Imagination Beyond National Jurisdiction - Computing and Envisioning Possible Sustainable Futures for the High Seas

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Abstract

The high seas are experiencing a stark increase in industrial activities, with resources being exploited unsustainably and shared unequally. This suggests the need for a transformation, a shift in the deeper structures of the system such as underlying paradigms and mind-sets. We created future visions by combining computational text analysis with a structured yet creative futuring approach. This process resulted in four science fiction stories, which aim to capture the complexity of the system, embrace the inherent uncertainty of the future and question current unsustainable trajectories, while emphasizing the vastness of future option space. The visions are analyzed using the concept of imaginaries, demonstrating that futuristic stories can be traced back to current realities and the scientific evidence they were based upon. We argue that engaging with alternative futures can open up transformative spaces to rethink the relationships between humans and the high seas, from which novel imaginaries can emerge.

Introduction

Another world is not only possible, she is on her way. On a quiet day, I can hear her breathing.

-Arundhati Roy

The impacts of human activities stretch across the global ocean and the extent, intensity, and diversity of ocean development during the ‘blue acceleration’ is unprecedented (1). This acceleration has led to an array of challenges, such as declines in marine biodiversity and species abundance (2), the depletion of fish stocks (3) and inequalities in the access to and benefit sharing of marine resources (4, 5). Further, there is a growing interest in expanding ocean geo-engineering (6, 7), commercial exploitation of marine genetic resources (8), as well as deep sea mining (9, 10). The future ocean might be ‘crowded’ with diverse drivers competing for resources and space (11), as new technologies constantly render new remote areas of the ocean accessible to exploitation (12, 11). Many challenges related to the ocean are amplified by the effects of climate change (13) and difficult to address because of the deeply intertwined connections between the ecological, socio-political, and economic spheres (14), as well as the ecological connectivity between coastal waters and the open ocean (15). Areas beyond national jurisdiction (ABNJ) are especially vulnerable to industrial activities since no state has the mandate for their protection (16) and high seas resources are instead governed by a complex network of regulations and institutions (11). Yet, the final phase of negotiations for the international legally binding instrument on the conservation and sustainable use of marine biological diversity of ABNJ (17) could present a unique window of opportunity to transform the way the high seas are governed and understood.

The ocean is often underrepresented in discourse about sustainable development (18). For the high seas, this might be due to their geographical distance to much of the world's population, which can render them ‘out of sight, out of mind’ (19). Scholars have called for a transformation in ABNJ (20,21), shifting the goals to which the system is oriented, including underlying paradigms, mind-sets and relationships

between people and the oceans (22). Imagining aspirational futures can be a catalyst for social-ecological transformations, as they encourage us to strive towards new desirable ways of being (23, 24). Future visions should address social dimensions, such as worldviews, values and inner connections between people and nature, since they are a powerful source of change (25). Because desirability is a normative concept (26), it is crucial to include a diversity of values and to create space for plural perspectives on what constitutes desirable human nature relationships (27). Envisioning diverse, plural futures can create openness to change and surprise, since it prepares for a variety of future developments and thus contributes to anticipation and response capacity (11,28). The 'ocean of surprises' (11) can be navigated by remaining flexible in how the unfolding future is imagined and by being receptive to emerging patterns (29,30). Engaging with possible futures further promotes a sense of empowerment and agency, (29) and can also be used to 'disturb the present' (31), to challenge currently held assumptions and unsustainable path dependencies.

In order to guide decision making and steer potentially transformative change, imaginative visions need to move beyond the individual and into processes of collective imagining(32). Imaginaries, defined as collectively held visions of the future (33),can shape the future by defining goals to be attained (34) and further agency by creating a sense of what is possible and desirable (35). They reinforce or recreate social norms and relationships by creating shared ideas and meanings about them (36). Imaginaries do not purely reside in people's minds, they are enacted through infrastructures, practices and meanings of social life (35). Imaginaries are involved in the production of scientific knowledge and technology, which are not created in a vacuum, but are rather embedded in social practices, identities, values, institutions and power structures, simultaneously influencing and being influenced by them (37). This idea can be extended by including the natural world, both as the context and a driver for social change, entangled in a co-production process with science and technology (32). Based on this notion, imaginaries might be able to recreate not just social relationships, but relationships between humans and nature as well. Disseminating an inspiring vision of the future, for example by creating and sharing a work of fiction, could open up a transformative space (38), as it is discussed and reflected upon by an audience. From such a transformative space, which is 'safe enough' to experiment with new ideas and mental models (38), novel imaginaries could emerge.

Future visions should be grounded in quantitative data since inclusion of empirical information increases their plausibility and legitimacy (39). Yet, basing future visions solely on current developments and underlying meanings prevents a necessary discussion of values and possibilities, inhibits novel ideas, creativity, and a diversity of alternatives, thus reinforcing the status quo (40, 41). These tendencies can create an 'imagination gap', which limits the futures we are able to attain (42). This gap can be addressed by using creative approaches, combining science and art (43). Story based visions can be especially impactful, as they are motivational by being emotionally charged (44). Science fiction stories in particular may be useful for envisioning transformed futures, since engagement with science fiction can loosen cognitive restrictions (45). Science fiction can also enable the exploration of non-linear change and the intertwined dynamics of humans and oceans (28). There is a critical need to engage with the imagination and draw on creative and dynamic stories about the future for improved decision-making in the

present (26,42). Hence, we aim to expand the notion of what is possible and creatively envision possible futures of the high seas, by ‘undefining’ the future, and then questioning it, but based on solid scientific evidence (46). To do this, we employ a computational text analysis to generate input for a creative visioning process, thereby generating futures that are both uniquely radical in their perspective while still grounded in scientific knowledge (47). Our aim is to create future visions that are both relevant and inspiring, emphasizing the plurality of possible futures and opening up transformative spaces to re-imagine human-ocean relationships, from which novel imaginaries could emerge.

Results

Results of the topic model

To firmly ground our future visions in scientific literature, we used topic modeling to analyze the abstracts of 8580 scientific articles. These articles were gathered using a literature search in Scopus. The topic model was used to structure the dataset and discover clusters of themes in the literature, also known as topics. We chose the Collapsed Gibbs Sampler (Gibbs) algorithm (Griffiths et al., 2004) to fit the topic model, based on its high entropy and log-likelihood scores (Table 1). The topic model resulted in 25 topics as well as the top 30 keywords most highly associated with each topic (Fig. 1). The topics and their associated keywords reveal thematically distinct topics that are most prevalent in the sampled academic literature. As shown in Table 2, the topics were oftentimes concerned with clearly defined concepts, such as marine ecosystem conservation, autonomous underwater vehicles, or life near hydrothermal vents. Some topics were more abstract and contained surprising keywords, such as Topic 23, which seems to be concerned with shipping and maritime trade but also contains words such as ‘train’ or ‘university’. These rather surprising keywords were intentionally included in the analysis, as they added variety and unexpected dynamics to the topics.

