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# Defining marine rewilding can help guide theory and practice in marine conservation



Esther E. Brooker<sup>1</sup> ✉, Gerald Midgley<sup>2,3,4,5,6,7,8</sup>, Neil Burns<sup>9</sup>, Charlotte E. Trotman<sup>10</sup>,  
Amanda Gregory<sup>2</sup> & Charlotte Rachael Hopkins<sup>1</sup>

Public concern over global climate change and biodiversity loss has accelerated international efforts to restore natural ecosystems through nature-based solutions. Rewilding is a growing conservation approach encompassing the recovery of ecological and trophic complexity through interventions such as habitat restoration and/or species reintroduction. Here we explore the nascent efforts of marine rewilding using a systems thinking methodology to inform a systematic review and iterative thematic analysis. Marine rewilding involves a diverse range of interventions, showing similarities in ecological principles with terrestrial rewilding, yet it diverges from terrestrial rewilding in the scale of initiatives, predictability of outcomes, and the prominence of social inclusion. To make progress in offering unifying concepts, we propose a definition for marine rewilding: a systemic process requiring deliberate human intervention that involves community participation and ocean stewardship to regenerate degraded marine ecosystems.

Increased anthropogenic pressure on global ecosystems has caused dramatic declines in biodiversity and has exacerbated the impacts of climate change<sup>1–3</sup>. Subsequently, global conservation initiatives have transitioned from seeking to maintain current conditions towards including more active ecological restoration<sup>4,5</sup>. Conservation scientists, policymakers and stakeholders have sought to address large-scale systemic issues, including climate change effects such as sea-level rise and coastal flooding, with actions that enhance natural ecosystems (and the services they provide) for the mutual benefit of nature and society. These actions are commonly known as nature-based solutions<sup>6</sup>. The United Nations' (UN) Decade of Ecosystem Restoration (2021–2030) has further strengthened national and international agendas for the enhancement of nature, and the recently agreed Global Biodiversity Framework included a target for 30% of the world's degraded land and aquatic ecosystems to be under effective restoration by 2030<sup>7</sup>.

The term 'rewilding' was first coined in the 1990s as a response to the decline of biodiversity and trophic (food web) relationships in terrestrial ecosystems, and is now considered a nature-based solution<sup>8–11</sup>. Although rewilding has gained momentum as a conservation discipline, scientific acceptance of a standard definition of it still appears to be lacking<sup>12</sup>. The

application of the term rewilding in relation to other conservation practices, such as restoration, and the end point to which an ecosystem should be rewilded, has been debated<sup>13,14</sup>. There are key differences in the philosophies of restoration and rewilding, with rewilding placing less emphasis on past baselines and taxonomic fidelity than restoration, as well as accepting alternative ecological outcomes and greater social participation<sup>14</sup>. There are also conflicting views on whether a rewilding baseline should accommodate modern human influences or be pre-industrial or even pre-human<sup>15</sup>. With environmental changes and shifting baselines comes potentially greater acceptance of novel ecosystems as an outcome<sup>16,17</sup>, as well as proliferation of more adaptable but harder to control weedy species, such as jellyfish<sup>18</sup>. The science and practice of rewilding the sea is less developed than that of terrestrial rewilding, in part due to added complexities of managing activities within the marine environment, accessibility and relative lack of research and monitoring<sup>14,19</sup>. With increasing pressures, terrestrial and marine ecosystems face greater risk of abrupt ecological tipping points, which can present challenges for human uses of natural resources and are more difficult to detect in marine environments where monitoring is lacking<sup>20,21</sup>. However, useful principles exist from already established terrestrial rewilding pioneers, as explained below.

<sup>1</sup>School of Environmental and Life Sciences, University of Hull, Hull, UK. <sup>2</sup>Centre for Systems Studies, Faculty of Business, Law and Politics, University of Hull, Hull, UK. <sup>3</sup>Birmingham Leadership Institute, University of Birmingham, Birmingham, UK. <sup>4</sup>School of Cybernetics, ANU College of Systems and Society, Australian National University, Canberra, Australia. <sup>5</sup>Department of Informatics, Linnaeus University, Växjö, Sweden. <sup>6</sup>H3Uni, Glenrothes, UK. <sup>7</sup>Schumacher Institute, Bristol, UK. <sup>8</sup>Andean Institute of Systems, Lima, Peru. <sup>9</sup>School of Social and Environmental Sustainability, University of Glasgow, Dumfries, UK. <sup>10</sup>Energy and Environment Institute, University of Hull, Hull, UK. ✉e-mail: [e.brooker-2021@hull.ac.uk](mailto:e.brooker-2021@hull.ac.uk)

Rewilding was presented by its pioneers as the large-scale restoration of wilderness, and they identified three key attributes: large core reserves (such as protected areas); landscape connectivity (linkages and corridors to connect species populations and habitats); and re-establishment of keystone species (often apex predators or large herbivores)<sup>8</sup>. The importance of keystone species in enabling natural ecosystem function is reflected in the term 'trophic rewilding', defined as "an ecological restoration strategy that uses species introductions to restore top-down trophic interactions and associated trophic cascades to promote self-regulating biodiverse ecosystems"<sup>22</sup>. The use of rewilding to improve ecological resilience can also be incorporated into the design of protected areas by factoring in natural complexity, structures and connectivity<sup>23</sup>.

Many authors argue that rewilding approaches are context-specific, which means they may not be directly transferable between different bioregions, human geographies or political systems<sup>24–26</sup>. Nevertheless, Carver et al.<sup>9</sup> provide a more recent and more detailed development of early thinking on rewilding, setting out 10 general principles. These include the importance of keystone species in improving ecosystem resilience; recognition of the fluctuating nature of ecosystems (intrinsically and in response to environmental changes), which makes monitoring and adaptation important; and the requirement to integrate stakeholders, traditional uses and local/indigenous knowledge into rewilding. However, these principles are framed around terrestrial approaches to rewilding, and the authors acknowledge the need for greater understanding of how they apply in marine, terrestrial and subterranean contexts<sup>9</sup>.

