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Marine biodiversity change impacts relational values: expert survey shows policy mismatch

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Understanding the complex ways that biodiversity change influences Nature's Contributions to People (NCPs) is at the heart of current debates on coastal conservation, as researchers and practitioners seek to translate ecological shifts into meaningful impacts for society and policy. Specifically, we often lack quantitative evaluations of this relationship. We address this gap through a survey of biodiversity experts, focusing on the Wadden Sea located along the coasts of Germany, Denmark, and the Netherlands, as well as Algoa Bay in South Africa. We asked the experts to assess which changes in Essential Biodiversity Variables (EBVs) of selected marine organism groups (phytoplankton, macrozoobenthos, birds, and fish) link to which NCP category. Expert opinions indicated a significant influence of biodiversity changes on non-material NCPs compared to material and regulating NCPs. Specifically, experts perceive significant impacts on experiences, learning, inspiration, and cultural identities derived from the marine environment. However, there is a lack of conservation focus on non-material NCPs with regards to marine biodiversity change, indicating a gap between stakeholder perceptions policy priorities. Our study emphasises the importance of integrating relational values into conservation strategies and calls for knowledge co-production involving diverse stakeholders to address power imbalances and develop more inclusive and effective management approaches for marine biodiversity.

Our study aims to add to the complex question, 'What does marine biodiversity change mean for people?'. This involves examining two components: marine biodiversity change and its implications for people. Nature's contributions to people (NCPs), provided by the ocean, are vital to human well-being, offering benefits such as food, climate regulation, and well-maintained ecological habitats[1,2]. Increasingly, changes in coastal biodiversity are a growing concern, with crucial habitats like salt marshes under threat - but biodiversity change comes in many forms[3] and can and should not be measured with only one value[4]. To date, few studies have connected the concept of NCPs to exactly which aspects of biodiversity are changing[5]. Most highlighted impacts focus on more tangible material contributions to people, such as food and raw materials, as well as regulating services like climate regulation[6]. Yet, there is much more to the relationship between people and the sea.

The concept of NCPs differs from the preceding concept of Ecosystem Services (ES). While ES is based mainly on natural sciences and economics, NCPs include perspectives from social sciences and humanities, emphasising relational values and diverse worldviews[7–9]. NCPs are anthropocentric, focusing on human well-being and recognising the plurality of values in human-nature interactions. It includes bi-directional relationships where humans benefit from and impact nature through actions like conservation and sustainable management[5,8,10]. Especially non-material NCPs play a crucial role in enhancing human well-being by influencing subjective and psychological aspects of people's lives. These contributions include

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opportunities for recreation, spiritual enrichment, aesthetic experiences, and social cohesion, often derived from natural environments like dunes, mudflats, or coral reefs[1]. They are also critical for psychological and physical well-being. The concept of cultural ecosystem services is closely aligned with non-material NCPs, as it highlights the diverse non-material benefits people obtain from nature, such as inspiration, cognitive development, and social relations[11]. This multidisciplinary approach allows for a deeper understanding of how non-material NCPs contribute to human well-being, fostering a more holistic appreciation of nature's role in supporting human quality of life[12]. A key partner in this quest is understanding the psychological construct of 'nature connectedness', which broadly refers to the extent that individuals think, feel, and act as though they are part of nature, with attitudes and behaviours that reflect one's interrelatedness with the rest of nature[13]. This relationship is shaped less by rational knowledge and more by worldviews (beliefs and life histories), affective meaningful experiences, and one's sense of ecological identity and belonging[13].

For this study, we adapted the NCP categories and specified them for coastal and marine environments (see Methods for the adapted list). Investigating the relationships between changes in marine biodiversity and their effects on humans, we aim to highlight the role of cultural aspects in understanding these impacts. Previously, little attention has been given to which exact aspects of biodiversity change influence NCPs in marine and coastal environments[10], a gap this study seeks to fill.

We classified the complexity of biodiversity change using a modified concept of Essential Biodiversity Variables (EBVs). An EBV is a measurable biological state variable documenting biodiversity[14]. EBVs highlight the need for multivariate assessments to fully understand biodiversity changes and their impacts[4]. They harmonise biodiversity research to facilitate monitoring and data integration[14]. Understanding various EBVs is crucial for assessing ES and NCPs, providing insights into the effects of biodiversity changes on people, and informing management. The social-ecological space between marine biodiversity change and what it means for people is where our study aims to add to. We add to this interdisciplinary field by honouring the complexities of both our central research concepts. We investigate biodiversity change through the multivariate lenses of EBVs and research the plurality of values that people draw from nature through NCPs. In particular, our interdisciplinary contribution is to nuance the conception of biodiversity for social science audiences that engage with this concept, and in turn to bring social science understandings of valuing nature to natural science audiences.