Table 1
The entropy and log-likelihood values for the four algorithms

	Model	Loglikelihood	Entropy
1	VEM0	-6538396	0.7975759
2	VEM_fixed	-6774400	2.2770459
3	Gibbs	-5981864	2.3732977
4	CTM	-6636617	1.3213523

Table 2

Topics that were included in the scenario building process (16 out of 25 topics), their respective keywords and which story-based vision they were included in.

Story	*Topic Number/ Label*	*Keywords*
Story 1 "Ocean Uprising"	*Topic 13 Marine Ecosystem Conservation* *Coral reef and seamount ecosystems are a habitat for high species biodiversity. These ecosystems are vulnerable and at risk and should be conserved and protected.*	*Ecosystem, coral, marine, impact, reef, environmental, identify, habitat, biodiversity, ecological, scale, assess, seamounts, sponge, conservation, potential, approach, spatial, e.g., assessment, driver, plastic, variable, environment, seamount, function, vulnerable, author, risk*
Story 1 "Ocean Uprising"	*Topic 15 Changes in Sediments* *Detailed descriptions of elements contained in sediment, some of these elements are used in geoengineering practices.*	*Sediment, rate, carbonate, ratio, value, dissolution, content, composition, accumulation, ca, isotope, sr, calcite, opal, clay, isotopic, bulk, biogenic, pore, mg, silica, variation, shell, weather, preservation, mineral, geochemical, diagenetic, fractionation, reflect*
Story 1 "Ocean Uprising"	*Topic 23 Risks of maritime trade* *The risks of container shipping and maritime trade; for example, oil spills, safety issues related to borders or piracy.*	*Ship, oil, vessel, port, spill, deepwater, trade, university, arm, situation, border, train, damage, exercise, report, roll, container, service, route, naval, ballast, boat, safety, dsw, uk, piracy, scenario, hand, response, mean*
Story 1 "Ocean Uprising"	*Topic 24 Autonomous underwater vehicle* *New technology, a submersible, autonomous underwater vehicle. It needs to be tested and monitored, it's operated remotely and has sensors and acoustic detection.*	*System, design, vehicle, underwater, test, monitor, network, sensor, detection, acoustic, performance, develop, technology, power, operate, propose, deploy, control, cable, communication, observatory, submersible, real, position, platform, noise, operation, equipment, autonomous*
Story 2 "Deep Connections"	*Topic 2 Life on Hydrothermal Vents* *Bacterial, microbes, mussels have adapted (changes in DNA, metabolism) to the extreme environment of hydrothermal vents.*	*Pressure, gene, vent, microbial, bacterium, cell, protein, bacterial, adaptation, hydrothermal, acid, genome, strain, environment, metabolic, isolate, sequence, dna, hydrostatic, activity, metabolism, enzyme, mussel, adapt, organism, extreme, membrane, molecular, specific, seep*
Story 2 "Deep Connections"	*Topic 3 Deep Sea Species Communities* *There exists an abundance of diverse animals (copepods, nematodes) in the deep sea. This richness can be sampled, collected, but also disturbed.*	*Community, species, diversity, abundance, depth, sample, taxon, benthic, structure, food, abyssal, composition, fauna, pattern, density, assemblage, biomass, distribution, size, richness, station, nematode, taxonomic, copepod, collect, dominant, difference, bathymetric, disturbance, functional*

Story	*Topic Number/ Label*	*Keywords*
Story 2 "Deep Connections"	*Topic 18 Resource Exploitation* *Manganese nodules contain valuable metals and minerals and are found on the seafloor. These (and other resources) can be exploited. This process is connected to new technology and has development potential, but there are also environmental concerns.*	*Mine, gas, hydrate, nodule, energy, exploitation, methane, mineral, material, plant, manganese, offshore, waste, future, process, technology, demand, potential, development, aquaculture, natural, seabed, resource, industry, disposal, industrial, hydrocarbon, corrosion, soil, stability*
Story 2 "Deep Connections"	*Topic 25 Failed Drill Project* *People want to drill into the crust of a volcanic structure underwater (most likely to extract resources). There are various risks associated with such drill projects.*	*Drill, ridge, magnetic, fluid, volcanic, site, plate, crust, arc, trench, spread, hole, seismic, leg, zone, core, basalt, rock, ash, fault, program, mantle, log, project, eruption, recover, age, polarity, basement, tectonic*
Story 3 "Kairei City"	*Topic 8 Carbon Cycles* *The ocean is strongly affected by anthropogenic emissions (carbon dioxide) into the atmosphere. The emissions are taken up by the ocean and lead to its acidification (change in ph.).*	*Ocean, global, climate, atmospheric, model, increase, atmosphere, carbon, change, emission, ph, oceanic, drive, dioxide, effect, acidification, cycle, reduction, American, anthropogenic, scenario, geophysical, decrease, century, feedback, perturbation, enhance, greenhouse, union, lead*
Story 3 "Kairei City"	*Topic 6 Increases in nutrients and primary production* *There is a constant flux of nutrients which enter the ocean and get recycled or deposited. The ocean is a nitrogen sink, but there can also be negative environmental consequences if too many nutrients enter the ocean.*	*Organic, flux, nutrient, production, carbon, phytoplankton, matter, particle, primary, nitrogen, export, sink, diatom, concentration, productivity, particulate, chlorophyll, total, bloom, rate, nitrate, trap, net, cl, oligotrophic, supply, upwelling, plankton, input, growth*
Story 3 "Kairei City"	*Topic 7 International governance* *The ABNJ are governed by international law (UNCLOS). While this can lead to mutual agreements and benefits it can also be a source of conflict and dispute. Fisheries, other resources, economic activities and maritime development need to be managed (sustainably).*	*International, management, resource, law, national, issue, unite, fishery, country, policy, article, convention, nation, economic, unclos, legal, development, maritime, sustainable, regime, jurisdiction, organization, conflict, agreement, benefit, action, governance, future, framework, dispute*
Story 3 "Kairei City"	*Topic 12 Sediment flows* *Sediments enter the ocean via rivers or erosion processes, slide down the shelfs and slopes of continental margins and end up on the ocean floor or as turbidites.*	*Shelf, sediment, slope, continental, margin, current, channel, canyon, flow, transport, fan, sand, grain, submarine, erosion, cm, fine, delta, river, outer, turbidity, edge, adjacent, deposit, turbidite, turbidites, supply, feature, mound, sedimentation*