The key attributes of terrestrial rewilding may be largely transferable to the marine environment, but the approaches to enabling it will vary. The active reintroduction or translocation of keystone marine species is still in early stages of research and practice, with a focus on bottom-up habitat forming species, such as oysters, corals and mangroves, and top-down trophic influences, such as shark and whale species<sup>27</sup>. New approaches have recently been tested for the captive rearing and reintroduction of marine megafauna species, such as the global ReShark Project<sup>28</sup>. Marine protected areas (MPAs) and the removal or reduction of human pressures are also cited as tools to enable rewilding of the seabed<sup>29</sup>. However, rewilding of marine habitat-forming species, such as seagrass beds, may not succeed at large scale or very rapidly by simply removing direct disturbance, and active intervention (restoration) to accelerate habitat recovery may be required to help expedite rewilding goals<sup>30</sup>. Even then, indirect pressures (such as land-based pollution run off) and the effects of climate change (e.g. marine heatwaves) will continue to have an influence, which may lead to unexpected outcomes, novel ecosystems, or simply failed attempts<sup>31</sup>.

Socio-cultural, traditional and indigenous narratives are increasingly recognised in terms of informing and enabling environmental conservation, and are seen as a critical factor in rewilding alongside ecological priorities<sup>9,25</sup>. To develop an understanding of marine rewilding, exploration beyond ecological criteria is needed to understand the wide range of values that are associated with it and identify key social parameters. We conducted a stakeholder consultation and drew on the methodology of boundary critique to inform an in-depth systematic review of the primary and grey literature on marine rewilding. Boundary critique is an approach to systems thinking that looks at the assumptions (about what matters in the context and what is relevant to framing) that underpin people's different perspectives on a complex issue<sup>32</sup>. We conducted an iterative thematic analysis<sup>33</sup> on the wide range of views presented in the literature to establish the types of interventions considered as marine rewilding and the common principles that underpin them. We posit some recommendations from the analysis for consideration in developing and implementing marine rewilding interventions. The insights from this study aim to enrich discourse on marine rewilding, foster clarity and improve research focus, ultimately contributing to the restoration and enhancement of marine environments using rewilding as a nature-based solution.

## Results

A total of 190 pieces of literature, comprising 65 primary papers and 125 grey literature articles, were used as the data set in the iterative thematic analysis. The articles directly linked the marine environment and rewilding processes, and included 75 different interventions or approaches to marine rewilding, grouped into 11 themes (Fig. 1).

The 11 themes to which the primary and grey literature were coded are shown in Fig. 1, including the full range of interventions that were cited as examples or case studies of marine rewilding within the data set.

An average of 2.35 (SD ± 1.01,  $n = 125$ ) themes per reviewed article were coded in the grey literature, and 2.63 (SD ± 1.41,  $n = 65$ ) in the primary literature. The percentage of articles in which each theme occurred and the scale at which each theme was observed to operate were variable between the primary and grey literatures (Fig. 1). Some themes occurred more in one type of literature (e.g., habitat restoration in the grey literature), whereas the occurrence of other themes was similar in both the primary and grey literatures (e.g. political intervention). Process-focused themes, such as repairing ecological linkages and climate change mitigation, occurred more in the primary literature, whereas practical interventions, such as habitat restoration, were described more frequently in the grey literature. Both the primary and grey literatures included social factors equally.

The scale of the interventions related to each theme described in the review articles was consistent in both primary and grey literature articles (Fig. 2). Examples of habitat restoration and best practice were all described at a local or individual project scale (although there were differences between articles in how scale was measured for some habitat projects, such as for seagrass restoration). Articles describing interventions relating to themes such as spatial protection and repairing ecological linkages varied, but generally suggested a more national county or country-wide approach, such as networks of marine reserves<sup>34</sup> and keystone species population recovery<sup>35</sup>. Articles describing interventions related to the themes of climate change-focused rewilding, social factors, reference conditions and political intervention made references about their global influence in specific and general ways, such as "Whale...migrations also translocate nutrients across vast geographical spaces" and "To consider trophic rewilding as a natural climate solution has much to offer"<sup>36</sup>.

One of the eligible articles and one article that was screened out referred to individual animals – the term rewilding was used in reference to them being rehabilitated for return to the wild. The eligible article referred to a seal that had become habituated to humans due to being fed, and the paper had a clear narrative in relation to the issue and explained the motivation for the intervention, although use of the term 'rewilding' did not fit with existing definitions<sup>37</sup>. The article that was screened out was about how a beluga whale (*Delphinapterus leucas*), thought to have been trained by humans, was adapting to life in the wild, which focused on dietary monitoring and facilitated rehabilitation, rather than an intention to rewild the animal or its habitat<sup>38</sup>.

There were a small number of themes that occurred together more frequently in the data set (Fig. 3), indicated by a higher proportion of the total number of themes, such as spatial protection and political intervention in the grey literature (67%) and repairing ecological linkages and consideration of land-based influences in the primary literature (64%). Differences in the proportions of themes that occurred together in the primary and grey literature articles can be seen in Fig. 3. For example, reduction of human pressures and repairing ecological linkages occurred more frequently together in the primary papers than in the grey literature (56% and 27%, respectively). The differences in themes between the two types of literature suggests variations in the perspectives or priorities for interventions considered to contribute to marine rewilding.

A limited number of the themes that occurred in articles together are arguably more strongly associated, with only 7 of the proportions being >50% in both the primary and grey literature sets, and the highest being 75%. This suggests that many of the themes or interventions are considered independently as marine rewilding in both the primary and grey literature articles.



**Fig. 1 | Pie and doughnut chart showing the results of an inductive thematic analysis of 190 pieces of primary and grey literature determined by a systematic review of marine rewilding.** Each of the 11 themes relates to interventions or key aspects of marine rewilding cited in the data set and is depicted by a different colour. The central pie chart shows the percentage of the total frequency by which each

theme was coded in the data set. The outer doughnut shows the specific interventions or examples recorded in the dataset under each theme, and the segment size represents the percentage frequency of these examples for each theme. Full details of the literature dataset and coding of the themes can be found in Supplementary Table 1.

