ARTICLE IN PRESS

Marine Policy xxx (xxxx) xxx

Contents lists available at ScienceDirect

Marine Policy

journal homepage: http://www.elsevier.com/locate/marpol

Emerging themes to support ambitious UK marine biodiversity conservation

Siân E. Rees [a,*], Emma V. Sheehan [a], Bryce D. Stewart [b], Robert Clark [c], Thomas Appleby [d], Martin J. Attrill [a], Peter J.S. Jones [e], David Johnson [f], Natasha Bradshaw [d], Simon Pittman [a,g], Jenny Oates [h], Jean-Luc Solandt [i]

[a] *School of Biological and Marine Science, University of Plymouth, Drake Circus, Plymouth, PL4 8AA, UK*
[b] *Department of Environment and Geography, Wentworth Way, University of York, Heslington, York, YO10 5NG, UK*
[c] *Institute of Fisheries Management, PO Box 679, Hull, HU5 9AX, UK*
[d] *University of the West of England, Frenchay Campus, Coldharbour Lane, Bristol, BS16 1QY, UK*
[e] *Department of Geography, University College London, Gower Street, London, WC1E 6BT, UK*
[f] *Global Ocean Biodiversity Initiative, Seascape Consultants, Romsey, SO51 0QA, UK*
[g] *Seascape Analytics Ltd, Devonport, Plymouth, PL2 1RP, UK*
[h] *WWF-UK. The Living Planet Centre, Rufford House, Brewery Road, Woking, Surrey, GU21 4LL, UK*
[i] *Marine Conservation Society, Overross House, Ross Park, Ross-on-Wye, Herefordshire, HR9 7US, UK*

A R T I C L E I N F O

Keywords:
Ecosystem services
Natural capital
MPAs
Convention on Biological Diversity
Monitoring
Whole-site
Ecosystem based fisheries management
OECM
Marine spatial planning

A B S T R A C T

Healthy marine ecosystems provide a wide range of resources and services that support life on Earth and contribute to human wellbeing. Marine Protected Areas (MPAs) are accepted as an important tool for the restoration and maintenance of marine ecosystem structure, function, health and ecosystem integrity through the conservation of significant species, habitats, or entire ecosystems. In recent years there has been a rapid expansion in the area of ocean designated as an MPA. Despite this progress in spatial protection targets and the progressive knowledge of the essential interdependence between the human and the ocean system, marine biodiversity continues to decline, placing in jeopardy the range of ecosystem services benefits humans rely on. There is a need to address this shortcoming. Ambitious marine conservation:

- Requires a shift from managing individual marine features within MPAs to whole-sites to enable repair and renewal of marine systems;
- Reflects an ambition for sustainable livelihoods by fully integrating fisheries management with conservation (Ecosystem Based Fisheries Management) as the two are critically interdependent;
- Establishes a world class and cost effective ecological and socio-economic monitoring and evaluation framework that includes the use of controls and sentinel sites to improve sustainability in marine management; and
- Challenges policy makers and practitioners to be progressive by integrating MPAs into the wider seascape as critical functional components rather than a competing interest and move beyond MPAs as the only tool to underpin the benefits derived from marine ecosystems by identifying other effective area-based conservation measures (OECMs) to establish synergies with wider governance frameworks.

1. Introduction

Marine ecosystems provide a wide range of resources and services that contribute to the survival of life on Earth and human well-being [1]. The ability of marine ecosystems to provide services for human well-being depends on the health and functionality of their physical and biological components, but multiple and pervasive human activities scale-up to adversely impact these marine ecosystems at both local and global scales [2,3]. Research shows that marine ecosystem degradation, the loss of marine species and population declines are impairing the quality and quantity of ecosystem services with potential negative consequences for human health and well-being [4–9]. To address marine

* Corresponding author. University of Plymouth, Drake Circus, Plymouth, PL4 8AA, UK.
E-mail address: sian.rees@plymouth.ac.uk (S.E. Rees).

https://doi.org/10.1016/j.marpol.2020.103864
Received 11 March 2019; Received in revised form 31 January 2020; Accepted 4 February 2020
0308-597X/© 2020 Published by Elsevier Ltd.

ecosystem decline caused by unsustainable human practices, national and global policy has developed goals and targets to protect and safeguard the oceans by implementing a range of sustainable management measures, including increasing the proportion of the ocean under protection [10–13].

Marine Protected Areas (MPAs) are accepted as an important tool for the restoration and maintenance of marine ecosystem structure, function, health, and ecosystem integrity through the conservation of significant species, habitats, or entire ecosystems [14–16]. The evidence and best-practice underpinning application of science for effective MPAs is now well established and globally there has been rapid increase in the proportion of the ocean with MPA status [17,18]. Several researchers have argued that the Convention on Biological Diversity (CBD) spatial area target of 10% of marine areas to designated as MPAs, is too low to achieve the objective of protecting biodiversity, underpinning ecosystem services and meeting socio-economic priorities [19]. It is also recognised that:

- no take marine reserves are the most effective mechanism to restore and preserve biodiversity [16];
- that area-based targets alone (which confer no positive or negative biodiversity outcomes) are an ineffective tool to stem the degradation and loss of marine habitats and species [20,21] and;
- that mechanisms in place to achieve the qualitative elements of Aichi Target 11 are not currently on track for 2020 [22].

Within the international policy arena, ambitious marine conservation links the social-ecological system and includes calls for accelerated progress towards achieving Aichi Target 11 [23,24]. The International Union for the Conservation of Nature (IUCN), amongst others has urged Parties to the CBD to develop post 2020 targets to achieve spatial management measures via MPAs for 30% of marine areas [23].