Story	*Topic Number/ Label*	*Keywords*
Story 4 "Myopia"	*Topic 14 Changes in Research* *Research of marine systems is vital to gain scientific knowledge, which is of high importance for the future. Yet, we should discuss the role that science plays and how research is done.*	*Understand, research, science, process, review, marine, study, interaction, provide, system, recent, information, role, discuss, focus, play, include, ocean, knowledge, springer, nature, future, key, environment, earth, importance, biological, highlight, scientific, decade*
Story 4 "Myopia"	*Topic 16 Ocean Current Model* *This apparently describes a numerical model that captures the dynamic movements of the waves and currents. The simulation is supposed to generate theory.*	*Wave, model, wind, velocity, tsunami, eddy, tidal, speed, simulation, dynamic, frequency, numerical, tide, force, flow, result, internal, theory, generate, energy, field, motion, stress, simulate, height, parameter, equation, amplitude, direction, dimensional*
Story 4 "Myopia"	*Topic 1 Continued Evolution of Fish* *Changes in habitats, population dynamics, genetics, migration patterns and lifecycles as well as predator/prey relationships. The focus seems to be on charismatic and commercially valuable fish species.*	*Fish, species, population, body, prey, habitat, animal, predator, life, pelagic, whale, evolutionary, individual, feed, morphological, larva, genus, catch, salmon, genetic, fishery, shark, tuna, larval, adult, migration, sp, family, live, swim*
Story 4 "Myopia"	*Topic 19 Remote Sensing* *Satellites can collect spatial data and (high resolution) images. Measurements and observations can thus be done remotely. This method can also include errors and biases.*	*Datum, measurement, satellite, estimate, resolution, observation, ocean, method, measure, error, sense, band, situ, image, analysis, dataset, derive, optical, bias, coefficient, product, provide, color, base, radar, algorithm, quality, spatial, remote, set*

Summary of the future visions

Based on these topics, we created four story-based visions (see Supplementary 1), using a structured futuring approach. This approach consisted of multiple, sequential scenario building exercises (Fig. 2), which were applied to envision imaginative, radically futuristic worlds. Characters, a plot and visual artwork were added to texturize our visions, creating a more vivid and immersive experience for potential audiences. The stories were written by the lead author and the artwork was created by an artist, in collaboration with the lead author.

In the first story, titled 'The Ocean Uprising', increased anthropogenic damage to the environment and decreased cognitive distance of the public to the ocean due to widespread use of AUVs (autonomous underwater vehicles) create a window of opportunity for a fundamental change. A group of disruptive activists who carry out a successful coup that involves blowing up a pipeline and bringing people together in a collaborative art project, finally have their goal of a sustainably used ocean in close reach. But when a new geo-engineering technique turns the seabed into a valuable resource, industry actors take charge of the sustainability transformation, and every inch of the seabed is privatized. While the industry actors curate an overly green image for themselves, they actually manage and conserve their resources

responsibly and ecosystems start to heal. All that's left for the members of the disruptive activism group, who gave up their dreams of an anarchist, egalitarian, sustainability revolution, is to accept the new technocratic rule over the ocean and find their place within it, as decolonial tour guides.

The second story, titled 'Deep Connections', takes place long after an environmental catastrophe forced people to migrate to the deep sea, where humans have perfectly adapted their bodies and lifestyles to the harsh conditions of their new home and created a thriving society in the deep. Drone technology allows them to collect natural resources without using violent extraction methods and also performs most manual labor tasks. The deep-sea dwelling people use their free time for ambitious research projects and to actively care for their environment, strengthening their emotional and spiritual connections to it. This story follows a protagonist who wants to contribute to their beloved community by going on a dangerous mission to the surface, but also yearns for the approval and moral support from their partner, who ultimately agrees to follow them to the sunlight zone.

The third story, titled 'Kairei City', centers around the high seas nation state, which came into being after failed international negotiations and a shocking invasion of ocean space made it clear that the High Seas are too valuable to be ruined by fragmented governance. The new regime strives to be inclusive to all voices, values and knowledge systems, asking every member of society to represent the ocean, which is recognized as a legal entity with inherent rights, in decision making processes. The high seas look quite different now, with large structures in which seaweed and kelp are grown and fish are farmed, moving around to chase the best environmental conditions and bioremediate degraded areas. Our protagonist moves to the capital city of this state and dives headfirst into a community whose identity is shaped by the experience of living in a world intertwined with the water.

In the fourth story, titled 'Myopia', complete remote sensing coverage, advanced modeling tools and sensors tagged onto almost everything that moves through the water, have turned the oceans completely transparent. While the protagonist of this story can see the ocean in all its depth and vastness through a sensing device implanted in his body, he hasn't physically been close to the ocean in years. This changes when a colleague asks him to help her hunt down an illegal fishing crew, which creates blind spots in the monitoring system to fly under the radar. When he finally reaches the vessel and confronts the crew, he realizes that things are not as clear cut in the real world compared to his data streams. While his perspective might be heavily mediated by technology, he has to make the most important choice of his career by following his intuition.

Results of the interviews

The story-based visions were presented to experts on high seas issues, who were tasked with reading the stories and participating in an interview afterwards. Since one aim of the interviews was to substantiate the connections between the futuristic stories and currently prevalent imaginaries, the experts were asked if they could relate elements of the stories to their own research experience, scientific discourse, or popular culture. We highlight reactions of interviewees to specific story elements (Tables 3, 4, 5, 6),

confirming that the stories contain topics of relevance for a scientific audience and showcasing the unique importance of fictional items for changing perspectives on the future. A more comprehensive version of these tables, containing story elements, interview quotes and references to scientific literature can be found in Supplementary 5.

