagrams reinforce these findings, with keywords such as **protection**, **management** or **strategy** tending to remain distanced from water-related keywords, yet closer to terrestrial keywords like **forest**. These diagrams show two main clusters of keywords: one set comprises keywords connected with activities such as **strategy** and **protection**; the second set is centred around biological terms such as **species** and (except for island countries) **forest**. The strongest links with **species** include stressor keywords such as **invasive** or **alien** plus generic terms like **threat** and **risk**. Of the strongest connections, **pollution** was the only stressor word found co-occurring with **water** or other ecosystem keywords for inland countries, with **climate** a notable absence, as the most common specific stressor word.

Links between intervention-related and other content

The relationship between “status” keywords (such as **degraded** or **vulnerable**) or “stressors” with “interventions” reveals the relative attention of interventions to potential priority areas. Figure 6 shows variation across the three territory types for four selected ecosystem categories (additional categories are shown in Fig. S4). Of most interest is the vertical position of lines, which shows the relative co-occurrence with intervention keywords relative to co-occurrence with status (or stressor) keywords, implying better linkage between identified ecosystem stressors or status, and interventions designed to address them within the NBSAP. Likewise, the vertical position of each country relative to the trendlines can be interpreted in the same way: Where a country is above the trendline, there is a relatively high co-occurrence of intervention with status/stressor keywords, and thus potentially, relatively high intervention–ecosystem content. Comparisons between ecosystems here must be viewed with care as different topics will require different numbers of words to discuss them, however comparisons within a particular topic should be meaningful.

There is large overlap between confidence intervals for territory types and geographical regions across the separate ecosystem keyword categories, but some interesting contrasts can be observed: For “marine” and “coastal” interventions, the relative attention to ecosystem-associated interventions is highest for island countries and lowest for inland. To a lesser extent, this same pattern can be observed for other aquatic ecosystems. By stratifying by geographical region (Fig. S4), some interesting patterns can be observed, such as relatively