Connecting the concepts of EBVs and NCPs, we conducted a survey targeting experts in marine biodiversity change and marine management (see Methods for specific stakeholders). Specifically, we sought insights into which NCPs are most affected by biodiversity change in the Wadden Sea, southern North Sea, and Algoa Bay, South Africa (see Methods for details on study sites). Our survey design involved querying individual NCPs in the context of four organism groups: phytoplankton, macrozoobenthos, birds, and fish. To limit survey length, EBV classes were condensed to species population, species traits and functions, and biomass and abundance. The survey, conducted from November 2022 to April 2023, included 40 respondents, with 26 self-identifying as experts in at least one organism group. Our data highlights the interconnectedness between people and nature and the shortcomings in current conservation policies. By acknowledging the intricacies of biodiversity change, our survey aims to provide decision-makers with highly targeted prioritisation advice for effective marine management strategies.

Results and discussion

Trends across NCP categories and EBV classes

Our generalised least squares (GLS) model tested for statistical differences between our two predictors, NCP category and EBV class (Fig. 1). Our analysis showed that, consistently across EBVs (all p values > 0.05), the responding experts estimated the impact of biodiversity change on non-material NCPs higher than the other two NCP categories. Specifically, our survey respondents voted the impact that biodiversity change has on 'Non-material NCPs' significantly higher and statistically different ($t = 3.316$, $p = 0.002$) from 'Regulating NCPs' ($t = 1.259$, $p = 0.2143$) and 'Material NCPs' ($t = 0.847$, $p = 0.567$).

Our findings suggest that different NCP categories more significantly influence expert weightings, whereas EBV classes do not exhibit the same effect. Specifically, expert weightings for 'Non-material NCPs' differ significantly from those for 'Regulating NCPs' and 'Material NCPs,' prompting a deeper examination of the 'Non-material NCP' category.

We did not focus on local trends of Algoa Bay and the Wadden Sea individually in this paper. Although our data allow for this comparison and further for a comparison across organism groups, we want to focus on the wider trends here and focus on the trends in NCPs and EBVs.

Our findings indicate that biodiversity changes significantly impact non-material NCPs in the coastal areas of the Wadden Sea and Algoa Bay. This stands in stark contrast to the current lack of research on the subject. Existing studies on ES and NCPs have primarily concentrated on regulating and material NCP categories, particularly in investigations concerning marine and coastal regions[15], resulting in an imbalance in knowledge regarding NCPs and a lack of information on non-material NCPs[16].

One possible explanation for this disparity is the intangible nature of non-material NCPs and the fact that it is simply difficult to measure something like cultural value[17]. The ES research has predominantly employed metrics derived from the natural sciences and economics, and the absence of metrics for cultural ES has skewed research towards other ES[7]. The concept of NCPs attempts to bridge this gap and go beyond it by including relational values, but the relative novelty of the concept compared to ES may explain why policy has not yet shifted its focus towards non-material NCPs.

The omission of non-material NCPs in conservation strategies may have led to a bias favouring the generation of other NCP categories at the expense of non-material NCPs. The variations in the impact of biodiversity changes on the NCP categories can also be associated with the trade-offs that may occur among them. NCPs are frequently generated synergistically, and in some cases, the provision of some NCPs comes at the expense of others, resulting in trade-offs. Trade-offs predominantly occur between non-material NCPs and other NCP categories[15]. In the marine environment, this can occur, for example, when maritime space is utilised for aquaculture or energy production (material NCPs), compromising the perceived aesthetic quality of an area and impacting potential recreational and cultural uses[15].

Non-material NCPs and their associated cultural elements serve as a foundation of key aspects of human well-being. Consistent with the lack of research on non-material NCPs, there is also limited understanding of the relationship between these NCPs and human well-being, particularly in marine and coastal areas[15,18]. The initial findings of our study, therefore, support the call in the previously cited literature for a higher inclusion of non-material NCPs in research and conservation, a marked increase in the employment of social science methods, and a better understanding of how these NCPs relate to human well-being.