2. The United Kingdom (UK) policy window

The UK is committed to a number of international and regional agreements, which link environmental protection with sustainable use. For example the European Union (EU) Common Fisheries Policy, the EU Marine Strategy Framework Directive and the EU Water Framework Directive. Specific to MPAs is the requirement to establish ecologically coherent and well-managed MPA networks [25–30]. There has been a great deal of progress relating to MPAs in domestic and Overseas Territory UK waters since the Wildlife and Countryside Act (1981) [31–34]. Initial development of a small suite of locally advocated Marine Nature Reserves that resulted in three sites by the mid-1990s has now reached 314 MPAs that cover 24% of the coasts and seas of domestic UK waters [35]. Despite this rapid expansion in the spatial extent of MPAs, in UK waters, there is a much more limited area of UK seas that have management measures to physically protect habitats from all forms of bottom towed fishing gear [36]. Regarding UK Overseas Territories, there is a Government commitment to create 4million km^2 of UKOTs waters as MPA (A Blue Belt) [37].

Currently, the delivery of MPA policy in the UK is to protect individual features within the boundaries of sites. The legislation used to protect and/or recover biodiversity is also feature based (e.g. the Habitats Directive throughout the European Union (EU), and Marine and Coastal Access Act in England and Wales). Conservation Advice is used by regulators when considering management of activities or in the licensing of development (also known as plans or projects), and applied to features (habitats and species) in MPAs. It has been argued that the feature based approach for marine conservation has not supported the recovery of marine biodiversity [38]. In addition, the UK MPA network as a whole does not meet the criteria defined for ecological coherence potentially leading to dysfunction in the flow of ecosystem services with potentially negative consequences for human well-being [24].

In 2011, the UK Government published the Natural Environment White Paper. Commitments have been made to a net gain policy for environment and biodiversity through supporting healthy, well-functioning ecosystems and ecologically coherent protected area networks [39]. More recently, in 2016, a policy window has opened in response to the UK's departure from the EU. Whilst there are diverging views on the positives and negatives of the UK's departure from the EU for marine biodiversity protection [40,133], the bottom line is that the UK's departure from the EU has not just the potential to change, in midstream, the direction of travel of much UK legislation that underpins the conservation of marine ecosystems, but is also set to replace an established constitutional framework around UK marine environmental law, with a devolved system of governance, which may result in differing cross-border strategic objectives for conservation [41]. This large-scale legal and regulatory change resulting from the potential EU departure has been met with a raft of policy reform including the release of the Government's A Green Future: Our 25 Year Plan to Improve the Environment (25YEP) [37], the advent of a new UK Marine Strategy [42], a Fisheries Bill, and an Environment Bill which was introduced to UK parliament in January 2020. The general ambition of the expected legislation is noted as 'the improvement and restoration of the environment and better outcomes for fish stocks, ecosystem health, livelihoods, human health and wellbeing'.

This paper offers a concise synthesis of four emergent themes in MPA science relevant for policy makers to address the challenge of protecting biodiversity, underpinning ecosystem services and meeting socio-economic priorities. The emerging themes by no means represent an exhaustive list of solutions but rather represent emerging perspectives from the authors who work on the front line of applied MPA research and practice in the UK (Fig. 1). We aim to inform future policy direction in both the UK and internationally to support an improved framework for marine biodiversity protection that enables sustainable development and underpins human well-being.

3. Emergent themes

3.1. The whole-site approach to MPA management

The whole-site approach is stated as an ambition in the Governments 25 YEP [37]. The whole-site approach for marine systems is not currently defined, though there is recognition that there needs to be a shift in policy focus from a fragmented approach that focusses on the management of features towards social-ecological systems management and resilience where 'the whole is more than the sum of its parts and has emergent properties which are a consequence of the dynamic interaction of its components though time' [42].

The whole-site approach for marine systems may be defined initially through capturing the essence of ecological integrity. Ulanowicz [43] interprets ecological integrity as the maintenance of system health, resilience to withstand stress and a capacity for adaption. Parrish et al. [44] go further and define ecological integrity as being met when the dominant ecological characteristics (composition, structure, function and ecological processes) of the system, ' … occur within their natural range of variation and can withstand and recover from most perturbations imposed by natural environmental dynamics or human disruptions'.

Within the EU Habitat's Directive and the Marine Strategy Framework Directive (MSFD) the notion of managing complex systems through an holistic functional approach is linked to definitions of integrity. Within the EU Habitats Directive, site integrity is defined as, 'the coherence of the site's ecological structure and function, across its whole area, or the habitats, complex of habitats and/or populations of species for which the site is or will be classified' [45]. A site can be described as having a high degree of integrity where the inherent potential for meeting site conservation objectives is realised, the capacity for self-repair and self-renewal under dynamic conditions is maintained, and a minimum of external management support is required [45,46].