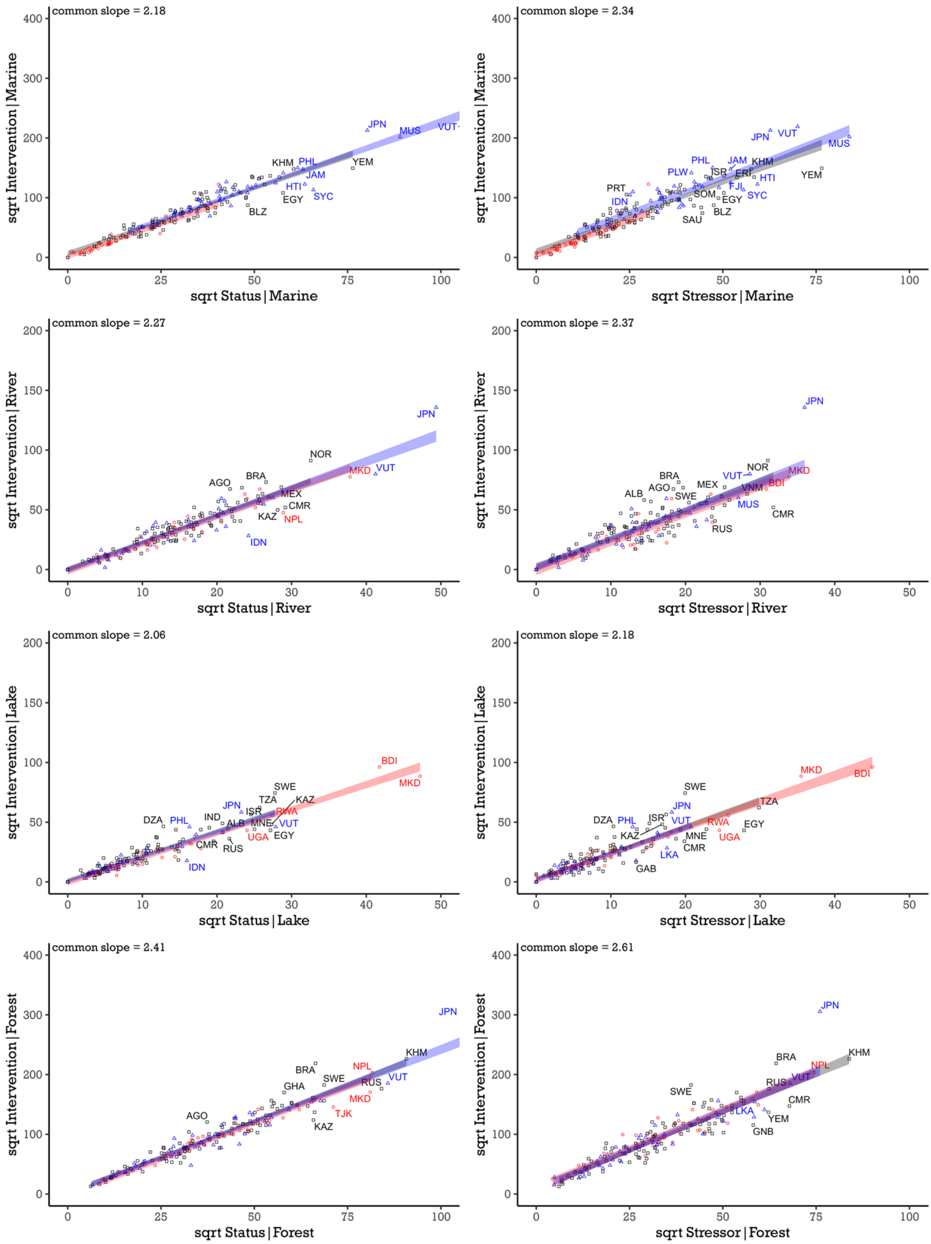

Fig. 6 Correlation of intervention and status- or stressor-related keywords for particular ecosystem categories. The square root of the number of co-occurrences of intervention and ecosystem keywords (y-axis) is shown versus the square root of the number of co-occurrences of status (left) or stressor (right) keywords within the same ecosystem. Four example ecosystem categories are shown: marine, river, lake, and forest. Each is broken down by island (blue), coast (grey), and inland (red) countries

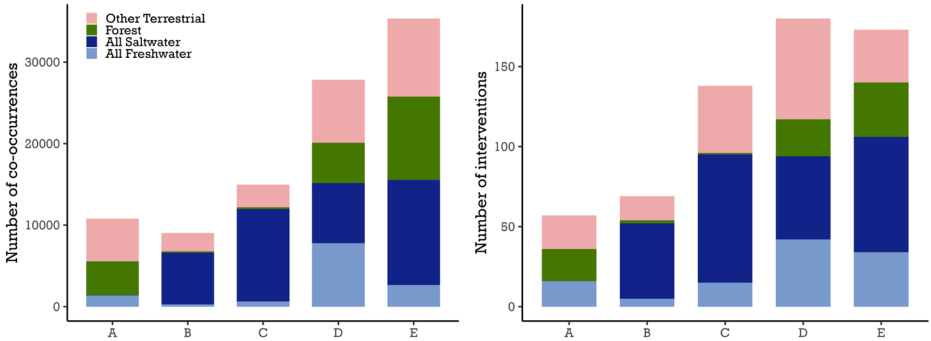

Fig. 7 Validation of text-analysis approach against human reading. The co-occurrences of intervention and ecosystem keywords (textual analysis) is compared with categorised interventions applying to the same grouped ecosystem categories (human reading). A sample of five (anonymised here to avoid criticism of specific countries) NBSAPs was analysed

high focus on marine and coastal category intervention content in Oceania, and "mountain" and freshwater categories for Asia. An exception is seen with countries in CIS and region where the reverse trend is seen.

Validation

For the five chosen countries, intervention–ecosystem keyword co-occurrence from text analysis was compared with ecosystem-specific intervention counts from human reading (Fig. 7). In the NBSAPs sampled for validation, patterns of co-occurrences strongly resemble those of interventions. This was not simply a case of longer NBSAP documents showing both, with a weaker association seen with document length (not shown). The text analysis also recovered satisfactorily the differences between NBSAPs in the ecosystem-level differences in focus. "Water" keywords not linked to a specific ecosystem were omitted in this comparison: No non-specific water-related interventions relating to ecosystems were identified for these countries through human reading. Though they may exist in other NBSAPs, this supports the earlier suggestion that these interventions may be more commercial than environmental in context.