Detailed findings on non-material NCPs

Experts assessed the impact of marine biodiversity changes on human experiences, like healing, recreation, and aesthetic enjoyment[19], with most respondents considering them extremely or very significant (Fig. 2), underlining their already known importance[19]. These results point to the natural environment having a profound impact on the human experience.

Non-material contributions extend to learning and inspiration, showing overall high importance, though slightly less so than experiences (Fig. 2). Notably, responses varied more regarding changes in biomass and abundance, suggesting some moderation in significance. Supporting identities, including spiritual and social cohesion[19], saw a slightly more moderate view on the significance of biodiversity changes compared to other non-material NCPs.

In Algoa Bay, the literature documents how stakeholders value non-material contributions, emphasising the ocean's importance for recreation, well-being, and cultural identity[20,21]. In the Wadden Sea, there are also

accounts in the literature and how residents derive aesthetic enjoyment and a sense of identity from the coastal environment, highlighting biodiversity's role in enhancing these experiences[22].

Overall, while existing literature offers insights, engaging a broader range of stakeholders as well as attending to the different dimensions of human well-being and the diverse forms of knowledge these stakeholders contribute is crucial for a comprehensive understanding of non-material NCPs, urging further research into the consequences of biodiversity changes[15,19].

Implications for conservation management

The survey results indicate that non-material NCPs are disproportionately affected by coastal biodiversity changes in the Wadden Sea and Algoa Bay, raising concerns due to their status as the least studied NCP category in marine and coastal environments[20]. Furthermore, it is also the NCP category that is least regarded by policy[10], showcasing a discrepancy between stakeholder perceptions and academic as well as policy priorities. Scientists, policymakers, and NGOs play crucial roles in shaping conservation strategies, with their focus potentially impacting coastal communities dependent on the ocean[15]. Adams and Morse[23] further highlight the bias in priorities, noting that non-material NCPs are not only under-researched but also frequently neglected in policy formulation. In response to an increasing need to make conservation more inclusive, effective, and socially just[24], the International Union for Conservation of Nature (IUCN) recently published Guidelines on the Cultural and Spiritual Significance of Nature.

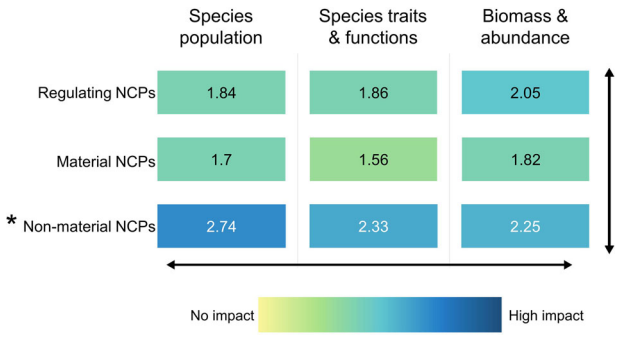

Fig. 1 | Weighted averages of responses by experts in our survey attributed to the impact of biodiversity change across three essential biodiversity variables (EBVs): species population, species traits and functions, biomass and abundance on categories of regulating, material and non-material Nature's Contributions to People (NCPs); arrows indicate how we tested for statistical difference and where we found this difference to be statistically significant (*).

The emphasis on material NCPs reflects the values inherent in coastal biodiversity policies and research, primarily prioritising instrumental values[23,25]. In contrast, non-material NCPs are implying relational values, which are significantly impacted by coastal biodiversity changes, underscoring the importance of integrating relational values into environmental management[10,25,26].

However, transitioning to relational values is complex as it involves diverse perspectives on human-nature relationships. There are worldviews, characterised by a nature-culture dichotomy, that often perceive nature as separate from human activities, perpetuating a simplified view of ecosystems[15,26]. This perception limits the effectiveness of conservation efforts by disregarding the interconnectedness of nature and culture[27] as the separation overlooks the reality of human influence on nearly every corner of the planet, highlighting the inseparability of humans and nature[26]. Moreover, culture permeates all aspects of human interaction with the environment, shaping existing ocean management and conservation strategies. The desire to protect nature as distinct from human activities, exemplified in the practices of many national parks, stems from a view that downplays the intertwined nature of culture and nature, thus prioritising instrumental values over relational ones[28].