Table 3
Reactions to story 1 'The Ocean Uprising'

Story Element	Interview Quote
The seafloor is privatized and is now owned by geo-engineering corporations	*"The idea that private entities ended up grabbing all the seafloor – I absolutely think that might happen. (…) But I see it more for extractive purposes. Perhaps that's me being too regimented in the now because that's on the cusp of happening." (Participant 5)*
The High Seas are temporarily inhabited by workers of high-profile jobs and wealthy tourists	*"I hope that we don't colonize the High Seas (…) (Participant 4)*
Corporations manage their area of the seafloor sustainably, for profit	*"When these companies are doing conservation and management of their areas, they are actually acting, in an effective way, at least they had a plan for this particular thing. And this you can see in FIPs, fisheries improvement projects, that a lot of stakeholders and industry are engaging with." (Participant 4)*
An activist group uses disruptive measures to fight for change	"*She is nodding back to her previous life where she used to do all these things that NGOs do now, and you see the same kinds of narratives, eco activists or eco terrorists." (Participant 5)*

Table 4
Reactions to story 2 'Deep Connections'

Story Element	Interview Quote
After an environmental catastrophe leaves their homeland uninhabitable, a group of people migrates to the deep sea	*"If we mess up to the point where it (the earth's surface) becomes uninhabitable which is not unimaginable, which is just an extrapolation of where we are at right now, then maybe we do find ourselves moving into the sea." (Participant 8)*
Hydrothermal vents are seen as sacred in their culture	*"We are working on hydrothermal vents, thinking about how they should be protected and understood, and I think what's quite nice about the story is that the awesomeness of it, the spirituality of it comes through." (Participant 6)*
Humans want to learn from octopi about how they engage with the world	*"I also liked the part about the octopus, how we view the world and gather information could be really, really different." (Participant 2)*
Natural resources are gathered where they are naturally occurring, without using destructive methods	*"And what I really liked was your thing about the non-renewable resources seeping out rather than needing destructive methods, they were just collecting." (Participant 2)*

Table 5
Reactions to story 3 'Kairei City'

Story Element	Interview Quote
People live in a city, floating on the High Seas	*"Then we can maybe get to the sea steading, where we have the floating cities, when the islands have been subjected to sea level rise." (Participant 2)*
All human-built structures (such as protected areas, aquaculture farms, kelp forests, the floating city itself) are moved around to adapt to changing environmental conditions	*"Shared fish, dynamic resources, nothing is fixed, and they manage things more mobile, which is close to what I do. So that was fun to see." (Participant 3)*
The High Seas are governed as a nation state	*"And there is this big institution that is taking care of international waters" (Participant 4)*
The concept of RFMOs (Regional Fisheries Organizations) is improved, by uniting these organizations and bestowing them with more power	*"It was interesting to see how there were some elements in that RFMO that are not actually included in today's RFMOs mandates." (Participant 4)*

Table 6
Reactions to story 4 'Myopia'

Story Element	Interview Quote
All environmental data has to be shared publicly, leading to a 'transparent ocean'	*"When you described the sharing of scientific data and a fully transparent ocean, that made complete sense. (…) sharing data has been the cornerstone of research for Antarctica since the sixties." (Participant 1)*
The narrator wears an implant consisting of sensors and data processors, allowing him to see data streams 'with his own eyes'	*"It's very plausible that we will be microchipped, they already have Google glasses that show you everything, so that's very much an extension of what already exists." (Participant 8)*
Some people defy the transparency laws and try to engage in illegal activities in secrecy	*"And for the IUU fishing story, that's how illegal fishers operate now, they turn off existing technology, VMS, AIS, to go under the radar when they fish." (Participant 8)*
Fish are evolving much faster, changing morphology, migration, and behavior	*"And I was interested in how fish evolve really quickly. (…) There is evidence, I've seen papers about the evolution being accelerated in fish that are overfished." (Participant 8)*

A second aim of the interviews was for participants to reflect on the value of story-based visions and their potential for fostering the emergence of novel imaginaries. In the analysis of the interviews, certain themes became apparent, which reveal how engagement with creative visions could open up transformative spaces. For example, interviewees described stories and art-science collaborations as powerful communication tools, which could interest diverse audiences and thus aid science communication and awareness raising.

"Art has been with us forever and it's something we really value and feel connected to, so I really believe in the power of art to create transformations. (Stories are) a different way of creating consciousness in the population, (engaging) different audiences and people. And I think that as scientists a big barrier we have, we don't communicate well." (Participant 4, Quote 1)

"People who don't know anything about the ocean but are into radical storytelling might be enthralled by these kinds of stories and it could make them look at the ocean differently (…) These kinds of stories could inspire people to learn more about the ocean." (Participant 8, Quote 2)

"Creative art is having a huge impact and it's just bringing home the message and getting people into action. Being empathetic instead of apathetic." (Participant 2, Quote 3)

The stories were also described as evoking an emotional response from the reader, which is understood as a substantial factor guiding decision-making. The vivid depictions of the high seas allow the audiences to truly experience this geographically distant region, fostering a more personal connection and a perceived closeness to it.

"I think stories can connect us to the ocean emotionally. Because obviously the water is a non-human environment. (…) Most of us will never go out to the high seas or the deep seas so that element chimes

with science fiction, because it's actually quite unknown to lots of people." (Participant 6, Quote 4)

"It's a different way of engaging people in the ocean and creating that sort of awe and fascination with the ocean." (Participant 8, Quote 5)

"Ultimately a lot of the time, decisions are made based on emotions, based on intuitive reactions that people have as humans, even if they're informed by knowledge." (Participant 7, Quote 6)

A common statement regarding the stories was that they could further broaden horizons regarding future possibilities. Creating and reading radically transformed futures could push people to explore the future of the high seas from different angles and experiment with new ideas or modes of thinking.

"I think some of the stuff is pushing our limits, pushing it to the extremes of what we can properly envision but I don't think that's a bad thing at all, I think the thread is still bringing you back to a believable extreme if you can put it like that." (Participant 2, Quote 8)

"It really helped to think a little bit outside of the box and outside of the framework that exists currently and just engage more with the future, I really loved that." (Participant 5, Quote 9)

"It has opened my mind a huge amount." (Participant 2, Quote 10)

Further, some interviewees stated their ideas for concrete applications of story-based visions, describing how they could exert positive influence in learning, planning and decision-making spaces.