Discussion

Through text-based analysis we have examined the representation of different ecosystems in NBSAPs, finding contrasting levels of attention across ecosystem types, notably between terrestrial and aquatic systems. The study did not directly assess reasons for this variation or the match between documentation in NBSAPs and conservation need. However, the validation process demonstrates that our approach shows promise in supporting appraisal of large numbers of these types of documents, and our approach has potential utility for individual countries to assess the position of their NBSAPs in regional or international context.

A lack of prominence was evident across freshwater ecosystem categories (Fig. 2). This may reflect a lack of research into freshwater environments, however focus in conservation effort does not necessarily reflect focus of conservation research (Di Marco et al. 2017). Yet, these areas contain some of the most diverse assemblages and threatened groups of species (Thomsen et al. 2012; Biggs et al. 2017). According to Bull and Strange (2018), the "no net loss" (NNL) biodiversity conservation strategy is overwhelmingly applied to terrestrial systems (66.7% forests and 17.5% wetlands), which is reflected in the study by the prominence of forest keywords (Fig. 2) and their appearance in our network diagrams (Fig. 4).

Other research has found that 81–91% of conservation studies are centred on terrestrial systems (Levin and Kochin 2004; Di Marco et al. 2017), with an absence of aquatic systems from some key analyses on the effectiveness of conservation policy (Miteva et al. 2012). Explanations for the reason for this vary, but Raffaelli et al. (2005) and Tittensor et al. (2010) outlined differences in approaches to marine and terrestrial systems, including focus on different spatial and temporal scales between terrestrial and ocean management approaches – finer spatial scale for terrestrial and finer temporal scale for marine – and differences exist in range and regional bias of biodiversity data sources (Geijzendorffer et al. 2016; Oestreich et al. 2020). Additionally, marine-systems knowledge remains underrepresented in biodiversity databases (Hughes et al. 2021) and conservation initiatives, which could hamper further study.

We found keywords related to interventions targeted at specific aquatic systems consistently underrepresented in NBSAPs across all geographic typologies (Fig. 4). Within aquatic systems, coastal and marine ecosystems received more attention than freshwater systems. Furthermore, our analysis shows few specific connections between freshwater environments and "policy makers", "stakeholders" or "social contexts" keywords (Fig. 4). Lack of attention to interventions, status and stressors for freshwater systems are particularly prominent in the heat maps, while aquatic keywords such as "fishing" have few connections in the network diagrams compared to terrestrial keywords such as "forest", they are well connected to species and governance keywords such as "protection" and "management". Such underrepresentation may reflect the lack of prominence of interventions targeting aquatic systems within policy mechanisms and funded research. Differences between aquatic systems and how they are considered in NBSAP interventions – either as a resource or a habitat – were uncovered in our analysis, but explicit connection between aquatic system types to "status" or "stressor" words, which has implications for interventions required, were uncommon.

Of marked concern to fisheries authorities will be lack of prominence (and co-occurrence with interventions) of fish and fishery issues (Fig. 5), which may hinder their inclusion in the biodiversity discourse (Friedman et al. 2018). While fishery production relies on ecosystem health, it has also been considered the most prominent threat to marine ecosystems, some of the most taxonomically diverse on the planet (May 1994; IPBES 2019). However, growing discussion suggests that there is an overemphasis on overfishing and a preoccupation with MPAs in terms of priorities for marine biodiversity conservation, while neglecting other stressors such as ocean warming, acidification, and pollution (Hilborn 2016; Halpern et al. 2019; Edgar et al. 2023). Meanwhile assessment of policy and research has highlighted a mismatch between government policy documents compared to approaches by NGOs and international organisation (e.g., IUCN) priorities (Mazor et al. 2018). For example, although pollution has received growing attention in policy and research, it remains low on the priority list, despite having been highlighted as a key driver of biodiversity loss (Mazor et al. 2018). Our results show little direct linkages in NBSAPs of stressors to aquatic environments (Figs. 4 and 6) compared to terrestrial, although **pollution** was apparent in the network diagram for the inland country group, linked to **water**.