Building on the analysis of the 11 themes shaped by the marine rewilding interventions identified, a further iterative review of the dataset to formulate more definitional themes resulted in the following set of points that encapsulate what marine rewilding can be said to consist of:

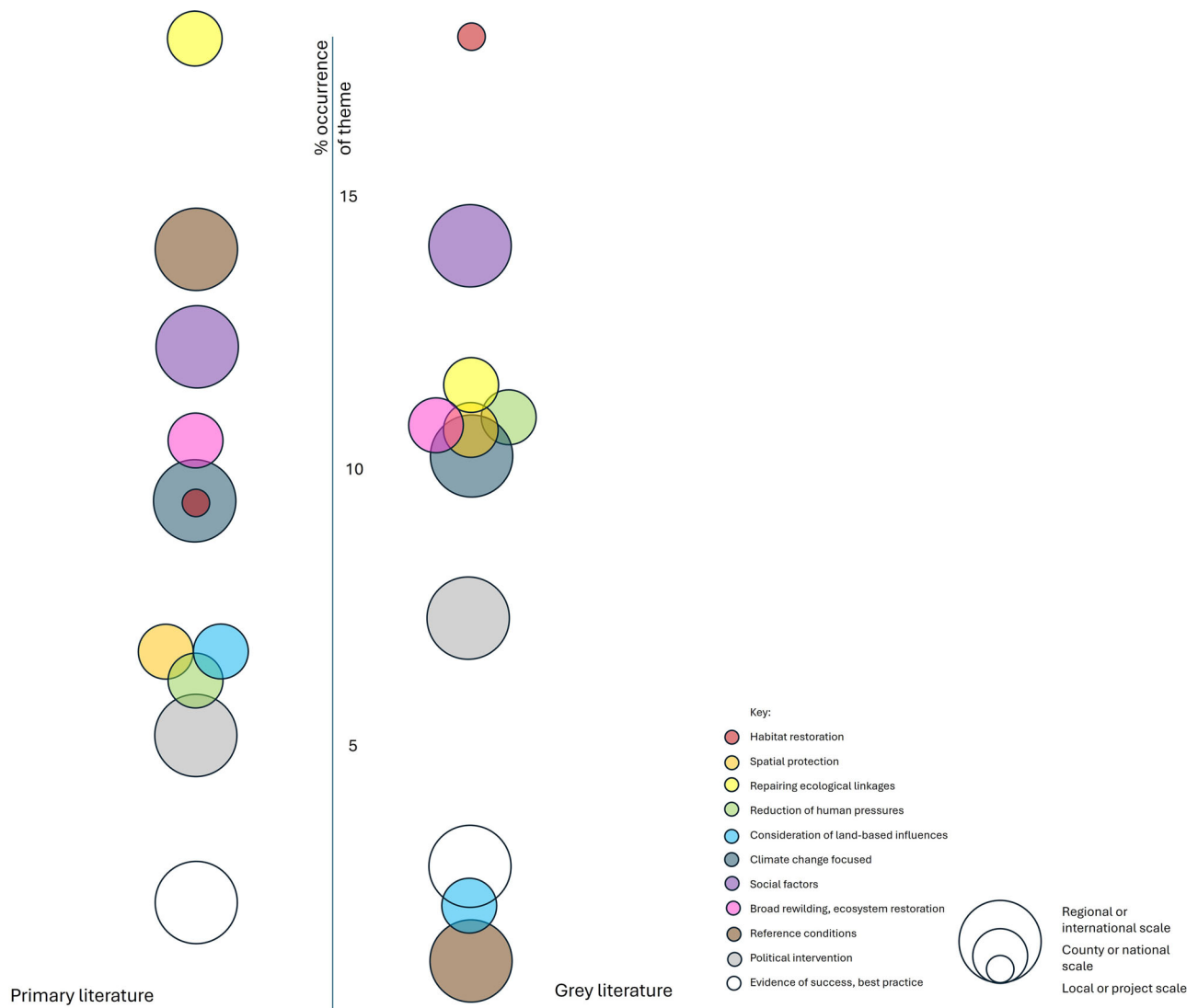
- Marine rewilding interventions require active and intentional change by humans to the current environmental conditions.
- Marine rewilding is a process, not necessarily an end point or a discrete intervention, and it can be highly iterative. A systemic approach is needed, as the marine environment is a complex transboundary space, which is more dynamic, less scientifically understood and less predictable than many terrestrial environments<sup>1</sup>. In line with a systemic approach, many projects referenced in the reviewed data are adaptive, taking account of new information or innovations (e.g. referring to future innovation in restoring shellfish reefs)<sup>39</sup>, or environmental changes<sup>9</sup>. Some papers talk about a requirement for a gradual phasing out of human management [e.g., ref. 40].
- Multiple approaches and scales of intervention are acknowledged in marine rewilding, from small-scale habitat restoration (e.g. artificial seawalls<sup>41</sup> and seagrass planting<sup>42</sup>) to larger scale protected areas and international treaties<sup>43</sup>. This is underscored by there being multiple themes coded to most of the articles. The data set also included

interventions that span environments influenced by the ocean, including coastal, subtidal and oceanic areas.

- The process of marine rewilding is about enabling change from the current environmental state to a more desirable one. All the articles implicitly or explicitly acknowledged a view that rewilding should create improvements to current environmental conditions, with an emphasis on sustainability and resilience rather than a return to pre-damage conditions.
- While there is a requirement for humans to drive marine rewilding efforts, the integration of social (including traditional cultural and economic) factors in the process and outcomes is critical to the success and ethos of marine rewilding processes<sup>44–46</sup>. Current definitions of rewilding rarely include this, and instead focus on ecological priorities (see Table 1), but our study found that the involvement of people was a clear thread throughout the dataset and should be integrated into a definition.

Based on these key points, we define marine rewilding as:

A collaborative, human-initiated, nature-led process involving a range of approaches that work systemically to make degraded marine and coastal environments more ecologically complex while supporting greater



**Fig. 2 | A bubble plot showing the percentage of primary ( $n = 65$ ) and grey literature (125) articles per theme related to marine rewilding identified between March and August 2023. Each theme is represented by a different colour, and the**

size of the bubble is representative of the scale at which marine rewilding interventions relating to each theme occur. The scale is qualitatively applied based on descriptions of interventions within the literature.

social inclusion and enabling sustainable economic and cultural opportunities.