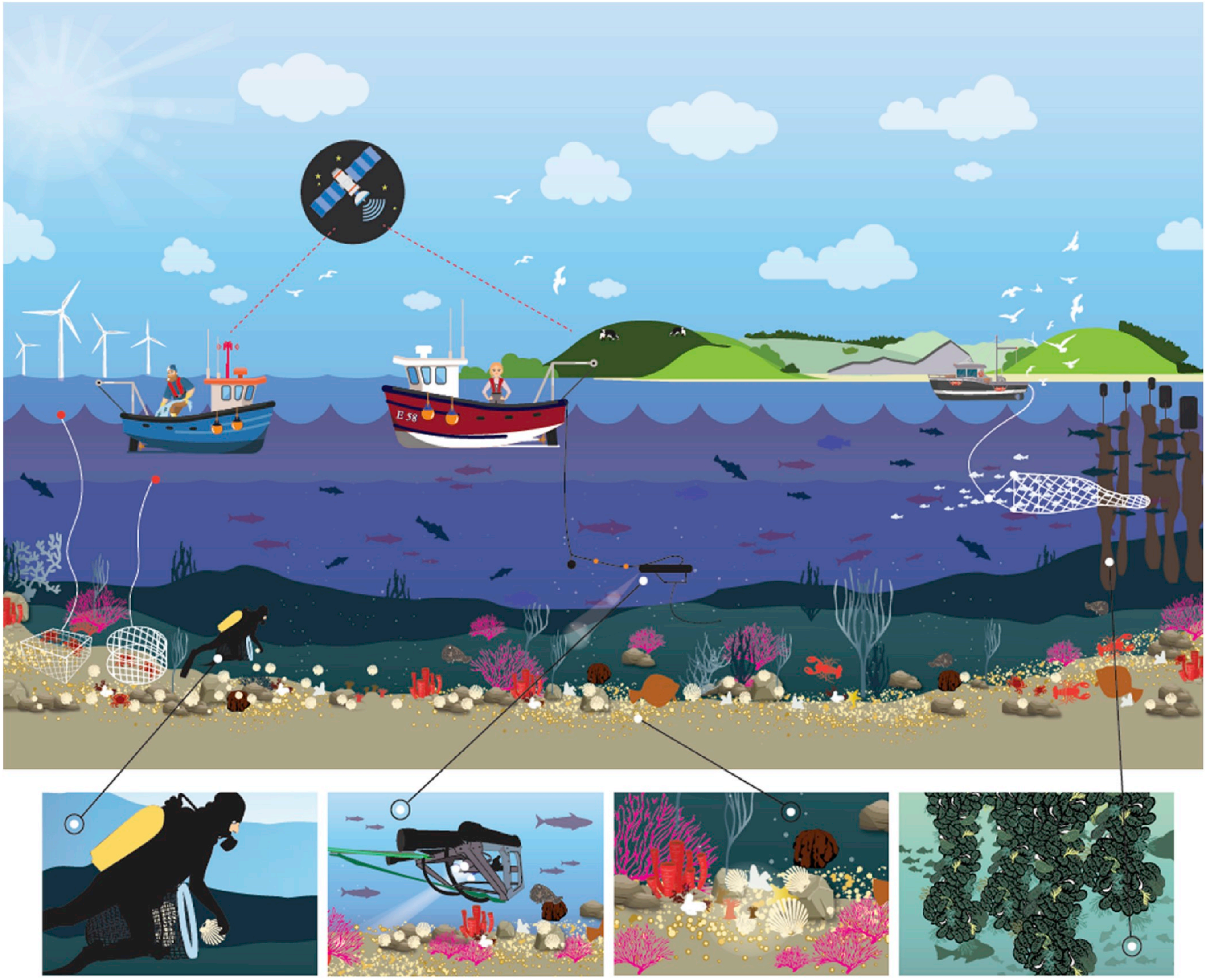

Fig. 1. Ambitious marine conservation 1) Reflects an ambition for sustainable livelihoods by fully integrating fisheries management with conservation (Ecosystem Based Fisheries Management) as the two are critically interdependent; 2) Establishes a world class and cost effective ecological and socio-economic monitoring and evaluation framework that includes the use of controls and Sentinel Sites to improve sustainability in marine management; 3) Requires a shift from managing individual marine features within MPAs to whole-sites to enable repair and renewal of marine systems; and 4) Challenges policy makers and practitioners to integrate MPAs into the wider seascape as critical functional components rather than a competing interest and move beyond MPAs as the only tool to underpin the benefits derived from marine ecosystems by identifying other effective area-based conservation measures (OECMs) to establish synergies with wider governance frameworks.

Within the EU Marine Strategy Framework Directive (Directive 2008/56/EC) sea-floor integrity is a descriptor used to assess Good Environmental Status [47]. Good Environmental Status is considered to be met when, 'sea-floor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected' [48].

The EU Directives have guided policy to instigate management measures that should restore and/or maintain ecological integrity. However, policy ambition to secure the sustainable management of complex systems in the UK remains restricted, within the management context, to achieving favorable condition of habitats and species (features) of conservation interest. This is opposed to the promotion of management measures that are directed to the recovery of ecosystem structure and function across the broad range of interlinked marine habitats [33].

Within the UK context, there is evidence from a long-term monitoring study in Lyme Bay [49]. Here, broad-scale habitat management measures have facilitated the removal of fishing pressures from both narrowly defined geogenic reef features of conservation interest (Reefs: Annex I of the Habitats Directive) as well as surrounding mixed sediment and sand habitats. This has resulted in a notable and significant increase in biodiversity, beyond that bounded by current site management objectives for individual features of conservation interest [50]. This has also delivered socio-economic as well as ecological benefits [51,52]. The evidence from Lyme Bay remains the only (marine) example of a long term, integrated ecological and socio-economic study of a conservation measure in the UK and has thus demonstrated the added potential value for biodiversity of a whole-site approach [34].

The enhanced potential for ecosystem recovery emerging from the synergistic functional linkages between adjacent habitat types is well documented from tropical ecosystems [53,54] but is rarely considered in MPA site designation and management in temperate regions. Consideration of ecological connectivity and geographical context are crucial variables in the performance of MPAs and should be central to a whole-site approach. The emerging science of seascape ecology, a marine sister science to terrestrial landscape ecology, provides conceptual and analytical frameworks to help gain a more holistic understand of a region and will be relevant to the application of science in a whole-site approach. The term seascape is applied in this context as analogous to landscape. Referring specifically to the three-dimensional ocean space comprising of both biotic and abiotic structural patterns (e.g. geological structure, plankton patches, plant communities, thermoclines) [55].

Rolling out a whole-site approach to management of MPAs in the UK sets a more ambitious horizon for marine conservation and the associated benefits than has been targeted previously. Central to this approach is a need to identify the wider ecological structures and processes that have the potential for recovery and renewal beyond the tightly delineated boundaries of features of conservation interest [38,56]. This also requires recognition that the whole-site approach to MPA management is integral to sustainable fisheries [57]. To build consensus for this approach amongst stakeholders, there is a need to establish design, management and monitoring objectives for MPAs that set goals for ecological as well as human well-being benefits (food, jobs, health and wellbeing) [24].

3.2. Fisheries management and MPAs

The purpose of a network of MPAs is to facilitate the recovery and prevalence of natural habitats and species which are threatened by human activities. Commercial fisheries are critically dependent on healthy functioning marine ecosystems (inside and outside MPAs), with many of the features of conservation interest (within MPAs) vital in supporting fish and shellfish during essential life history stages [58–60]. In a recent study from the Mediterranean, small-scale recreational and commercial fishing has been shown to operate at a higher intensity within multiple use MPAs compared to outside; access to key habitat areas and the removal of gear conflict have supported this proliferation [61].