For terrestrial biodiversity loss, habitat loss, land degradation and urbanization are considered the most important drivers (Mazor et al. 2018), whereas for marine biodiversity loss, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and others note overexploitation as a key historical driver (Mazor et al. 2018; Bull and Strange 2018; IPBES 2019). The structure of the CBD's new framework, the GBF, has elevated the focus on social issues in the context of "meeting people's needs". Therefore, the balance of NBSAP focus on reducing threats to biodiversity compared to threats to ecosystem services will be given greater consideration in GBF planning and delivery by 2030.

Presently, climate change and pollution are considered by some researchers to be the most important drivers of biodiversity loss and redistribution in aquatic systems, including, but not limited to, coral bleaching, changes in migration patterns, and distributions and ranges of fish stocks, resulting from increased marine and freshwater temperatures, increased wave action, storm events, reduced river flow, increased evaporation and rainfall and associated changes in water quality (Poff and Brinson 2002; Prakash 2021). However, there has been little progress on achieving the Aichi targets, despite a high level of research emphasis on climate change (Mazor et al. 2018). Therefore, there is an urgent need to realign research and policy interests towards more scientific, data-based strategies (Thomsen et al. 2012; Edgar et al. 2016).

A known imbalance is a persistent asymmetry in research focus, particularly specific geographical areas, with most research taking place in temperate climates, which tend to be less diverse than tropical climates (Tittensor et al. 2010; Geijzendorffer et al. 2016; Menge et al. 2009). There are also biases in the organisms targeted, with research favouring plants and vertebrates, particularly charismatic megafauna, which is potentially economically motivated by tourism (Ellison 2008). This leaves fundamental gaps in our knowledge of aquatic systems from the micro to the macro scale, and of the physical-chemical mechanisms of their environments (Biggs et al. 2017). For example, fewer than 15% of marine species have been assessed for the IUCN Red List (IUCN 2024). This may reflect an economic bias in NBSAP focus, where short-term commercial value of ecosystems and resources take precedence over their intrinsic value or longer-term economic importance. Currently, only 2 % of invertebrates have been assessed for the IUCN Red List (IUCN 2024), despite being most at risk of extinction. At an even lower size range, our analysis found a lack of attention at microbial scale: microbial keywords are sufficiently rare as to not even feature in the analysis, despite microbial and bacterial related terms occurring 4.7 times on average per NBSAP (fungal 3.3, viral 0.5, but antimicrobial resistance almost absent). This largely reflects a lack of attention of conservation scientists to the importance of communities of smaller organisms, despite the ecosystem services they provide in terrestrial and aquatic environments (Beattie 2014).

Towards a diagnostic tool for biodiversity plan appraisal

The strength of the approach tested in this study is that text analysis delivers a rapid overview of planned national conservation interventions, as documented in NBSAPs, in the context of global approaches. Comparing individual national plans against global conservation planning priorities shows the differences in emphasis between neighbours and across nations. At its simplest, this kind of text analysis identifies consistency or "disjointedness" in the coverage of NBSAPs in relation to the GBF, or sectoral interests (e.g., fisheries, forestry, agriculture, climate action). Despite a framework existing for the creation of NBSAPs, huge variation remains across these documents, for example in the 100-fold range in document length.

This broad text-analysis approach comes with caveats and limitations. We used entire documents, thus repeated elements from titles, tables and figures inevitably remain in the processed text. Despite this, junk words (e.g., labels such as "iii") and local word-ordering do not unduly influence the results, other than in the process of defining window length for word co-location. Our approach indicates where words co-occur, but not why. For example, a particular neighbouring word could imply a negative (e.g., non-**agricultural**) or a red herring (e.g., phylogenetic **tree**). Homonyms (e.g., river **bank** *versus* central **bank**), words with a broad semantic range (**water**) and polysemic words (**waste** [garbage] *versus* **waste** [squander]) are not so easily categorized. Documents and topics will also vary in verbosity across styles of English or translation and quality of translation of foreign languages into English. As a practical solution available to most practitioners, the Microsoft translation software employed in this study was advised by professional translation services as delivering sufficient accuracy for the task at hand. Moreover, the in-built translation should not greatly affect the analysis with regards to co-location of keywords within the defined window.