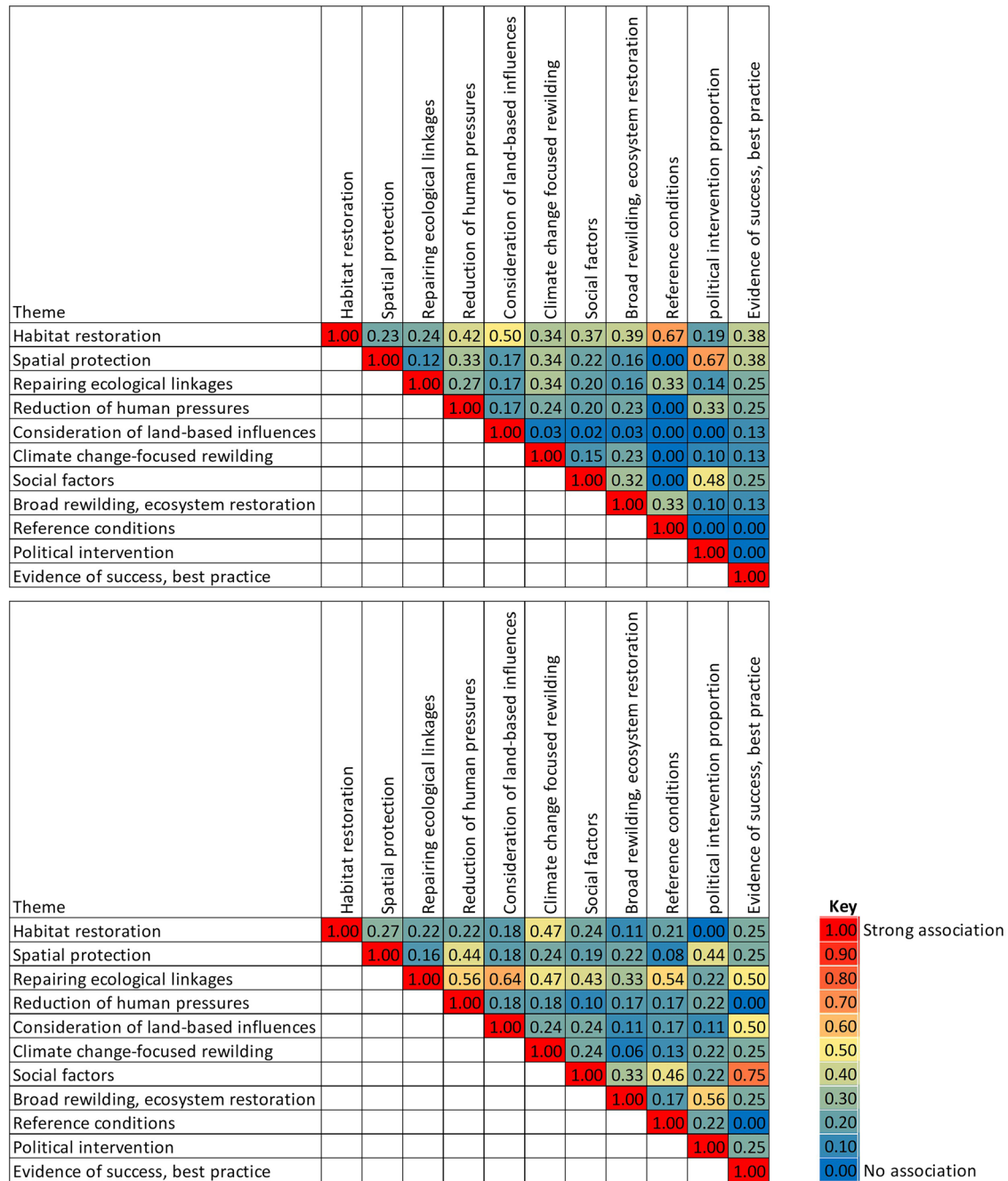
### Discussion

Definitions of marine rewilding in the primary and grey literatures are limited. Table 1 provides examples of the definitions in our data set that explicitly attempt to define marine rewilding<sup>30,36,47</sup>, along with examples of more general (non-marine-specific) definitions<sup>9,40,48</sup>. These definitions were chosen because they are posited based on wider literature reviews and/or extensive expert input. However, most references in the dataset that included a definition of rewilding largely did so based on terrestrial experiences and applied the principles to marine environments.

While our own definition of marine rewilding is broad, the range of views on the topic reflects the importance of it, the level of interest it has engendered, and the tensions that can emerge between people pursuing different values (what matters to people in the context of action) though rewilding initiatives. Explorations of a diversity of definitions raises the question of why we should seek to define marine rewilding at all. It could be argued that the different ways people perceive marine rewilding are valid in their own contexts, and boundary critique (understanding people’s assumptions about what matters to them and what is included in or

excluded from their framing) is valuable to ensure that the range of views is properly considered. However, from a scientific perspective, allowing definitions of marine rewilding to diversify too much risks rendering the term meaningless for application across interventions<sup>49</sup>. Informing future developments in marine rewilding requires the development of a justifiable definition that others can then engage with.

From our analysis of the themes in the data set, we concluded that there are core similarities and differences between marine and terrestrial rewilding. The wording of our definition reflects these similarities, and challenges some of the established views about rewilding (as expressed in Table 1), such as differences in the implementation and scale of marine rewilding in comparison to terrestrial rewilding. The 11 themes and examples of marine rewilding initiatives included in the results (see Fig. 1) align more specifically than our definition with some of the early principles of rewilding<sup>8</sup> and the more recent 10 principles for rewilding put forward by Carver et al.<sup>9</sup>. The key similarities include the need for core reserves (spatial protection) and keystone species (repairing ecological linkages). However, the framing of our definition places greater emphasis on non-ecological aspects, such as social values, and reflects the potential for the rewilding process to result in an alternative ecological state instead of turning back time to an original state. We break down the key aspects of our definition of



**Fig. 3 | Matrices showing which of 11 marine rewilding themes occur together most frequently as a proportion in the grey literature (n = 125) and primary literature articles (n = 65). The themes that were coded in articles together more**

frequently (strong associations) are represented by the red and orange colours. The blue colours denote a weaker associations (themes are less frequently coded in articles together).

marine rewilding and elaborate on these differences and challenges to other definitions in the following discussion.

Many of the texts we reviewed refer to passive rewilding in relation to approaches that leave areas of land or sea to regenerate naturally, without human interference (e.g. see refs. 41,50). We suggest that the term passive rewilding may be misleading. Passive rewilding still requires active intervention to ensure human activity is eliminated or minimised so a rewilded environment can be enabled or maintained<sup>51,52</sup>. This is a view of intervention that is consistent with systems thinking, and we note that all the marine rewilding texts reviewed describe at least one human intervention to initiate and (in many cases) to maintain the marine rewilding process, even when the authors explicitly state that it is passive<sup>53</sup>. Given that few areas of the world’s ocean are considered untouched by human activities<sup>54</sup>, we argue that

interventions referred to as passive rewilding still require active change or adaptation, and these changes must be accounted for as part of the process<sup>9</sup>. While the need for active intervention is true of rewilding in other environments (e.g. on land), the more dynamic and less predictable nature of the marine environment will likely require greater elements of iterative and adaptive management, as discussed in the next section.