"We should have all the policy makers at these intergovernmental organizations and all these scientists that work in these spaces be part of this exercise, just to tweak things. I know they might not like it, but I think there would be a lot who do engage with it, and it does shift perceptions." (Participant 3, Quote 11)

"I see a huge potential in using these kinds of stories in schools (…) you're really bringing home the issues by putting them into something that they can identify with (…) You could give them all topics and say, 'write a story around that'." (Participant 2, Quote 12)

"If we have any kind of strategy or horizon scanning type of work, it might be useful to have an introductory talk by someone who writes creative, fantastic futures. (…) If you can show that the horizon can have these insane things, not just the things you're thinking of from a current point of view, that would make individuals more confident in their thoughts. Because otherwise people won't say things that might sound weird." (Participant 1, Quote 13)

Discussion

Future elements described in the science fiction stories are clearly related to the topics and keywords identified using topic modeling (Table 2). Similar to Keys and Meyer (47), who compare their story-based visions to other visioning work based in the arctic region, the results show that the stories, while radically different from the present, relate to current realities. We advance this idea further, by showing that story

elements are either an exaggerated extrapolation of current scientific evidence or visible in contemporary scientific or popular discourse (Table 3, 4, 5, 6). The emphasis on the close ties between story elements and present developments could help to convince expert audiences, who are unfamiliar with creative explorations of scientific topics, that the science fiction stories are not pure escapism, but contain valuable knowledge. It is important to attune the story-based visions to relevant topics in current discourse, since ‘possibility must emerge out of actuality’ (48). Our argument is that the future emerges from the present, and thus even creative future visions should integrate elements of the present, for the audience to be able to relate to them. Yet, while the visions are clearly rooted in the present, they contain imaginations of an unknown future. Looking ahead to this unknown future, we have no choice but to rely on imaginaries, to structure our expectations of what's to come (30). We can use this uncertainty to our advantage, by framing the vast option space of an unknown future as room to act, to change the present status quo that seems ‘immutable, inevitable and invulnerable’, to feel hopeful (49).

Imagination

Milkoreit (32) writes that ‘imagination lies at the heart of social change’, as visions of the future drive change by motivating and directing actions and decision-making (50). Works of fiction can support sustainability transformations, as they facilitate imagination processes, by offering verbal and visual source material (32, 51, 52). Interviewees stated that the visions could help to open people's minds, guiding them to think outside of the box (Quote 9, 7, 10) (53). The story-based visions, being radically futuristic, have the potential to boost the imagination and spark original, experimental ideas in a potential audience. To discover truly different futures, we have to ‘think the unthinkable’ (54) and engaging with outlandish science fiction might create the mind space to do so.

The high seas are unknown to most people and a system this large cannot be experienced directly (55) (Quote 4), which might promote a perception of the open oceans as distant and disconnected from humanity. Therefore, stories that take place on the high seas and describe them and the human-nature interactions taking place there vividly, could allow the audience to experience an ocean they have never seen before (52). Engaging with future visions, in which human lives are deeply intertwined with the oceans, can allow people to relate to them on an emotional level, increasing empathy (Quote 3) (42, 56). In every embodied experience, the ocean is local (55), so telling stories from the perspective of a person living there, imagining them as ‘peopled’ spaces, could foster the integration of socio-cultural perspectives (57). These perspectives, containing beliefs about values, norms, and worldviews, are necessary when imagining collective futures (32). In other words, being able to realize yourself in a character in a story about the high seas brings them that much closer to your reality rather than as a place ‘out there’ about which you do not have to be concerned.

The art of communication

To contribute to the imagining of collective futures, elements of the visions must enter into discursive meaning-making processes, being communicated to and between people (32). Thereby, the visions are not suggestions of normatively desirable futures, but instead could serve as opportunities to reflect on the

social, technological, or political developments presented in the stories, as well as their (un)desirability. For this reason, the visions cover a wide variety of possible future trajectories, including elements which might be understood as dystopian by some. However, to fully exploit the potential of the visions to open up spaces in which people can think through possible future trajectories, they need to be widely disseminated, critiqued, extended and revised. Communicating the visions using science fiction stories in combination with visual artwork could be a fruitful approach, since stories are more enticing and inclusive than traditional scientific communication (58) (Quote 1, 2) and art-science collaborations may be interesting and accessible to audiences beyond academia (28). Further, stories are evocative and layered, and therefore readers can derive their own meanings from the text, which could make the experience more personal, as they offer readers the space for self-reflection and critical thinking. Interviewees stated that the story-based visions could awaken fascination and awe for the oceans (Quote 5) and inspire people to learn more about them (Quote 2). These ideas are mirrored in the call for an 'inspiring and engaging ocean' issued by the UN Decade of Ocean Science for Sustainable Development. The UN Ocean Decade uses artistic means of communication, aiming to raise awareness, inspire people to learn about the ocean and reach audiences, which might not engage with the topic otherwise (59). Communicating possible futures by using stories might be able to elicit a heightened interest and care in audiences, since stories are emotionally charged and represent a fundamental mode of human thought and memory (44, 58, 60).

Visioning approaches, which combine science and art can aid to address the previously mentioned 'imagination gap' (43). This could be of relevance for intergovernmental processes, such as the negotiations of the United Nations Intergovernmental Conference on Marine Biodiversity of Areas Beyond National Jurisdictions. These negotiations could be conceptualized as a crossroads, deciding whether future high seas governance remains at the current status quo, or transforms the way we govern and relate to the oceans (21). Embracing imaginative futures thinking as part of this policy process could have value in unsticking the negotiations, by provoking decision makers to question the currently dominant values and beliefs (61) and stimulating new ways of thinking about international collaboration on the high seas. Innovative ideas, conceived and debated as part of these processes could form a novel, sustainable and just high seas imaginary. This imaginary could then become a material and institutional reality, being enacted through infrastructures, practices, and meanings (32, 35)

Limitations and further research

Further research is needed to evolve this methodological approach, for example by adding a participatory element, thus adding a diversity of perspectives on the future of the high seas, accounting for the multitude of ways to relate to the oceans (27, 62). Moreover, artists could be included from the beginning, allowing for a continuous cross-fertilization between art and research processes. Additionally, since only papers in English were included, there is a gap in the literature of papers in other languages that might provide new perspectives. Future studies can address this limitation by including scientific articles in other languages. A potential bias further exists regarding the interview participant selection. As the interviewees were people who had already participated in a series of workshops that used creative

futuring methods, they were part of a small subset of high seas experts that were familiar with some of the concepts and methods in this paper. It was important to question people, who had this experience and were willing to take time to read the stories and reflect on them, yet it is important to consider that their responses are not indicative of all high seas experts. It would be a useful extension in further work to question a much wider audience and get more insights as to whether the themes of the stories resonate or are useful for provoking new insights.