Conservation strategies like marine protected areas (MPAs) that are driven by instrumental and intrinsic values can enhance biodiversity but may also perpetuate social injustices and reinforce the nature-culture divide[10]. Prioritising the nature-culture dichotomy and resulting policy perspectives risks obscuring and silencing forms of knowledge and governance that do not fit into these dominant paradigms. However, many rights- and stakeholder groups, including Indigenous communities, sub-

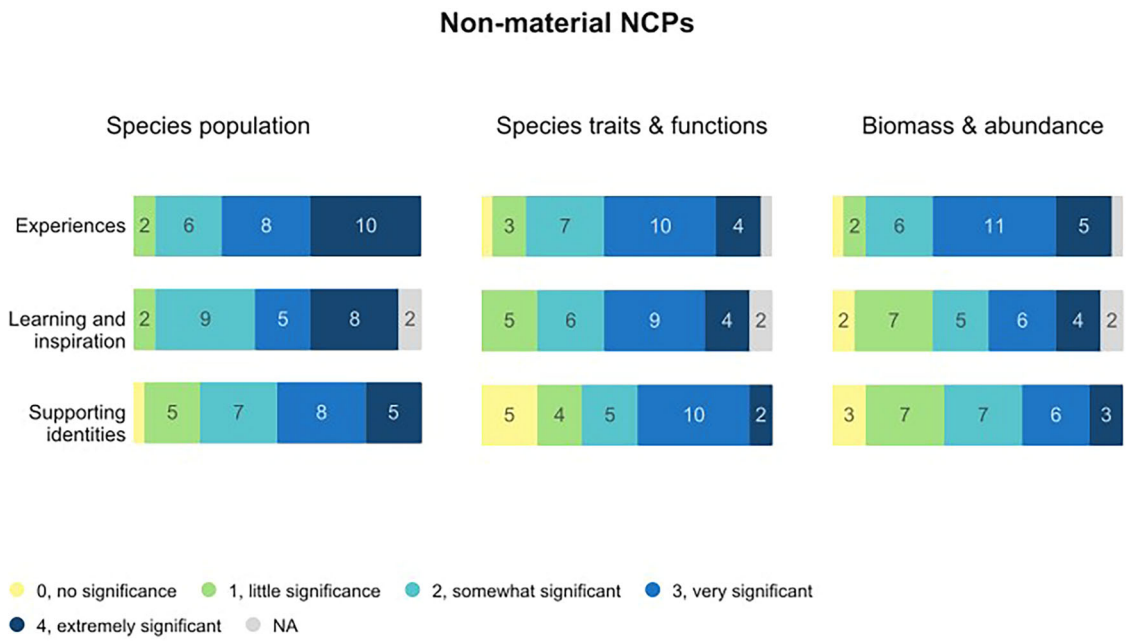

Fig. 2 | Impact significance of biodiversity change in three biodiversity variables (species population, species traits and functions, biomass and abundance) on detailed groupings of non-material Nature's Contributions to People (NCPs); most heavily impacted NCPs are found at the top, decreasing in impact towards the bottom (ranking is done for the column of species population).

sistence fishers, women, and youth, frequently feel excluded from decision-making processes and face restricted access to the ocean due to conservation measures[20]. In Algoa Bay, this exclusion extends to limitations on fishing activities, closure of coastal areas, and restricted access to sacred heritage sites, thus exacerbating social inequalities, reminiscent of apartheid-era segregation. While conservation efforts in the Wadden Sea do not reinforce social inequalities to this degree, there is much opposition and resistance from local residents towards the Schleswig-Holstein Wadden Sea National Park[26,29].

The importance of proper knowledge co-production for conservation

The importance of inclusion, representation, and participation in conservation practices is crucial for recognising the complexity of nature-culture relationships and the impacts of biodiversity changes on non-material NCPs[20]. One avenue for attending to these diverse perspectives is through knowledge co-production[22,30]. If done right, with care and respect for the wishes and needs of stakeholders and communities, knowledge co-production can take the form of a *partnership* that benefits not only researchers but communities as well, through access to resources and support, funding, and further research opportunities[31]. Particularly when working with Indigenous communities, foregrounding 'Indigenous values of relational reciprocity and self-determination' is more important than reaching an appropriate level of 'diversity'[31]. Indeed, as Wilson et al. [32], p. 131) note, 'Indigenous peoples want to conduct their own research, in their own way, in their own words, under their terms, and for their own purposes.' Knowledge co-production, then, must be mutually beneficial and relevant to both researchers and the communities with which they work[33]. If not, there is a very real risk that this process can reinforce and perpetuate, rather than challenge and resist, colonial violence and power imbalances.