Commercial fishing activity in UK waters takes many forms and is widespread [62]. Fishing often overlaps with MPAs and, in many instances, predates their designation. Fishing effort displacement from MPAs remains a key narrative in the fisheries and conservation debate, noting that MPA management measures can displace fishing effort. This displacement of effort can result in unintended impacts or consequences unless activity is managed within the context of on an ecosystem [63]. Within UK policy, the systematic conservation of marine ecosystems and the management of fisheries have developed along separate paths despite the obvious synergies. Historically there has been an overriding legal presumption that human activities are permissible in the sea, particularly in respect of fishing where there is an automatic public right to fish [64]. Since 2009, and the introduction of the Marine and Coastal Access Act, fisheries management in England and Scotland has attempted to reconcile the two objectives (conservation and fisheries) through a process to assess the compatibility of the fishing activity with the objectives of the MPAs [32,65]. This revised approach to management in MPAs assesses the compatibility of commercial fishing with the objectives of MPAs in a risk prioritised, phased approach. The approach highlights those features of conservation interest most vulnerable to fishing pressure and is applied to the activities of both UK and non-UK fishing vessels. This sea-change in systemic application of management to fisheries has since resulted in many features within inshore sites (over 25) being protected over some or all of their area from all forms of bottom trawling and dredging in English waters, whilst Scottish waters have seen similar restrictions in 19 vulnerable inshore sites. The Scottish Government is also currently consulting on appropriate fisheries management measures for Priority Marine Features outside of Marine Protected Areas [66]. This is an early and progressive signal of policy that recognises the synergies between conservation and sustainable livelihoods. The key driver of the success of the revised approach to fisheries management is firmly based in the EU Habitats Directive (92/43/EEC) backed up by the arbitration mechanism of the European Court of Justice, the European Commission and the UK Courts. At present, legal problems with the Common Fisheries Policy have prevented the application of the Habitats Directive to fisheries in offshore waters: the sole competence of the EU in fisheries has been interpreted to make the application of the Directive discretionary. Efforts are being made to continue the revised approach offshore but these are very slow and controversial [67].

Recent research indicates that fisheries management should be done at the landscape scale because many fish species require a variety of habitats during ontogeny [60]. Identification and protection of essential fish habitat is a key priority in ecosystem-based approaches to fisheries management [68,69]. Alongside management of threats to conservation features, opportunities now exist in the UK to lead in the implementation of ecosystem-based fisheries management (EBFM) which, to date, has remained largely an academic pursuit [133]. To operationalise EBFM, fishery ecosystem plans have been proposed as a structured whole-of-system place-based planning process that uses adaptive management to provide opportunities to consider overarching management goals for the fishery system and evaluate trade-offs and account for uncertainty [70].

The future success of the revised approach to fisheries, which will support ambitious marine conservation, requires the development of strong, linked UK legislation for biodiversity protection and fisheries management that recognises that critical fish/shellfish habitat (nursery areas, spawning grounds) are also features of conservation interest. MPAs are an effective area-based management tool for contributing to goals of EBFM and can be integrated within a broader EBFM framework to address a subset of goals such as regulating extractive uses, protecting habitat and biodiversity and rebuilding overexploited stocks. Such ambitious legislation must be relevant to both inshore and offshore MPAs and fisheries and backed up by an effective UK based arbitration mechanism that mirrors the societal desire for fish and shellfish along with ‘clean, healthy, safe, productive and biologically diverse oceans and seas’ [71]. This could be enabled though proposals for a UK Office of Environmental Protection [42].

Fishing is a constantly evolving industry that tends to adapt as new markets and technology drive innovation across the sector. The pace of change means that the process of fisheries management in UK MPAs is largely reactive rather than proactive. Fisheries management through the creation of byelaws (in England and Wales) and Marine Conservation Orders (MCOs) (in Scotland) remain the key tool for limiting pressure on benthic ecosystems within MPAs. Adaptive tools for fisheries management have long been promoted as a tool to support sustainable development [72]. More recently, adaptive fisheries management is viewed as a tool to improve the resilience of small-scale fisheries to ecological and economic shifts [73].

Ambitious marine conservation also reflects a parallel ambition for sustainable livelihoods. Sustainable and equitable solutions for fisheries will require nuanced policies [74]. In the UK, this will require wider adoption of flexible schemes through management using the principle of subsidiarity. This will enable management to be both responsive to emerging pressures that require restrictions on time, spatial activity, gear and catch and resilience to external forces such as climate change or a large scale regulatory change that may impact upon a fisherman's ability to achieve their livelihood. Such a system requires a presumption in favour of conservation and precaution in recognition that healthy functioning marine ecosystems support the long-term sustainability of fisheries, particularly the resilience of a low impact inshore fishing fleet.

3.3. Monitoring and evaluation of MPAs

MPA effectiveness in meeting ecological and socio-economic goals and objectives varies widely due to differences in ecological response, threats and levels of protection [15,61,75]. Evaluation and reporting on MPA performance, particularly in terms of impact on conservation status is an important statutory duty and in the UK is the responsibility of the UK statutory agencies. There are high economic and social costs linked to investments in MPAs that are wasted if the MPAs do not achieve their initial conservation objectives [76,77]. A monitoring framework and the evaluation of management measures in terms of their effectiveness in achieving pre-defined outcomes is vital to identify learning and good practice to support adaptive management for improved sustainability [22,78,79]. Additionally, analysis shows that every dollar invested globally in effectively managed MPAs has the potential to be at least tripled in benefits returned through factors such as employment, coastal protection and fisheries [80]. Thus, there is an opportunity to create new proposals for sustainable finance mechanisms for MPAs that can facilitate and increase investment in effective management of MPAs. These will demand that outcomes and performance metrics are of a standard acceptable for investors to manage financial risk. Additionally, supporting legislation will need to be flexible and adaptive to accommodate change.