Conclusions

This study set out to creatively explore possible futures of the high seas, while adapting a visioning approach, which combines computational text analysis, scenario building and science fiction story telling. The method presented in this thesis creates radical yet scientifically grounded visions, which can be linked to current realities. Envisioning and debating possible futures could open up transformative spaces to reflect on the ways in which we value and relate to the high seas, inspiring us to (re)discover the meaning of our relationships to the oceans. These transformative spaces could foster collective processes of future oriented meaning making regarding sustainable and just high seas; with novel imaginaries emerging from these processes. Embodying scientific evidence in radical futures that make use of imaginative capacity and the underutilized tools of the arts results in a significant contribution to research on futures for the high seas. At the same time, it offers an evocative means for connecting people with a dissociated part of our planet. This study offers an interesting pathway forward, fusing scientific literature and imagination in the field of futures studies.

Methods

A computational text analysis, specifically topic modeling, was used to study which topics are most prevalent in scientific literature regarding the future of the high seas. These topics, which could also represent concepts, events, or framings (63) were used as input for a structured futuring approach. This is a systematic yet creative approach to develop a detailed world in which the story takes place (Fig. 2), to which characters and a plot are added as the future visions evolve (47). The resulting stories were analyzed using expert interviews, to reveal which elements of these futures can be related back to current realities. The stories were accompanied by four visual artworks, which were created by an artist in collaboration with the lead author.

Data collection

To gather the scientific data to draw upon as the basis for the visioning process, abstracts of scientific documents across a broad range of disciplines were analyzed. Since the number of documents available is quite large and is increasing ever faster, an automated review using computational text analysis was used to gain an overview of the literature and to structure the data in a comprehensible manner. Topic models can be used to rapidly analyze large, text-based datasets to discover clusters of themes prevalent in the literature (64), also known as topics. Latent Dirichlet Allocation (LDA) is an algorithm, which allows

the probabilistic modeling of term frequency occurrences in documents (65). To gather the data which would be fed into the topic model, a search string was developed, which consisted of descriptive words for the high seas, words related to high seas governance as well as words related to the future and change (see Supplementary 2). The search string was applied to Scopus and yielded n = 8846 results. To explore a wide range of ideas about the future but focus on modern high seas governance, the scope was limited to articles written after the UNCLOS was signed in 1982. This exclusion criterion led to n = 8580 articles being selected as input for the topic model. The abstracts of these articles were downloaded and read into R Studio (66).

Topic modeling

Firstly, the data were transformed into a tidy data structure (67) and a list of 'stopwords' (and, or, in, like, so) was removed. The data were then transformed into a document term matrix, which served as the input for the topic model. There are multiple algorithms with which one could fit a topic model. Thus, to compare model performance and inform the choice of algorithm for this specific corpus, the entropy, log-likelihood and perplexity scores for four different algorithms (VEM0, VEM_fixed, Gibbs and CTM) were calculated (68) (Table 1, 7). Since the number of topics that best describe the content of a corpus is generally not known beforehand, multiple models were fitted and the statistically optimal number of topics was determined through calculations (68) (Fig. 3). To choose the statistically best number of topics given the data, only log-likelihood and entropy were calculated, since perplexity cannot be calculated for the chosen algorithm, the Gibbs sampler (68). As shown in Fig. 3, by increasing the number of topics from 5 to 100, the entropy values are raised, yet the alpha values are reduced. This suggests that despite the better statistical fit of a model with a larger number of topics, the main content of the corpus can still be captured by a few, and fewer topics will result in a more even probability distribution of words per topic (69). Therefore, while the statistically optimal model in my results has 80 topics by log-likelihood and 100 by entropy, it is useful to choose a simpler model with fewer topics, especially since the increase in log-likelihood diminishes after 25 topics. A lower number of topics can also be chosen as a conservative measure against overfitting of the model, and it is common practice when there is a preference for a more parsimonious model (70). Fitting the model with fewer topics was useful for the purpose of this study, as the topics were intended as the basis for a creative visioning process and therefore needed to be interpretable by the author (63). Apart from the explanatory power of the model, the focus was also on the latent meaning in the corpus and semantically meaningful topics, which are oftentimes not correlated with the statistical fit of a model (71). Thus, the topic model was fit with 25 topics.

Table 7
The perplexity values for the three algorithms

	Model	Perplexity
1	VEM0	1587.299
2	VEM_fixed	2071.033
3	CTM	1773.127

The LDAvis package in R was used to visualize the topics, gain an understanding of them in relation to each other and fine-tune the keywords, the words most highly associated with each topic (72) (Fig. 1). The horizontal bar chart on the right side of the interface represents the individual keywords most salient in the selected topic with saliency described as the estimated term frequency within the selected topic (saliency (term w) = frequency(w) *[sum_t p(t | w) * log(p(t | w)/p(t))] (73). The overlaid bars represent the corpus wide frequency of a given keyword as well as the topic-specific frequency of the term (73). A challenge when interpreting the topics based on the most frequent keywords, is that common words in the corpus (in this case words like ocean, sea, marine etc.) often appear as one of the top keywords for multiple topics, making it hard to differentiate the meanings of these topics (72). A potential solution to this problem is to adjust the value of lambda, also known as relevance (relevance (term w | topic t) = λ * p(w | t) + (1 - λ) * p(w | t)/p(w)) in the LDAvis interface (72). This adds weight to the ratio of the frequency of a term given a specific topic to the overall frequency of a term, the ratio of red to gray bars (see Fig. 1). By adjusting the value of lambda, the words can be re-ranked, excluding words that are frequent in the overall corpus and introducing new words, which are more specific to a topic of interest (72). Sievert and Shirley (72) conducted a study which suggested that ranking terms according to relevance, where lambda is lower than 1, can improve topic interpretability. According to this evidence and the authors' subjective perception of topic interpretability, the value of lambda was adjusted to 0.6. This step is important to more clearly differentiate the topics from each other, so that the visions have very different starting points and therefore more variety and surprise (74).