Indigenous and local knowledge is highly contextual and relational, and its significance and meaning may be lost in the process of translation[34]. Many Indigenous scholars call for 'recognition based on its own scientific merit and its inclusion as a distinct knowledge system,'[32], p. 132). Framing entire knowledge systems as 'traditional' or 'local' may in itself be a colonial act which diminishes their legitimacy, global relevance, and authority, and may even lead to researchers speaking not only about but also *for* communities 'by undertaking expert inquiries into what 'local' people think, feel, know, and want'[34,35], p. 107). Further, the desires to improve, to make the world a better place, and to advance scientific understanding often motivated historical colonial governance of and research 'on' Indigenous people[34,36]. There is, therefore, a deep-seated distrust of researchers, who are often perceived as only benefiting their own objectives[36]. Indeed, as de Leeuw et al. [33], p. 184) note, 'Indigenous peoples have insisted that they are 'researched to death', that research continues to be 'about' as opposed to 'with' or 'by' them, and that their stories are being 'stolen.'' It is thus vital in knowledge co-production to respect a community's wishes, even if it means non-participation or outright refusal[37]. More broadly, care should be given to communities' needs and interests when designing knowledge co-production processes, as well as ensuring that the outcomes of these processes are accessible and beneficial in the long term[36].

Nonetheless, regional-level co-production can promote the inclusion and representation of plural voices, guiding the implementation of conservation strategies that address regional needs and values[38]. 'Management of marine resources is management of people,' and the social sciences are equipped to explore and understand the human dimensions of the oceans[39,40], p. 30). In particular, social science approaches may offer insight into the effectiveness of conservation and management measures, the social and political conditions that might impact such measures, and the impacts of such measures on human well-being. Further, the social sciences offer a multitude of relational approaches to the oceans that transcend the nature-culture binary, which is crucial to incorporating non-material NCPS into policy[40]. Indeed, in recognising plural worldviews and relational values, the social sciences have the potential to guide 'a planning practice that seeks to comprehend the relational complexities of the marine world'[41], p. 95). However, the social sciences are often relegated to the sidelines and reduced to scientific communication, education, and social impact and indicator analysis[42]. Additionally, social approaches, if not done with care, have the potential to cause more harm than good. The social sciences, then, are not 'good' by default; rather, there is a need for *critical* social science approaches that go beyond communication and education, that account for power dynamics, historical and cultural sensitivities, and for 'the complexity of socio-spatial relationships in marine environments'[37,42], p. 39).

Lastly, it is not a case of needing *more* social science methods, but rather of viewing social science research as equally legitimate as the 'natural' sciences in policymaking, and of meaningfully engaging with it for conservation and management measures that are socially relevant and sustainable transitions that are just[42]. Our survey underscores the importance of this meaningful engagement to enhance both environmental protection and human well-being, and calls for careful knowledge co-production at the regional level, inclusive of diverse stakeholders and local communities, focusing on relational values to tackle the underlying causes of sustainability challenges and biodiversity change[43].

Other ways to engage with cultural values to aid integrating non-material NCPs into policy

To ensure that non-material NCPs inform policymaking, it is essential to engage stakeholders through participatory methods, adopt frameworks that highlight intangible values, and incorporate these into well-being assessments. Equally important is to support traditional ecological knowledge and community-based conservation approaches that emphasise spiritual and emotional ties to nature, integrating the cultural and relational values of nature in conservation policies. Such methods give voice to both individuals and communities, facilitating the integration of intangible values into policy objectives and decision-making processes.

For instance, engaging local stakeholders through participatory mapping and valuation methods can help capture diverse perceptions and values associated with non-material NCPs[44]. This approach allows for the identification of priority areas and the understanding of different stakeholders' perspectives, which is crucial for informed land-use decisions and policy development. Additionally, implementing a triad of social spaces—lived, perceived, and conceived spaces—can make non-material NCPs more visible and integrate them into decision-making processes[45]. This framework helps in recognising the plurality of values and socio-spatial relationships, thereby enhancing the operationalisation of NCPs in environmental management and marine-use planning. Case studies highlight how improved coastal planning can lead to better integration of non-material NCPs[46]. Emerging management strategies incorporate stakeholder engagement and policy support to balance conservation with human services, including non-material benefits such as recreation, aesthetic value, and community identity. For instance, through the replacement of 'hard engineering' like marinas and sea walls through ecological solutions like mangrove, coral, or oyster restoration.