Marine rewilding interventions are also intentional in their goals, with actions designed to deliver marine rewilding outcomes. Clover (2022)<sup>47</sup>, which was the most frequently duplicated hit in our review of the grey literature, cites the return of bluefin tuna to UK waters as an example of successful marine rewilding. However, this case can be debated. While increasing populations of a depleted species is a positive ecological development, the results of this review suggest it is important to distinguish

**Table 1 | A selection of definitions of rewilding from the primary literature, some of which are non-marine specific and others specifically reference marine rewilding**

Type	Source	Definition of rewilding
General	Carver et al. <sup>9</sup>	“The process of rebuilding, following major human disturbance, a natural ecosystem by restoring natural processes and the complete or near complete food web at all trophic levels as a self-sustaining and resilient ecosystem with biota that would have been present had the disturbance not occurred...” “That is, they require no or minimal management (i.e., ...nature doing what nature does)...it is recognized that ecosystems are dynamic.” “...Restoration of functioning native ecosystems containing the full range of species at all trophic levels while reducing human control and pressures.”
General	Pettorelli et al. <sup>48</sup>	“The reorganisation of biota and ecosystem processes to set an identified social–ecological system on a preferred trajectory, leading to the self-sustaining provision of ecosystem services with minimal ongoing management.”
General	Perino et al. <sup>40</sup>	“Restore self-sustaining and complex ecosystems, with interlinked ecological processes that promote and support one another while minimizing or gradually reducing human interventions.”
Marine	van Katwijk et al. <sup>30</sup>	“...A type of restoration that aims at self-sustainability, thereby reinstating natural dynamic processes in coastal zones.”
General/ marine	Schmitz et al. <sup>36</sup>	“...Protecting and restoring the ability of animal species to reach ecologically meaningful densities so that as they move and interact with each other they can fulfil their functional roles across landscapes and seascapes.”
Marine	Clover C <sup>47</sup>	“...To bring back lost and depleted species to our oceans and restore ecosystems that have been harmed by human activities – simply by stepping back and letting nature repair the damage, or by reintroducing species or restoring habitats.”

between deliberate rewilding efforts and population recovery due to other reasons. Rewilding often involves deliberate interventions such as habitat restoration, species recovery or management changes, but the underlying rationale of the bluefin tuna example is different as it seeks to address a gap in ecological function without necessarily achieving a previous or explicitly different ecological state. Additionally, Clover mentions the potential resumption of commercial bluefin tuna fishing in the UK, which raises concerns about long-term sustainability. Rewilding processes aim for long-term population health and ecosystem resilience, not short-term exploitation.

Analysis of the primary and grey literatures reveals a strong consensus that marine rewilding is not a singular event but rather an ongoing dynamic process<sup>9,40</sup>. This is evident in several key aspects:

- Continuous knowledge acquisition is highlighted by references to the “ongoing accumulation of scientific evidence”<sup>9</sup>, the evolving understanding of marine ecosystems and the need for continual learning to inform rewilding strategies.
- Active management, typified by the prevalent use of active verbs like “pulling back,” “restoring,” and “rehabilitating”<sup>55,56</sup>, suggests the necessity for ongoing interventions to address existing ecological damage and promote recovery.
- Recognition of the ever-changing human influence on marine environments is underscored by references to “ongoing loss” of biodiversity<sup>56,56</sup> and the dynamic nature of reference conditions<sup>44</sup>. This necessitates flexible baselines that acknowledge past human impact while seeking to implement interventions for a more sustainable future.

We find that this is true of rewilding generally, as highlighted in Carver et al.’s<sup>9</sup> rewilding principles 3 and 4, in which environmental variability and the dynamic nature of ecosystems are factored into interventions. However, we suggest that, in a marine context, the nature of oceanic ecosystems and processes require fundamentally different approaches to enable rewilding. The greater paucity of marine baseline data in comparison to terrestrial environments, the dynamic connectivity of the ocean<sup>21,39</sup> and the different ownership rights of land in contrast to the foreshore and seabed (except for First Nations and Customary Rights in some countries<sup>37,58</sup>) restrict physical separation of areas or private administration of marine rewilding. However, this will be different where land-based interventions deliver marine rewilding benefits, as described in the following paragraph.

Our synthesis suggests marine rewilding necessitates a systemic approach that recognises the complex interplay between marine ecosystems and socio-economic structures, and goes beyond isolated interventions to embrace integrated, adaptive strategies. This kind of approach aligns with concepts such as relational ecosystem-based management, and

it emphasises the importance of the human-nature relationship<sup>59</sup>. Consideration of the interconnectedness of marine and terrestrial systems and the limitations of more traditional spatially-defined conservation tools is important for successful marine rewilding. Prevalent themes in the literature that underpin the systemic approach include consideration of land-based influences, social factors and political intervention. Several articles describe management of land and islands as parts of efforts to achieve rewilding in the ocean. Examples of terrestrial interventions needed to rewild marine environments include eradicating invasive rats from islands to recover breeding seabird populations, improve nutrient cycling and support healthier coral reefs<sup>60–62</sup>; removing litter from beaches<sup>63</sup>; and managing the impacts of trampling by large herbivores in coastal marshes<sup>64</sup>.

Social factors linked to marine rewilding encompass a range of considerations across many levels (Fig. 1), including education about reducing human impacts on the marine environment<sup>65</sup> and the health benefits of more biodiverse ecosystems<sup>66</sup>. It may therefore be beneficial for marine rewilding initiatives to consider aspects beyond nature conservation by forging connections with social support systems, educational programmes and healthcare initiatives.

Many of the reviewed articles highlighted marine protected areas (MPAs) as a tool for marine rewilding. While there is a growing body of evidence demonstrating localised benefits to marine biodiversity and livelihoods (e.g. refs. 65,67), MPAs and other spatial measures face limitations due to the ocean’s lack of clear physical boundaries and the interconnectedness of land and sea. Overcoming these challenges is dependent on effective policymaking and political cooperation, such as for the conservation and sustainable use of Marine Biological Diversity of areas beyond National Jurisdiction (through the BBNJ Agreement)<sup>43</sup>. If societal values, policy frameworks, and ecological realities are misaligned, progress can be hindered. When such gaps exist, marine rewilding initiatives may encounter slow progress or stakeholder rejection<sup>68,69</sup>, which underscores the critical importance of a systemic and inclusive approach.