A further step in analysis beyond our present study could be to refine some of the subjective steps in our analysis such as wildcarding prior to assessment, or to cross-reference keywords with results from manual textual analysis. However, this would be a huge undertaking for all 182 NBSAPs, further highlighting the potential of our approach as a practical tool to making "broad brush" assessments. Nevertheless, the validation exercise of a sample of NBSAPs demonstrated the accuracy of our methodology, and that allowances made for potential pitfalls during the pre-processing and wildcarding steps were productive. The validation exercise used a much more detailed approach but was very time consuming and could not have reasonably been done for all NBSAPs. However, the level of detail was obviously much greater and individual interventions could be assessed for their specific aims that would be challenging to achieve using the text-mining approach.

From a more nuanced perspective, deeper examination of NBSAPs will be required to understand issues or detailed descriptions of interventions, as well as the necessary mechanisms required for successful implementation in policy and practice at a global, regional and national scale, including periodic assessment of their effectiveness (Mattison and Norris 2005; Biggs et al. 2017). An example is posed by spatial conservation measures: Not all keywords in this space are uniquely related to the marine environment. For example, though biosphere reserves feature strongly across geographical regions and territory types, they are not uniquely applied to marine systems.

Failure of NBSAPs to document operational realities may particularly result where their writing is largely the responsibility of national environmental authorities, while overlapping responsibilities for biodiversity conservation across social-environmental systems falls to a broad range of government departments. Specificities of further analysis could include different themes around inclusivity, regulation, stewardship interventions and the capacity to deliver actions, including the ability to monitor, fund, regulate and enforce interventions for a variety of stakeholder interests across the wide scope of biodiversity conservation processes.

Our approach is not based on artificial intelligence – AI text-analysis is however a growth area, particularly through the growing popularity of large and small language models as well as other forms of natural language processing (NLP). Such models however act as a "black box" and benefit from additional validation by approaches such as that which we introduce here to ensure results are accurate. For example, Cogburn et al. (2025) used a hybrid approach, combining text mining, natural language processing, and generative AI to assess 170 state reports on the UN Convention on the Rights of Persons with Disabilities. Our approach could likewise assist in validating future NLP assessment of these NBSAP documents.

Conclusion

The task of garnering collective effort to improve the planet's health is urgent, as direct and indirect anthropogenic, and synergistic pressures are increasingly evident (Halpern et al. 2019), and well-crafted conservation planning at a national scale, linked to global goals and targets of the GBF, is required. Our analysis provides a methodology that allows practitioners to identify potential mismatches between recorded national strategies and global approaches to delivering biodiversity conservation, and we identify variation in NBSAP focus across country groupings and ecosystem categories. Without the use of such tools and models in creation and review of NBSAPs, any misalignment with overarching global frameworks or fracturing across sectoral and cross-sectoral policies (Prip et al. 2010; UNEP 2018; Whitehorn et al. 2019; Zinngrebe 2023) might mean GBF planning may fail to create synergies with existing frameworks while realizing the global vision for people and nature between now and 2050.

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Author contributions All authors conceptualized the project. K.F. performed funding acquisition. K.F. and R.N. carried out project administration. Methodology, software and visualization were devised by D.G. Formal analysis, investigation, resources, and data curation were carried out by D.G. and R.N. Validation was performed by R.N. K.F., R.N. and D.G wrote the original draft. All authors reviewed and edited the manuscript.

Data availability The datasets analysed during this study are publicly available, at the locations indicated in the Data Sources section. The text analysis dictionaries used are provided in the electronic supplementary material.

Declarations

Competing interests The authors declare no competing interests.

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