On a regional scale, management of the Litoral Norte MPA in Portugal explicitly considered non-material NCPs—such as engagement with nature, sense of place, solitude, and spirituality—by surveying users and incorporating their well-being dimensions into conservation practice and policy[10]. These well-being dimensions were explicitly considered in conservation practice and policy, supporting both biodiversity and human well-being by recognising and fostering cultural and spiritual connections to the marine environment.

Further, employing participatory methods, such as art-based interventions[47] or the practice of walking, effectively assesses the emotional and spiritual contributions of natural environments[48]. While in-situ methodologies for measuring emotional connections to the oceans have particular challenges, such as the ability to swim, the Wadden Sea marks a special case, as walking methods are common practice here. The Wadden Sea is almost entirely walkable at low tide[49].

Additionally, more quantitative evaluations of biodiversity-driven NCP changes, like we did here, but in other spatial contexts, can provide critical insights for adaptive policy development. Conducting quantitative assessments of how biodiversity changes are affecting NCPs in other places, including non-material contributions, can provide insights into the spatial and temporal dynamics of these contributions. Understanding these dynamics can help policymakers anticipate trade-offs and synergies, thereby supporting more informed and adaptive policy frameworks[50]. These strategies collectively support the integration of diverse values into environmental management and policy planning, promoting sustainable and inclusive decision-making.

Limitations and future research

A limitation of this study is its small sample size. Although, as marine biodiversity experts, our small sample group was carefully chosen for the particular knowledge the survey required. As Hesse-Biber and Leavy argue, 'The goal is to look at a 'process' or the 'meanings' individuals attribute to their given social situation, not necessarily to make generalizations.'[51], p. 119). Nevertheless, the low responses led us to not conducting an in-depth statistical analysis. The survey, distributed among numerous partners, saw limited completion rates, indicating possible issues with participant engagement. The survey's complexity may have deterred respondents, evident from incomplete responses and feedback highlighting confusion. Balancing the need for detailed data collection with participant engagement poses a challenge in survey design, often resulting in a trade-off between complexity and participation rates[52]. The inclusion of open-text questions, while intended to gather comprehensive insights, may have added unnecessary complexity, potentially contributing to respondent disengagement. A more focused survey, centred on the effects of biodiversity changes on NCPs, followed by separate, in-depth interviews, might improve participation rates without compromising data quality.

Furthermore, the study primarily engaged conservation and research professionals, neglecting perspectives from more non-academic stakeholders[52]. This limits the generalisations we could draw from our analysis. Future research could strive for broader inclusivity, incorporating diverse knowledge holders to inform conservation practices more comprehensively, especially to advance our understanding of relational values and non-material NCPs. For instance, a broader stakeholder analysis might enable a wider audience[53]. In particular, including perspectives of local community residents, who are experiencing biodiversity change 'on the ground', may offer valuable insights. Future studies could employ real-world lab frameworks to co-design studies with Indigenous groups and local communities, using methods like deliberative mapping and photovoice to document non-material NCP perceptions[54].

While this study offers insights into stakeholders' perceptions across two coastal regions, it overlooks intra-regional variations and differences between organism groups. Subsequent investigations could delve deeper into these aspects, analysing responses regionally and by organism group to uncover nuanced drivers of NCPs[51]. While resource-intensive, expanding this research to encompass diverse coastal regions could enhance understanding and inform tailored conservation strategies.

Conclusion

Our study highlights that marine biodiversity changes primarily affect the non-material Nature's Contributions to People (NCPs) over regulating or material NCPs in the Wadden Sea and Algoa Bay. Our findings further cement the importance of various components within human-nature relationships and show that many aspects in multivariate biodiversity change have an effect on the plurality of values that people draw from the sea.

Additionally, our study quantitatively revealed that, within the two examined regions, the impact in different Essential Biodiversity Variables (EBV) was more consistent across all classes compared to the different NCP categories. Although some deviations across responses in EBV classes were noted, they were not statistically significant. On average, our survey results show that experts evaluated the impact of coastal biodiversity changes on people to be more consistent across EBV classes and more varied across NCP categories. We propose the necessity for further investigation into the effects of EBVs on NCPs to deepen the understanding of our findings.