Structured futuring

While most of the topics clearly described a theme, were coherent and related to the high seas and future change, some topics were not interpretable, or not related to the topic of this study and were therefore discarded. An example of a discarded topic would be a topic consisting of words for coastal areas, lakes and rivers, which does not describe the high seas. Ultimately, 16 out of 25 topics were used as a basis for the scenarios (Table 2). To move from topics to future visions, a structured futuring approach was employed, which guided the worldbuilding process (47). Firstly, the keywords were summarized into topic labels, short sentences, that describe the content of the topic (75). To explore the interplay of different topics, the topics were grouped into four clusters, each consisting of four topics. Since maximizing the diversity of the starting points of a visioning process can spark creativity (74), particularly dissimilar topics were clustered, using the intertopic distance map in the LDAvis tool. Further, topics from different

STEEP (Social, Technological, Economic, Ecological, Political) categories were clustered together (74), to ensure that visions were not one-sided but included aspects from multiple categories.

Topics and keywords were then explored using future wheels (76). For this exercise, the topic labels were placed in the middle of the future wheels and keywords were filled in as primary or secondary impacts of this topic if they fit as such. The outcomes of all future wheels in a cluster were connected to each other using cross-impact matrices (24). These matrices were used to reveal potential contradictions, synergies or reinforcing feedback loops, as the impacts of one topic can diminish or amplify impacts of another topic. The resulting events, ideas and developments were then mapped onto the three horizons framework to create a timeline of events (77). This exercise was used to identify changes that had to occur in the present for a particular future to emerge, detailing the decline of current unsustainable elements, or the rise of future sustainable elements (77). Lastly, the emerging world was fleshed out using the cultural iceberg model (*sensu* 78), which was applied to imagine socio-cultural details, which make the visions more vivid and immersive. Over the course of these exercises, certain elements of the visions were 'pushed towards ridiculousness' (74), applying insights from science fiction (53). This was done to erase 'blind spots' created by the assumption that we will follow current trajectories into the future (74). The results of these exercises then served as the material for a creative and iterative story writing process, translating the various future elements into science fiction stories.

Interviews

To inquire whether the outcomes of such a creative visioning process contain knowledge, which is valuable and relevant to the high seas scientific community, as well as to further substantiate the connections between story elements and current realities, eight semi-structured interviews with international experts on high seas issues were conducted. The majority of the interviews (six out of eight) were held during an in-person workshop in Cape Town, South Africa; two interviews were held online using Zoom. The interviews had an average length of 20 minutes and were conducted in English. For a description of demographic features of the interviewees and their fields of work see Table 8. Prior to the interviews, the participants signed a consent form, which stated that while anonymous responses from the interviews could be used in presentations and publications, no personal data would be collected and shared. The interviews were recorded and transcribed, yet the recordings and transcriptions are not publicly available, in accordance with the consent form.

Table 8

Description of demographic features and fields of work of the interviewees

Demographic Feature	Category	Number of Participants
Gender	Female	5
	Male	3
Field of Work	Academic Research	3
	Science Policy Interface	3
	Non-Governmental Organization	2
Age Group	29 and under	/
	30–40	3
	40–50	4
	50 and over	1

The interviewees were selected because they were experts regarding ocean issues and had just participated in a workshop series on the future of the high seas. Over the course of the workshop, participants had used various methods to explore the future of the high seas, including creative methods, such as working with an artist and co-writing science fiction inspired, character driven stories (79). Hence, they had valuable insights into the concepts and methods used in this study and could answer the questions based on their own, recent experiences. The interviews were therefore designed to capitalize on this experience, by focusing the questions on how creative futuring methods can be used to benefit visioning processes or high seas research in general. The interviews consisted of seven questions (see Supplementary 3), but interviewees were encouraged to add explanations and spontaneous thoughts, to allow for the expression of more personal insights and opinions. In preparation for the interviews, participants were asked to read two of the four science fiction stories.

One aim of the interviews was to investigate whether high seas experts recognized elements of the scientific evidence written into the science fiction stories, either from their own work and professional knowledge or from present realities, which could include scientific publications from any disciplines, popular media, or societal discourses. These questions were related to the claim that radically futuristic stories can be clearly connected to the evidence they were based upon, in this case the scientific evidence collected through computational text analysis. Further they were asked if and how their recent experience with radical and creative work on futures affected their view on the future of the high seas. Another question asked if and how future visions could be used to advance high seas research and communication. A focus was placed on how the visions could be used to open up spaces for dialogue and reflection, with regards to audiences both in and beyond academia. These questions were asked to inquire whether experts were interested in and related to creative futures work and story-based visions. Overall, the interview questions oftentimes prompted discussions about personal expectations, hopes

and fears for the future of the high seas, as well as comments and critiques of the story-based visions themselves. The interview transcriptions were coded deductively, since the aim was to record the participants' thoughts on these specific questions. Due to the deductive coding, four categories emerged, namely story elements related to current realities, positive aspects and the potential of working with creative visioning methods and the resulting stories, specific applications for such methods and stories, as well as limitations and critiques. Excerpts from the interviews, sorted into these four broad categories, can be found in Supplementary 4. The methods were performed in accordance with relevant guidelines and regulations and approved by the Stockholm Resilience Centre.

Declarations

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Author Contributions

HML designed the study with JCR, LMP, and PWK; HML collected, analyzed and interpreted the data and wrote the manuscript; LMP supervised the project; JCR provided technical support, regarding the analysis; PWK, LMP, AM and JCR provided conceptual support and revised the manuscript.

Competing Interests Statement

The authors declare that there are no competing financial or non-financial interests in relation to the work described.

Data Availability Statement

All code used in this publication can be accessed on GitHubhttps://github.com/HannahMarlen/High-Seas-Topic-Model/blob/main/Final%20Code. The data analyzed in this paper, abstracts from scientific articles, can be downloaded from Scopus using the search string described in the paper.