When examining the evidence for the monitoring and evaluation of MPA effectiveness, through the lens of applied research, to date, there has been limited focus on developing experimental practice that includes the use of balanced designs and the integration of controls across operationally relevant spatial and temporal scales with sufficient sampling stations to detect a range of effects [79,81]. The lack of synchronous, spatially-explicit data at multiple scales, across multiple MPAs is a major challenge in detecting relatively short-term (5–10 year) effects across MPA networks. Furthermore, the choice of indicators and data collected often fall short of the full suite of variables required to report on stated ecological goals and objectives, needed to assess functional changes and social effects [82]. This has contributed to the growing issue of a data-rich-information-poor (DRIP) evidence base for evaluating the effectiveness of management measures [83]. These data cannot be reliably scaled-up to report on the effectiveness of conservation beyond local scales.

Moving forward, to support ambitious marine conservation there is a need to review ecological monitoring protocol to include recent advancements in experimental design, and the development, quality, reliability, cost and size reduction, of underwater technology (towed video, ROV, baited video) [60,84,85]. This approach should also help overcome the narrow focus of many previous MPA studies that have often only monitored one or a few key species or habitats [86]. Given the cost and time of robust ecological monitoring surveys, and the number of marine sites with interconnected and overlapping activities to manage, an appropriate strategy would be to invest in question-driven strategic, comparable monitoring of a suite of sentinel sites that can assess change at appropriate ecosystem temporal and spatial scales. Sentinel sites at vulnerable locations across an observation network could form an early warning system for change in ecosystem integrity where set thresholds of change have been exceeded. This would require a network of sentinel sites that span the geographical spread of the UK's waters and encompasses the environmental variables and human pressures under scrutiny. To avoid the risk of interpreting a specific exogenous impact on a single sentinel site as phase shift, an ambitious approach could go further by incorporating an integrative strategy using statistical modelling and adaptive sampling to identify change [87,88]. The alternative (and current data collection norm), which involves doing some monitoring at lots of sites only serves to add to the issue of DRIP data [83]. Overall, experimental design must also be commensurate with regional and global data streams to track and manage ecosystem health at greater scales [89] and consider ecosystem function, such as on-going work on the risk of different fishing gears on multi-species assemblages [90,91].

Ecological monitoring studies for evaluation purposes need to be designed to take into account the impact of MPA management measurement by defining appropriate controls [92]. Control sites support evidence-based decision-making by providing an opportunity to undertake statistical or observational comparisons of the condition of the marine resource between impacted and unimpacted areas. Control sites (which must be multiple locations to assess variability and not a single control site) also enable the benchmarking of any changes against responses to the wider environmental conditions, such as climate, storminess and cold winters. Consideration of the surrounding seascape and landscape for sampling sites in comparative evaluations will be important in accounting for confounding variables linked to different geographical context and operating across different spatial and temporal scales. To date, very few MPAs in the UK have been monitored using an experimental design that can evaluate the effectiveness of a management measure on the ecology of an MPA [93]. There are particular challenges associated with identifying suitable controls because the sites chosen as MPAs are, by definition, often unique. Furthermore, due to high habitat variability (spatial and temporal) in complex marine ecosystems it can be very challenging to find ecologically equivalent control sites and to link effects observed in an MPA to the restrictions therein [94].

There are examples in international research that demonstrate how control sites have been negotiated with local resource users leading to the co-construction of knowledge towards an ambition for sustainable development [95,96]. In a recent attempt to combine data sets from MPAs around the UK that were annually monitored and comprised samples from inside and outside the MPA with controls resulted in only two MPAs, Lamlash Bay Marine Reserve [97–99] and Lyme Bay [49]. Robust ecological monitoring surveys, as described above, incorporate multiple fished controls to try to disentangle the natural temporal and spatial variability in the system from the changes resulting from removing or introducing impacts. A fundamental issue associated with the monitoring of MPAs, besides habitat variability, is that there are fished controls to understand the impact of fishing, but no unimpacted sites to inform targets for recovery. This lack of quantitative baseline data hinders the appropriate management of all marine resources. This is further compounded by the fact that regardless of whether MPAs have appropriate controls for comparison of impact, nearly all lack any comparison sites which demonstrate what targets recovery should be aiming for. The lack of observed recovery of certain species inside UK MPAs has been attributed to a) insufficient protection (only a handful of very small UK MPAs currently offer full (no-take) protection); b) most UK MPA do not meet the conditions of viability in that they are much smaller than the movement range of many mobile species and; c) target species have declined regionally in many areas, making recovery difficult, even inside MPAs [59,86].

To set the path towards increased ambition for marine conservation, the UK MPA network needs to incorporate, where appropriate, a suite of control sites within the MPA boundaries where all destructive human activity is excluded. Over time, these sites could provide data allowing informed future management for MPAs and all marine developments. There is an opportunity within current policy reform to revisit proposals for Reference Areas in inshore waters that reframe the importance of these areas not as no take zones but as areas that support robust experimental design enabling sound evidence-based decision-making [24]. Reference areas, or we suggest Restoration Areas, provide an opportunity to show and track the path of recovery where no human-derived disturbance is allowed and these offer a powerful observation tool for adaptive management of an ecologically coherent MPA network. If located in carefully chosen places to both optimise monitoring objectives and through local consultation to minimise opposition to closure, the creation of restoration areas should minimise social impacts. In other parts of the world, fisher-scientist partnerships have been particularly important to delivering robust monitoring protocol [100,101].

From a socio-economic perspective, there is limited research on the economic benefits of MPAs [102]. The study from Lyme Bay, UK remains the only socio-economic evaluation of an MPA that links socio-economic outcomes with ecological recovery [52]. There has however, been rapid development in the application of natural capital approaches to improve evaluation processes. The development of Natural Capital tools that can evaluate socio-economic outcomes from marine conservation by explicitly linking marine habitat extent and condition with changes in the socio-economic system are currently being refined and tested [103, 104]. To advance knowledge on the relationship between successful biodiversity conservation and socio-economic outcomes, ambitious marine conservation must employ policy-relevant social-ecological appraisal mechanisms for MPA monitoring and assessment (e.g. natural capital accounts, Asset and Risk Registers, Environmental Impact Assessments, Sustainability Appraisal) [104–107].