Previous definitions of rewilding focus on ecological restoration, and they treat social, economic and cultural ecosystem services as co-benefits<sup>70</sup>. However, more recent research says that social and economic considerations are more than co-benefits: they are integral to rewilding and are key drivers for its implementation and outcomes<sup>40,71</sup>. There is a particular emphasis in some parts of the world on integrating indigenous peoples’ practices and cultures in rewilding initiatives<sup>51</sup>. Social factors relating to marine rewilding interventions are the third most frequent of the themes identified in our data set. Numerous examples state that social involvement and/or acceptance is essential in marine rewilding and should be included in the scope of any intervention<sup>72,73</sup>. When enabling ecological recovery in an area requires that human activities must change or cease, there are both

social and economic impacts to one or more parties<sup>74</sup>. There is also a strong cultural association, as rewilding stems from recognition of historical human interactions within the environment, such as indigenous practices and traditional ecological knowledge (TEK)<sup>9</sup>. The effects of these interactions may be interpreted differently by different stakeholders, resulting in tensions or conflicts. In rewilding, the values of stakeholders must be considered<sup>72</sup>, which reflect the diverse ways people relate to and benefit from nature, influencing perspectives that shape decision-making and societal norms critical for addressing the biodiversity crisis and achieving sustainability<sup>75,76</sup>. This aligns with Carver et al.'s<sup>9</sup> rewilding principles 6 and 7, which outline the need for local stakeholder involvement and inclusion of TEK, but this is not explicitly included in the definition of rewilding provided in their text (see Table 1). Social factors are arguably so critical to successful rewilding that it should be recognised in how it is defined, particularly as rewilding seeks to integrate the needs, rights and practices of indigenous peoples and focus on a socio-ecological state of genuine co-existence between nature and people<sup>9,26,51</sup>.

The role of humans in a rewilded marine system is intertwined with the baseline and goals for the rewilding initiatives undertaken to achieve it. Establishing a baseline for marine rewilding efforts presents a considerable challenge. One article in our review suggests that species reintroductions can be done once the existing habitat is not going to be impacted by humans any longer<sup>77</sup>. However, most articles support outcomes in which people and nature coexist sustainably, without any reference to a 'pristine' state of nature excluding humans. Unlike terrestrial ecosystems, where pristine states might be achievable in some cases, the concept of a pre-anthropogenic marine environment is largely unrealistic. A growing body of research (e.g. ref. 78) highlights human interaction with marine ecosystems has occurred for millennia, predating even the industrial revolution, which is often used as a reference point. With a continually rising global human population and increasing demands on ocean resources, aiming to replicate a pre-industrial ocean state is simply not feasible<sup>79</sup>. Furthermore, while a core tenet of marine rewilding is the gradual reduction of human management as ecosystems regain self-sustaining levels, ongoing support might be necessary to maintain the restored habitats and species populations in the face of changing environmental conditions and human geographies.

Definitions of terrestrial rewilding often emphasise large-scale actions. We found this to be a key distinction between marine rewilding and Carver et al.'s (2021) rewilding principle 2, which focuses on landscape-scale planning<sup>9</sup>. We have not included scale in our definition of marine rewilding as there are a wide range of views in the reviewed literature as to what scale of intervention is considered appropriate, and (in our view) there are no compelling reasons to focus on just one. Marine habitat restoration projects, such as coral reef, mangrove and seagrass restoration, are widely cited as rewilding initiatives, and were the most frequently coded theme in our data set. There were articles claiming that such projects are not large-scale enough to be considered rewilding<sup>80</sup>. However, other articles propose that projects planting >100,000 shoots of seagrass can reasonably be described as large-scale restoration<sup>81</sup>, which is the scale at which many current seagrass restoration projects are operating<sup>82</sup>. Parameters of scale may therefore be relative to the marine rewilding project being studied, and a universal specification of a correct scale cannot be proposed without it appearing arbitrary and unnecessary.

The results of our analysis of the literature show a wide and varied range of views about what marine rewilding is and what initiatives can be considered as valid approaches to its implementation (see Fig. 1). Many of the publications that describe a marine rewilding approach highlight the underpinning reasons for action – largely for addressing climate change impacts or biodiversity loss, enhancing ecosystem service benefits, or to fill a specific ecological gap. Ten specific habitats are linked to marine rewilding in our review, with seagrass and kelp forest restoration being the most frequently cited examples. Habitat restoration examples in the literature are linked to aspirational benefits, including increasing carbon sequestration, increasing available habitat for other marine and coastal species, and

providing improved economic opportunities, such as for tourism<sup>83</sup> and fishing<sup>84</sup>. The act of valuing a rewilded state implicitly acknowledges that the current state of the marine environment is degraded or compromised by human impacts. By restoring or changing degraded ecosystems and promoting a return of marine biodiversity, rewilding efforts represent a vision of a healthier ocean. This is clearly a common theme across a diversity of definitions and approaches.

Different stakeholders' values in relation to nature, particularly relational values that inspire action, will prioritise one state over another<sup>85</sup>, yet the reason why one state is seen as better than another in a particular context is rarely made explicit in the literature, except in general terms. One example of where detail is provided is Lake Markermeer in the Netherlands, a freshwater lake that was formed by closing an estuary for flood protection. The Dutch nature conservation authorities took a rewilding approach to enhancing the ecological productivity, while maintaining existing ecosystem services rather than transforming the lake back to its original marine state<sup>86</sup>. This approach was considered to have greater instrumental value than returning the area to its former state, partly because the reference conditions were too altered to reverse. Maintenance of key socio-economic functions of the lake's current state, including flood protection and aquatic recreation, were said to be the most important concerns that needed to be accounted for in decision-making. This is the level of justification it is reasonable to expect in relation to the value judgements used when saying one habitat or ecosystem condition is preferable to another. Being explicit about purposes and values, and justifying choices between them, is fundamental to systems thinking<sup>32,87–91</sup> and achieving the goals of an intervention. To develop a more systemic approach to marine rewilding, it is essential first to frame the problem accurately and clarify what specific environmental challenge an intervention seeks to tackle, addressing questions such as, what interventions are necessary and appropriate, and whose perspectives and values are involved? Clear framing of environmental problems ensures alignment between the underlying causes of the issue and the systemic solutions proposed<sup>92</sup>.