Moreover, our findings suggest the need for a paradigm shift towards incorporating relational values in conservation management and policy, which marine social sciences have repeatedly reported about. Our findings emphasise the inadequacy of solely relying on instrumental values, calling for the integration of value pluralism in conservation strategies. We emphasise embracing diverse knowledge systems through proper knowledge co-production. By prioritising relational values and recognising the importance of all relevant NCPs, we argue that more effective management strategies can be formulated to better safeguard biodiversity against changes and promote stewardship for sustained human well-being.

Methods

Data collection and expert selection

We collected our data through a survey directed at experts in marine biodiversity change. To address the complexity of biodiversity change, our survey focused on individual NCPs within four organism groups (phytoplankton, macrozoobenthos, birds, fish), previously analysed for trends and drivers[3,4]. We condensed the EBV classes to three: 'species population,' 'species traits and functions,' and 'biomass and abundance' to increase the chance of survey completion, while still keeping some complexity to biodiversity variables.

Our survey respondents consisted of practitioners, biodiversity scientists, conservation workers, and park rangers who are working with Wadden Sea or Algoa Bay marine biodiversity on a regular basis. Due to their in-depth knowledge of the regional ecology and of the local NCPs derived from the two coastal biomes, we found them as excellent survey respondents. The contacted experts required specific knowledge about regional and/or local biodiversity dynamics in at least one of our four organism groups and at least of our two study sites. Experts in Germany were workers at the National Park Authority Wadden Sea (NLPVW), at the Lower Saxony Water Management, Coastal and Nature Protection Agency (NLWKN), or marine biodiversity change scientists working in the EU-project ACTNOW. In South Africa, experts were members of the South African National Parks (SANPARKS), the South African Institute for Aquatic Biodiversity (SAIAB), the South African Environmental Observation Network (SAEON), or from the Wildlife and Environment Society of South Africa (WESSA).

The survey, conducted from November 2022 to April 2023, was answered by 40 respondents (12 from the Wadden Sea and 28 from Algoa Bay). Through one of the leading questions of the survey, 26 respondents self-identified as experts on at least one organism group. The rest of the survey was made up of complex, closed-ended questions to evaluate the impact of biodiversity changes on NCPs in form of four matrices, one per organism group.

Study sites

The study investigated the Wadden Sea (Southern North Sea) and Algoa Bay (South Africa), both noted for their high biodiversity and geomorphology. The Wadden Sea is a UNESCO World Heritage Site since 2009, both regions are under conservation policies due to their ecological significance. They face challenges integrating diverse knowledge sources and stakeholders due to their complex socio-ecological dynamics and histories of anthropogenic impacts.

Survey

Using Qualtrics, the survey combined open-ended and closed-ended questions, structured by organism groups (Fig. 3). Participants rated the significance of biodiversity changes on NCPs using Likert scales. Responses were aggregated to determine the average significance of changes in biodiversity on NCPs, weighted from 0 ('no significance') to 4 ('extremely