3.4. The seascape approach – beyond MPA boundaries

The functional integrity and health of marine ecosystems is dependent not only on the protection provided though MPA management measures, but also on the ecological, economic and social interactions with surrounding areas (including terrestrial landscapes) [22]. Recent research demonstrates that there are gaps in a UK ecologically coherent network of MPAs [108–110]. Worldwide, many MPAs are less effective than intended [111]. Several researchers have argued that the CBD target of 10% is too low to achieve the objective of protecting biodiversity underpinning ecosystem services and meeting socio-economic priorities and have called for 30% to form the revised post 2020 target [19,23]. Within the marine planning framework it must be recognised that MPAs alone (covering the CBD required 10% of the marine environment) cannot meet all the needs of society (jobs, ecosystem services, climate resilience, water purification) without being fully integrated into sustainable development planning within the wider seascape and linked to coastal communities. It is therefore widely considered that the main frontier in conservation is how the remaining 90% of marine area (if 10% fall within the required CBD definition of a protected area) is managed for sustainable outcomes [112].

Ecologically coherent networks of MPAs have long been considered by many as being an essential and central element of an ecosystem-based approach to the management of our seas [72]. Aichi target 11 for MPAs includes that they should be integrated into the wider seascape [113]. With this in mind there is a real opportunity for the UK Government to be ambitious and integrate many of the existing strands of expertise that inform MPA science, sustainable fisheries and marine spatial planning across the whole seascape. The emerging interdisciplinary science of seascape ecology which recognises the importance of scale, context and connectivity and readily bridges the information gap between ecology and management has potential to become the focal core of a new marine sustainability science [55].

Sustainable management of 100% of UK waters requires an ambition that MPAs are integrated into the marine planning framework not as a sectoral or competing interest within the seascape but as a key functional support system. The directional change from UK Government to place Natural Capital at the heart of decision-making [37,114] represents a transition from policy approaches that primarily promote biodiversity conservation (e.g. European Union (EU) Habitats Directive, OSPAR) to policy approaches that aim to integrate socio-economic outcomes and their dependency on natural resources into the decision making process [42,71]. Transitioning towards a decision-making process based on marine plans that underpins the functional integrity and health of marine ecosystems, as well as realising benefits to society, requires a distinction between areas that are important for biodiversity (species-rich, functionally diverse or are important for an iconic aspect of biodiversity) and areas that are important for ecosystem services (realised benefits such as recreation services, flood protection and food). The two (areas important for biodiversity and areas important for ecosystem services) are not always commensurate or co-located [22, 115]. In a novel application of a natural capital asset risk register [116] to marine systems to determine the future risk of a breakdown between the natural capital assets (habitats and species) and the flow of benefits (ecosystem services), it was found that there is a medium to high risk of loss of the ecosystem service benefits linked to food provision and recreation/tourism due to chronic impacts on the assets (habitats and species) both inside and outside MPAs [104]. In short, MPAs are not enough to maintain the long-term flow of benefits.

Marine Planning exists as a tool to underpin the triple bottom-line of sustainable development with benefits for economy, ecology and society [117]. These principles for sustainability are enshrined in the UK's approach to marine planning and licensing, which has a clear legislative basis and a detailed iterative process covering scoping issues, evidence collection, vision and objectives setting, options development and plan drafting, review and adoption. However, the planning process has been criticised for supporting political expedience and blue growth opportunities that are not commensurate with healthy functioning ecosystems [118]. An ambitious approach to Marine Planning should acknowledge that features of conservation importance are also the critical natural capital underpinning human well-being at the broadest level and these cannot be traded against short-term, localised benefits to specific sectors society. Additionally, some trade-offs between desired ecosystem services within the planning context can change the flows among multiple ecosystem services leading to what has been described as 'off stage ecosystem burdens' that can compromise wider trajectories towards sustainability [119]. A post implementation evaluation of marine plans will judge whether the marine planning framework has indeed supported a balance between economic needs and protection of the environment. Such an evaluation will only be possible if baselines and appropriate evaluation metrics have been identified, against which change can be robustly evaluated.

Ambitious marine conservation challenges policy makers and practitioners to think beyond MPAs and to integrate them with other forms of management, which could also deliver wider benefits for biodiversity. In addition to MPAs the CBD Aichi target 11 includes a suite of other in situ areas as other effective area-based conservation measures (OECMs). The CBD adopted a definition of OECMs as 'a geographically defined area other than a Protected Area, which is governed and managed in ways that achieve positive and sustained long-term outcomes for the in situ conservation of biodiversity, with associated ecosystem functions and services and where applicable, cultural, spiritual, socio–economic, and other locally relevant values' [120]. From an international perspective OECMs may align with management measures initiated by sectoral organisations such as Regional Fisheries Management Organisations (overlapping with Vulnerable Marine Ecosystems (VMEs), International Maritime Organization (overlapping with Particularly Sensitive Sea Areas, Special Areas) and the International Seabed Authority (overlapping with Areas of Particular Environmental Interest) [22]. Areas defined as Locally Managed Marine Areas (LMMA) with biodiversity objectives also potentially fit within this OECM bracket [121]. It is also potentially feasible that Marine Plans could operate as OECMs, with biodiversity as the foundational structure. International OECMs align with the UK Government's Blue Belt programme for the overseas territories. From a mainland UK perspective, OECMs may be linked to spatial measures such as fisheries management, protected wrecks, safety zones around Offshore Renewable Energy Installations (OREI) and voluntary nature conservation areas [122]. Through a more systematic review of these OECMs in delivering or supporting biodiversity benefits, an ambitious and coherent plan for environmental net gain for ecology, economy and society across the seascape becomes a more realistic possibility.