## Conclusions

Marine rewilding as a concept is not well developed. Our systematic review highlights diverse outlooks on both marine rewilding as a discipline and how it is applied. We therefore propose a broad definition with principles that can be imbued with local meanings when applied to specific circumstances or locales. Our recommendations for marine rewilding interventions are summarised as follows:

- Focus on process: marine rewilding is an ongoing collaborative process that requires continuous learning, active management and adaptation to changing circumstances.
- Think systemically: marine rewilding needs to consider the complex relationships between the marine environment, social structures and economic factors. Practitioners also need to look beyond isolated interventions and consider a bigger picture (while recognising that there is no possibility of a fully comprehensive understanding, so value and boundary judgements are inevitable)<sup>32,93</sup>.
- Prioritise social and cultural considerations: involve stakeholders and indigenous peoples (when locally relevant) in the co-design and implementation of marine rewilding initiatives, and evaluate the social and cultural impacts.
- Embrace a flexible baseline: recognise that a pristine, pre-human marine environment is likely not achievable. Set baselines that aim for a more sustainable future despite the increasing influence of humans.
- Scale is relative: there is no one-size-fits-all approach to scale in marine rewilding. Interventions should determine the appropriate scale based on the specific goals and project type.
- Define the core values and goals of the marine rewilding intervention, including those of indigenous peoples, being clear about the purpose, motivation and vision of the people involved for the restored ecosystem<sup>92</sup>.

Rewilding is a powerful and progressive concept, prompting a rethink of traditional conservation management. Marine rewilding is less advanced in its definition, but there are a growing number of ocean initiatives that fall under this broad approach. The definition and principles outlined here contribute to promoting the acceptance of marine rewilding in established conservation policy and practice and can inform future initiatives.

### Methods

We conducted an anonymous stakeholder consultation exercise between 10<sup>th</sup> February 2023 and 6<sup>th</sup> March 2023 via the Jisc Online Survey platform. Informed consent was provided by participants prior to completing the survey. The consultation was initially circulated to approximately 40 UK-based individuals and organisations known to the researchers, who were directly involved or had an interest in marine conservation and rewilding, with a total estimated reach of over 100 individuals (because many of the first 40 contacts shared the survey with their wider networks to recruit more respondents). This is commonly called snowball sampling, and its use in surveys has been attributed to Coleman (1958-1959)<sup>94</sup> and Goodman (1961)<sup>95</sup>. As the online consultation was anonymous, we could not identify which responses came from direct approaches and which came through snowballing. Ethics approval for the survey was granted by the University of Hull (FEC\_2023\_36).

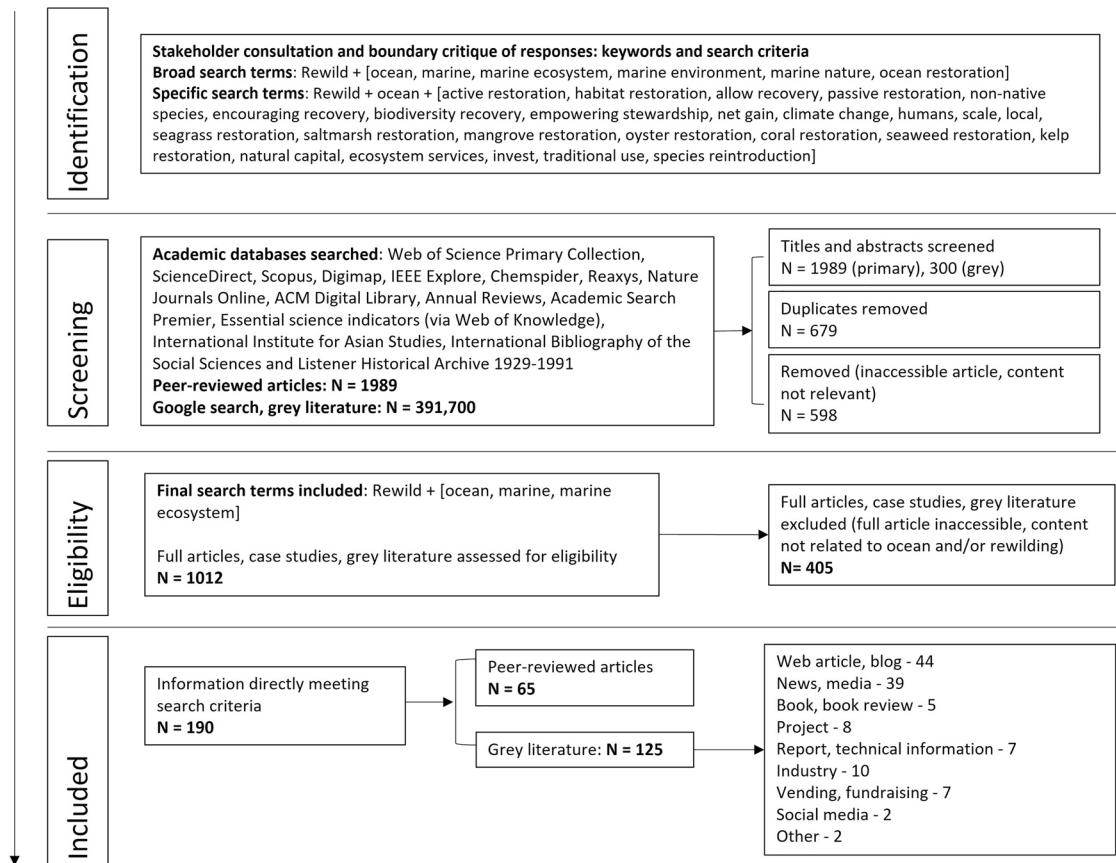
The consultation asked participants to reply to a series of short-answer questions about their understanding of marine rewilding and to state whether they agreed or disagreed with 23 statements describing environmental, social and economic considerations of nature conservation as applied to marine rewilding. The full design of the survey is provided in Supplementary Table 2. The responses to the consultation were compiled by the lead researcher. The research team reviewed the

responses collectively, discussed common and diverging positions and iteratively formulated the boundaries of the systematic review. As we reviewed the responses, we considered questions from the methodology of boundary critique<sup>96</sup>, such as:

- What factors are being included or excluded?
- What factors are being marginalised?
- What are the key values and purposes of the respondents?
- What are the potential areas of conflict?