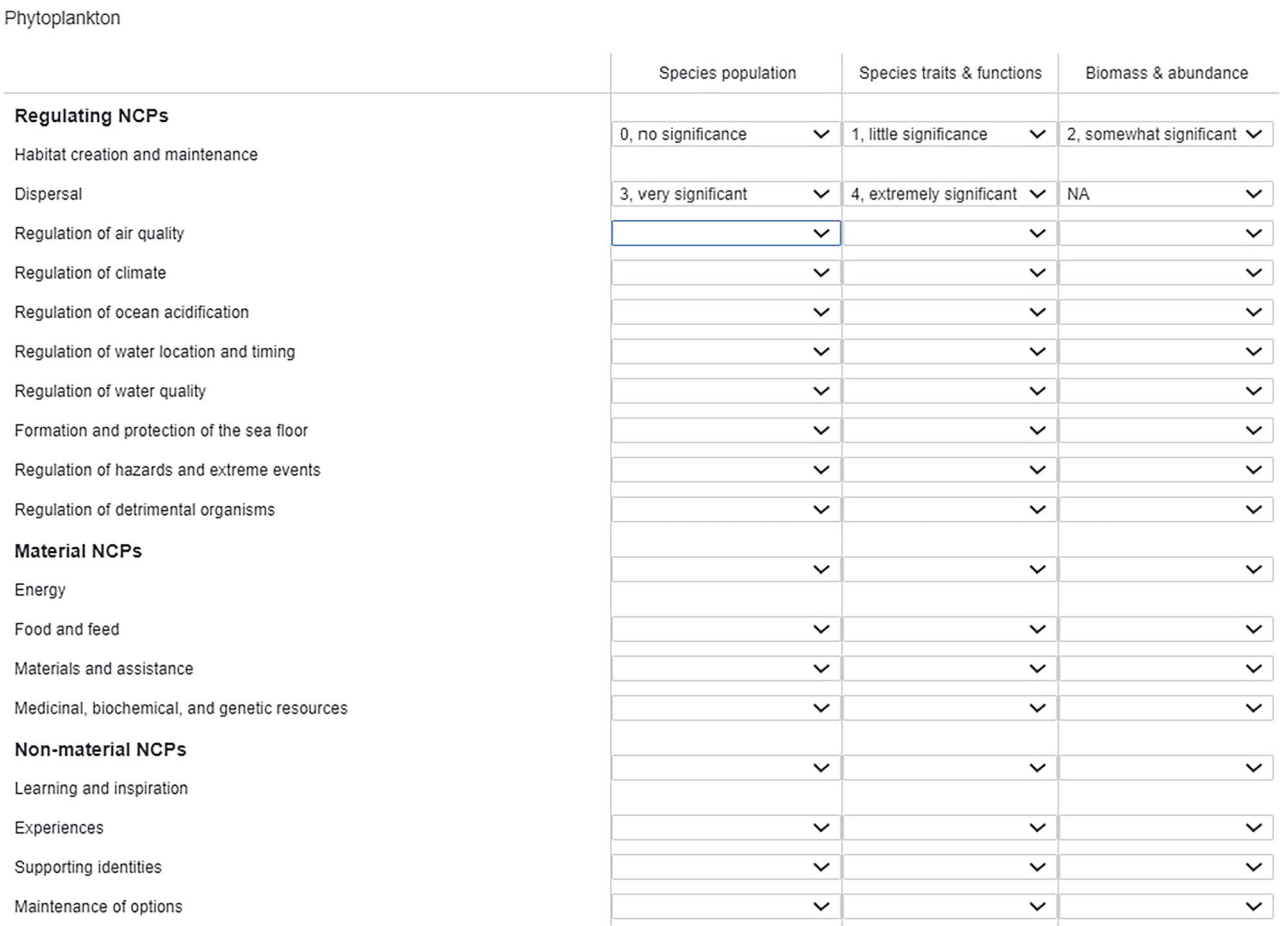

Fig. 3 | Survey question on the effects of changes in phytoplankton diversity on NCPs.

significant'), with 'NA' responses not being weighted. The results provided a comprehensive view of the impact of marine and coastal biodiversity changes on NCPs.

Lastly, the answers concerning the 'maintenance of options' NCP included a majority of NA answers; the results for this contribution have therefore been excluded. The high number of NA would be interesting to investigate, but the lack of information on the reasons for participants to choose this response hinders the possibility of interpreting them. This NCP has been excluded from our analysis in order to avoid an overly speculative interpretation.

Statistical analysis

We employed a generalised least squares (GLS) model to examine the effects of NCP category (regulating, material, non-material) and EBV (species population, species traits and functions, biomass and abundance) on the average weighting given to them by our survey respondents. We grouped the data by NCP category and EBV, then calculated the weighted average for each group with the number of votes given for every Likert scale response as the weighting factor. We implemented the GLS model using the gls-function from the nlme-package[55] in R version 4.1.2[56], with restricted maximum likelihood (REML) for parameter estimation. We chose this model to account for potential correlations and unequal variances within the dataset, to safeguard against clustered data structured due to the aggregation done to get the average weight within each group. We specified average weight as the response variable in our model formula, with NCP category and EBV class as fixed-effect predictors. We then used the resulting model coefficients to assess the significance of each predictor on the average weight, while controlling for the correlation structure within the data. The residual plots of all four models suggested good model fits. To further investigate significant differences, we did a pairwise comparison with a Tukey post-hoc test.

Data availability

All data and R-code used to analyse the data are available in our open-source repository: https://github.com/JanDajka/NCPsCoastalBiodiversityChange.

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