Outside of MPAs, fisheries management represents the most obvious (and immediate) candidate for integration with MPA management due to the UK's departure from the EU Common Fisheries Policy and the requirement for a new Fisheries Bill [133]. Fisheries management has long focussed on stock assessments as a means of moderating fishing effort within defined limits of stock sustainability. However, stock assessments provide minimum insight into the broader ecological sustainability of fisheries within the social-ecological system. Extractive commercial fishing activities can impact on the structure and function of ecosystems as well as the trophic structure of associated species [123, 124]. Recognition of these wider ecological impacts is the basis for more recent calls for a shift towards ecosystem-based fisheries management (EBFM) [125]. However, while the need for EBFM is now widely recognised, it has rarely been fully implemented [126]. If ecological functions are impaired, all ecosystem services (beyond food provision) have the potential to be impacted, and feature-based management potentially will be ineffective in preventing this. This fundamental link is recognised within the MSFD and effort to achieve Good Environmental Status. In addition, such ecological interconnectedness raises issues linked to rights and equity beyond the rights of fishers, recognising that wider direct and indirect users of a given marine area often have to bear the environmental costs associated with the ecosystem impacts of fishing [127]. Within an ambitious framework, recognition of this would include the integration of conservation with fisheries policy (inside and outside of the 12 nm limit), and stipulate compliance with conservation management as a condition of access. Though a reassessment of the current measurement of fisheries allocation, based on stock assessments and historic national catches (relative stability) there is a window of opportunity for a more integrated stock methodology (supported by healthy functioning marine ecosystems), that would include small pelagic fish species, to be adopted both for the UK and between the UK, the EU and other coastal states [128]. This reassessment must take into account the role of small-scale fisheries in supporting coastal communities and how locally accountable governance could evolve to support this and appropriate definitions of 'significant adverse impact'.

Beyond fisheries management, there is innovation emerging in terrestrial and marine governance approaches stemming from Whole-scale Thinking which could offer opportunities for a more ambitious approach to marine conservation though joining up conventional administrative, sectoral and geographical boundaries across air, sea and water [129]. This type of governance approach depends on integration of natural capital approaches and strong partnership working that brings together diverse organisations who agree to collaborate (across disciplines) closely to solve problems of common concern. Enabling conditions for good governance involves linking people to place, finding common ground and guiding people towards useful actions [130]. Independent Coastal and Estuary Partnerships supported by a wide range of public and private sector partners, have the potential to extend seaward to support marine governance and encourage further stewardship action. New and novel proposals for National Marine Parks (NMPs) for coastal cities that aim to reconnect urban communities with their seascape, such as the proposal for Plymouth, UK [131]. NMPs, in the coastal city context, offer a vehicle for connecting the social, economic and health benefits that flow from marine ecosystems to the more terrestrially focussed economic growth and productivity agenda embodied in city plans [132].

4. Conclusion

The UK's exit from the EU has initiated major policy reform. As well as raising concerns, inter alia, about the loss of legal obligations to the European Commission related to the conservation of marine biodiversity and the sustainable management of fisheries, the UK exit from the EU provides an opportunity for the UK to re-examine its national and international obligations. The UK now has the chance to develop a strengthened governance framework to meet the ambition 'to be the first generation that leaves the environment in a better state than that in which we inherited it' [42]. In this way, the UK could also fulfil its goal to be a global leader in fisheries management and marine conservation, and in doing so influence marine management measures on the international stage, such as the next set of CBD targets, due for renewal in 2020.

Marine ecosystems provide a wide range of resources and services that contribute to human wellbeing and life on Earth. Despite this essential interdependence between the human and the ocean system, marine biodiversity continues to decline, placing in jeopardy the range of ecosystem services benefits humans rely on. Turning this tide requires that challenges are made in current modes of operation, most importantly:

- shifting from managing individual marine features within MPAs to whole-sites to enable repair and renewal of marine systems, and
- fully integrating fisheries management with conservation (Ecosystem Based Fisheries Management) as the two are critically interdependent.

In addition, we stress it is important to:

- establish world class and cost effective ecological and socio-economic monitoring and evaluation to improve sustainability in marine management,
- fully integrate MPAs into the wider seascape as critical functional components rather than a competing interest, and
- move beyond MPAs as the only tool to underpin the benefits derived from marine ecosystems by identifying OECMs and establish synergies with wider governance frameworks.

Acknowledgements

TA's and NB's contribution are part funded by the Lloyd's Register Foundation, a charitable foundation helping to protect life and property by supporting engineering-related education, public engagement and the application of research. SR is funded though NERC- SWEEP NE/P011217/1. Many thanks to Piers Dunstan of CSIRO, Adam Rees of the Blue Marine Foundation and contacts from the Inshore Fisheries and Conservation Authority (IFCA) for comments on an earlier version of this paper. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The authors would like to thank the two blind peer reviewers whose comments were valued and improved this manuscript.