We also used the methodology of boundary critique for our analysis of the consultation responses to decide on the systematic review search terms. In systems thinking, boundary critique identifies underlying assumptions and values in stakeholder definition and problem-solving, revealing new avenues for understanding<sup>96</sup>. Boundary critique acknowledges that choices about what to include or exclude in the framing of a definition reflects people’s values (defined as what matters to people in a context of action)<sup>32,97</sup>, and the methodology encourages consideration of diverse perspectives when defining boundaries. While commonly used in action research<sup>98,99</sup>, boundary critique is also applicable to literature reviews, demanding explicit justification for inclusion or exclusion of information sources<sup>100</sup>. This aligns with the theory’s focus on explicating potentially relevant normative positions, aiding analysis of contested concepts by looking at multiple, value-based perspectives.

A total of 19 responses to the consultation were received, from which we identified an initial set of 31 search criteria for a systematic review of the primary and grey literatures on marine rewilding (Fig. 4). We defined ‘marine’ as including oceanic, shallow seas and transitional (coastal, intertidal) areas that are influenced by seawater, as these were all areas referenced by respondents.



**Fig. 4 | Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA)<sup>100</sup> flow diagram to show primary and grey literature articles included and excluded in the systematic review on marine rewilding.** The review was an iterative process, starting with the identification of search terms, screening of

literature based on the search terms, assessment of article eligibility (the content of each article needed to contain direct and relevant reference to the search terms), and it was concluded once a final list of eligible articles had been generated for analysis.



A systematic review of the peer-reviewed and grey literature on marine rewilding was then conducted, which followed the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) Statement<sup>101</sup>. Data for the review was collected between March and August 2023.

The academic databases used to search for primary and grey literature articles are listed in Fig. 4. An advanced Google search was also used to search for grey literature. The Google advanced search was applied to:

- “Find pages with...” all these words: [search terms]
- “Then narrow your results by...” language: English; region: any region; late update: anytime; terms appearing: anywhere on the page; file type: any format; usage rights: not filtered by licence.

Any Google results listed as sponsored were excluded to reduce potential bias of the search caused by paid advertising. A broad approach to the grey literature was taken to be inclusive of a wide range of contributions, including from civil society grassroots groups and industry leaders in marine rewilding initiatives. The grey literature included material published online, such as blogs, opinion pieces, project briefs and mission statements, in addition to more traditional grey literature material, such as technical reports, white papers, guidelines and policy documents. Duplicates were removed at the screening stage, including any articles relating to the book *Rewilding the sea: how to save our oceans* by Charles Clover<sup>47</sup> (after the first hit) and any press releases related to the book published in multiple news outlets. The first 100 Google hits for each search term were screened. To quality assure the review data, a random sub-sample of 10% of eligible articles was independently reviewed by one of the co-authors of this study.

During the screening stage of the literature review, the decision was taken to proceed with three search terms: “rewild\* + ocean”, “rewild\* + marine” and “rewild\* + marine + ecosystem\*” (the truncation operator \* was used to factor in variants of a term, such as “rewild”, “rewilded”, “rewilding”). No unique peer reviewed papers were identified beyond these three search terms, and theme saturation was considered to have been reached within the “rewild\* + ocean” articles. This decision was consistent with boundary critique methodology, which is iterative and is open to change in response to the data<sup>102</sup>.

A total of 65 unique primary (peer-reviewed) articles and 125 pieces of grey literature were identified that directly corresponded to the final three search terms (Fig. 1). Most of the peer-review studies included in the review were qualitative or discursive in nature. An initial database of information sources was compiled based on the search criteria and screened for relevance, as per the flow diagram (Fig. 2).

Text relevant to the search terms from the final set of included articles was extracted. An inductive, iterative thematic analysis<sup>33</sup> was used to identify recurring themes in the data. All articles were then read in full, and an iterative list of 11 themes was finalised as a synthesis of marine rewilding interventions mentioned in the reviewed literature. Each article was re-examined and coded by the theme(s) identified. To quality assure (QA) the themes, a random sub-set of 10% of the coded articles was reviewed by one of the co-authors of this study. The QA of the themes was broadly in agreement with the original coding of the data, but some minor adjustments were made based on the QA feedback. Marine rewilding references that describe habitat restoration were categorised separately to species reintroduction. Despite most of the examples cited perhaps being more accurately described as habitat-forming species (such as oysters and seagrass), the purpose of these restoration projects was to achieve it at a habitat scale. The proposed definition of marine rewilding was developed iteratively as the articles were reviewed, with key ideas explored and discussed by the research team.

To explore the relationships between the themes, the proportion was calculated for each theme, using the frequency each occurs with each of the other themes within an article and the total frequency of each theme. This is represented in the following equation, where *theme n* represents the number of occurrences of a theme and *Max (all themes)* is the highest number of

co-occurrences that theme *n* has with any of the other themes.

$$Proportion = \left( \frac{theme\ 'n'}{Max(all\ themes)} \right)$$

The proportions were calculated in Microsoft Excel, and the formula used was: =n/(MAX(range)), where ‘n’ is the number of occurrences of a theme. The scale of each theme was also broadly categorised based on the scale at which associated rewilding interventions described in the literature took place or on which there was a suggested effect. These were local or project scale, such as habitat restoration; county or national scale, such as repairing ecological linkages (ecosystem level); and regional or international scale, such as political intervention (which included international cooperation for interventions, such as the High Seas Treaty).

### Reporting summary

Further information on the research design is available in the Nature Portfolio Reporting Summary linked to this article.

### Data availability

The data from the anonymous stakeholder survey and the full data *corpus* and data set used in the systematic review are available here: <https://doi.org/10.6084/m9.figshare.28067465.v2> The majority of articles used in the systematic review are publicly available online. Where possible, the authors have archived articles not publicly available for reference in relation to this study, but have not made these available to protect copyright. The data for Fig. 1 are presented in Supplementary Table 1.

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### Author contributions

Esther E. Brooker (lead author) led on conceptualisation, methodology and data collection, analysis, discussion, original draft manuscript, and manuscript review and revisions. Gerald Midgley contributed to conceptualisation, methodology, analysis (boundary critique), manuscript review and revisions, and supervision. Neil Burns contributed to methodology, analysis, discussion, manuscript review and revisions, and supervision. Charlotte E. Trotman contributed to analysis (quality assurance of the data set and coding), discussion and manuscript review and revisions. Amanda Gregory contributed to analysis (boundary critique) and manuscript review. Charlotte Rachael Hopkins (senior author) contributed to conceptualisation, methodology, analysis, discussion, original draft manuscript, manuscript review and revisions, and supervision.

### Competing interests

The authors declare no competing interests.

### Additional information

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**Correspondence** and requests for materials should be addressed to Esther E. Brooker.

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