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Figures

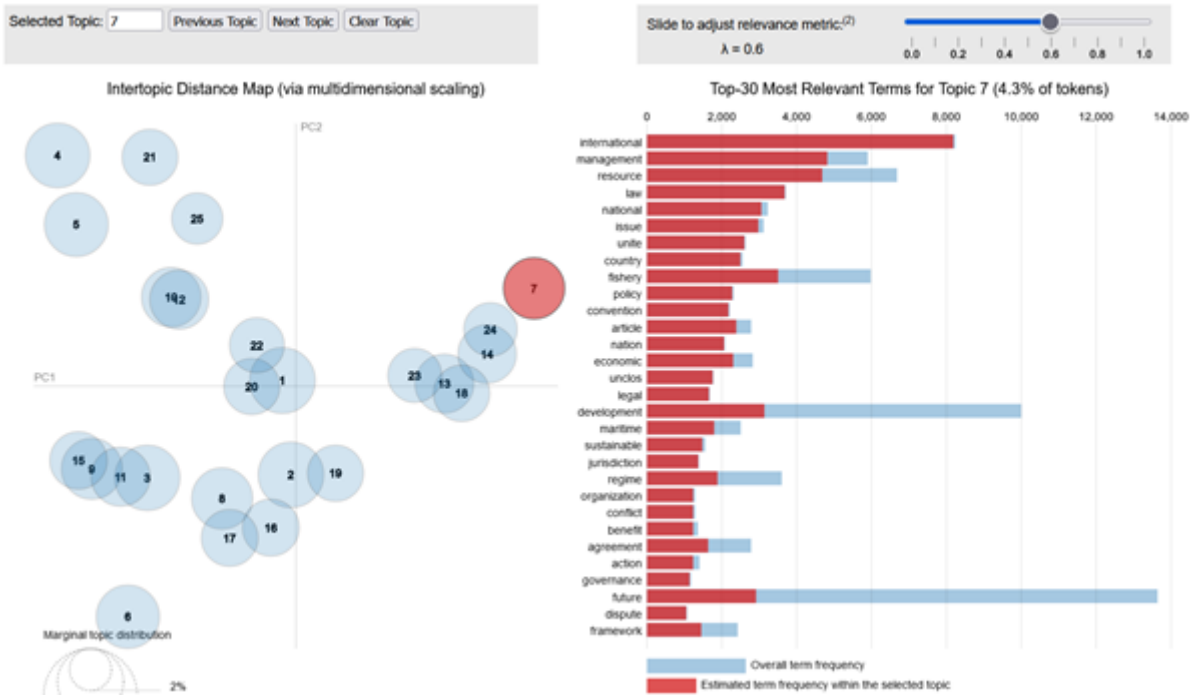

Figure 1

The 25 topics visualized using the LDAvis template, including the 30 keywords for one particular topic (Topic 7). On the left side of the LDAvis interface, one can see the intertopic distance map, with each circle representing a topic. The sizes of the circles are proportional to the relative prevalence of the topics in the corpus and the distance between the topics represents their (dis)similarity. On the right side, there is a horizontal bar chart representing the individual keywords most salient in the currently selected topic. Saliency is described as the estimated term frequency within the selected topic (73).

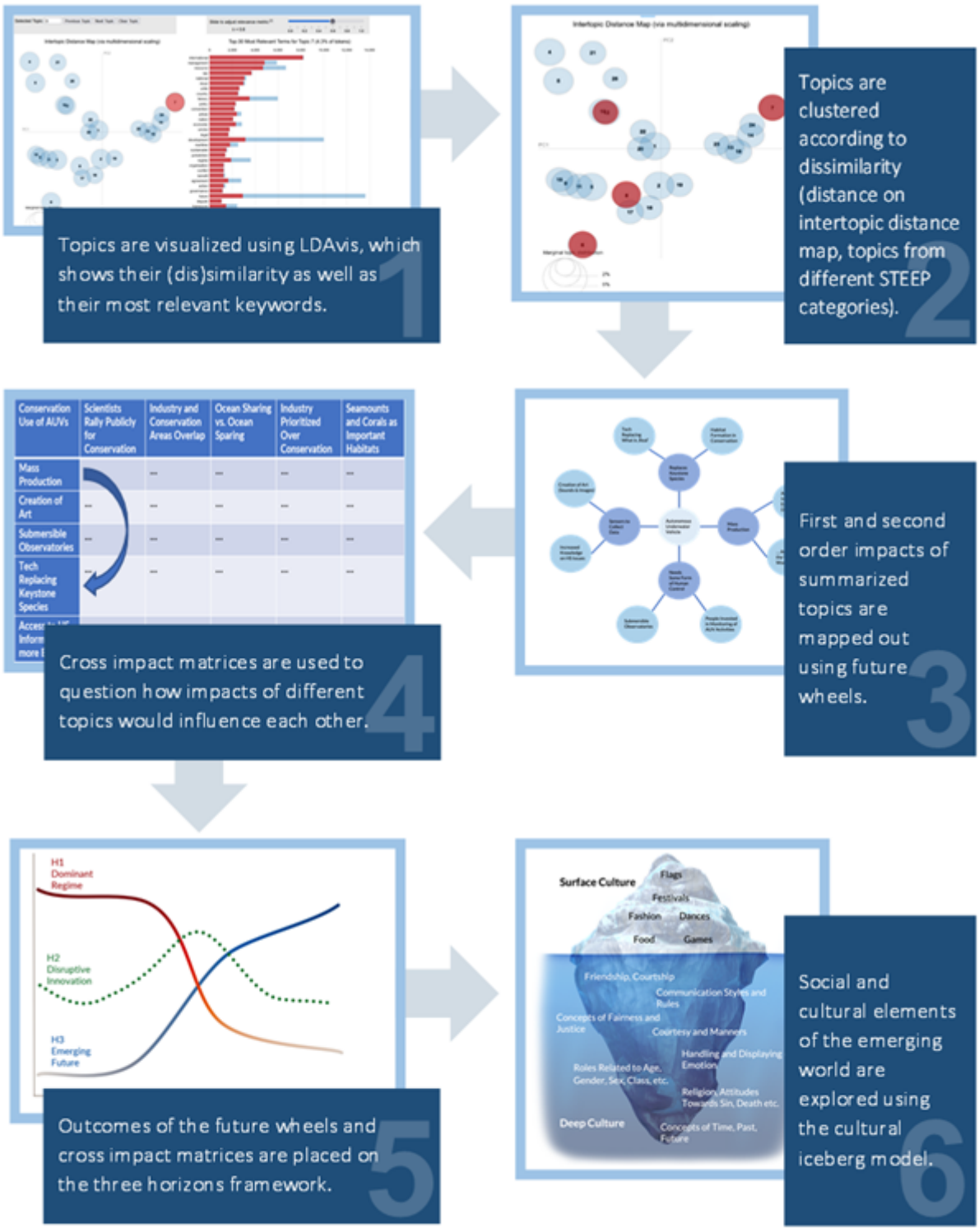

Figure 2

The sequence of steps of the structured futuring approach. While the steps were followed linearly, each exercise was not building on the previous one exclusively, but also took inspiration from outcomes of the other exercises as well as new ideas.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Additionalimage1.png
- Additionalimage2.png
- Additionalimage3.png
- Additionalimage4.png
- SupplementaryMaterialLbkeretal.2022.docx