References

[1] UNEP, Marine and Coastal Ecosystems and Human Well-Being : a Synthesis Report Based on the Findings of the Millennium Ecosystem Assessment, United Nations Environment Programme, 2006, p. 76.
[2] B.S. Halpern, S. Walbridge, K.A. Selkoe, C.V. Kappel, F. Micheli, C. D'Agrosa, J. F. Bruno, K.S. Casey, C. Ebert, H.E. Fox, R. Fujita, D. Heinemann, H.S. Lenihan, E. M.P. Madin, M.T. Perry, E.R. Selig, M. Spalding, R. Steneck, R. Watson, A global map of human impact on marine ecosystems, Science 319 (5865) (2008) 948–952.
[3] H. Österblom, J.-B. Jouffray, C. Folke, B. Crona, M. Troell, A. Merrie, J. Rockström, Transnational corporations as 'keystone actors' in marine ecosystems, PloS One 10 (5) (2015), e0127533.
[4] F.S. Chapin III, E.S. Zavaleta, V.T. Eviner, R.L. Naylor, P.M. Vitousek, H. L. Reynolds, D.U. Hooper, S. Lavorel, O.E. Sala, S.E. Hobbie, M.C. Mack, S. Díaz, Consequences of changing biodiversity, Nature 405 (2000) 234–242.
[5] C. Folke, S. Carpenter, B. Walker, M. Scheffer, T. Elmqvist, L. Gunderson, C. S. Holling, Regime shifts, resilience, and biodiversity in ecosystem management, Annu. Rev. Ecol. Evol. Syst. 35 (1) (2004) 557–581.
[6] D.U. Hooper, F.S. Chapin, J.J. Ewel, A. Hector, P. Inchausti, S. Lavorel, J. H. Lawton, D.M. Lodge, M. Loreau, S. Naeem, B. Schmid, H. Setälä, A.J. Symstad, J. Vandermeer, D.A. Wardle, Effects of biodiversity on ecosystem functioning: a consensus of current knowledge, Ecol. Monogr. 75 (1) (2005) 3–35.
[7] H.K. Lotze, H.S. Lenihan, B.J. Bourque, R.H. Bradbury, R.G. Cooke, M.C. Kay, S. M. Kidwell, M.X. Kirby, C.H. Peterson, J.B.C. Jackson, Depletion, degradation, and recovery potential of estuaries and coastal seas, Science 312 (5781) (2006) 1806–1809.
[8] UNEP, Marine and Coastal Ecosystems and Human Well-Being: A Synthesis Report Based on the Findings of the Millennium Ecosystem Assessment, UNEP, 2006, p. 76.
[9] B. Worm, E.B. Barbier, N. Beaumont, J.E. Duffy, C. Folke, B.S. Halpern, J.B. C. Jackson, H.K. Lotze, F. Micheli, S.R. Palumbi, E. Sala, K.A. Selkoe, J. J. Stachowicz, R. Watson, Impacts of biodiversity loss on ocean ecosystem services, Science 314 (5800) (2006) 787–790.
[10] CBD, Convention on Biological Diversity, 1992 (United Nations).
[11] OSPAR Convention, Convention for the Protection of the Marine Environment of the North-East Atlantic. O. Commission, 2002.
[12] CBD, Convention on Biological Diversity, COP 10. Decision X/2, Strategic Plan for Biodiversity, 2010, 2011-2020.
[13] United Nations, Introduction and Proposed Goals and Targets on Sustainable Development for the Post-2015 Development Agenda. Zero Draft (Rev. 1), Open Working Group 13—Revised Version 19 July, 2014.
[14] J. Sobel, C.P. Dahlgren, Marine Reserves: A Guide to Science, Design and Use, Island Press, Washington DC, 2004.

[15] G.J. Edgar, R.D. Stuart-Smith, T.J. Willis, S. Kininmonth, S.C. Baker, S. Banks, N. S. Barrett, M.A. Becerro, A.T.F. Bernard, J. Berkhout, C.D. Buxton, S.J. Campbell, A.T. Cooper, M. Davey, S.C. Edgar, G. Forsterra, D.E. Galvan, A.J. Irigoyen, D. J. Kushner, R. Moura, P.E. Parnell, N.T. Shears, G. Soler, E.M.A. Strain, R. J. Thomson, Global conservation outcomes depend on marine protected areas with five key features, Nature 506 (7487) (2014) 216–220.
[16] E. Sala, S. Giakoumi, P. Handling, Linwood, No-take marine reserves are the most effective protected areas in the ocean, ICES (Int. Counc. Explor. Sea) J. Mar. Sci. 75 (3) (2018) 1166–1168.
[17] J. Lubchenco, K. Grorud-Colvert, Making waves: the science and politics of ocean protection, Science 350 (6259) (2015) 382–383.
[18] UNEP WCMC IUCN, NGS, Protected Planet Report 2018 Cambridge UK; Gland, UNEP-WCMC, IUCN and NGS, Switzerland; and Washington, D.C., USA, 2018, p. 70.
[19] B.C. O'Leary, M. Winther-Janson, J.M. Bainbridge, J. Aitken, J.P. Hawkins, C. M. Roberts, Effective coverage targets for ocean protection, Conserv. Lett. 9 (6) (2016) 398–404.
[20] D. Spalding, I. Meliane, N.J. Bennett, P. Dearden, P.G. Patil, R.D. Brumbaugh, Building towards the marine conservation end-game: consolidating the role of MPAs in a future ocean, Aquat. Conserv. Mar. Freshw. Ecosyst. 26 (2016) 185–199.
[21] P.J.S. Jones, E.M. De Santo, Viewpoint – is the race for remote, very large marine protected areas (VLMPAs) taking us down the wrong track? Mar. Pol. 73 (2016) 231–234.
[22] S.E. Rees, N.L. Foster, O. Langmead, S. Pittman, D.E. Johnson, Defining the Qualitative Elements of Aichi Biodiversity Target 11 with Regard to the Marine and Coastal Environment in Order to Strengthen Global Efforts for Marine Biodiversity Conservation Outlined in the United Nations Sustainable Development Goal 14, 2017 (Marine Policy).
[23] IUCN, IUCN Resolutions, Recommendations and Other Decisions. Gland, Switzerrland, IUCN, 2016, p. 106pp.
[24] S.E. Rees, S.J. Pittman, N. Foster, O. Langmead, C. Griffiths, S. Fletcher, D. E. Johnson, M. Attrill, Bridging the divide: social–ecological coherence in Marine Protected Area network design, Aquat. Conserv. Mar. Freshw. Ecosyst. 28 (3) (2018) 754–763.
[25] EC, Council Directive 92/43/EEC of 21 May 1992 on the Conservation of Natural Habitats and of Wild Fauna and Flora, Official Journal of the European Communities, 1992.
[26] UN, Report of the World Summit on Sustainable Development, vol. 32, United Nations, Para, 2002 c.
[27] OSPAR, OSPAR Recommendation 2002/3 on a Network of Marine Protected Areas, 2003. Avalaible at, http://www.ospar.org/content/content.asp?menu=00700302_210000_000000_000000. (Accessed 7 March 2013).
[28] CBD, Decision Adopted by the Conference of the Parties to the Convention on Biological Diversity at its Seventh Meeting, 2004. Convention on Biological Diversity UNEP/CBD/COP/DEC/VII/5.
[29] EC, Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 Establishing a Framework for Community Action in the Field of Marine Environmental Policy (Marine Strategy Framework Directive), Official Journal of the European Union, 2008.
[30] United Nations, Transforming Our World: the 2030 Agenda for Sustainable Development A/RES/70/1, United Nations, 2015, p. 41.
[31] P.J.S. Jones, Marine protected areas in the UK: challenges in combining top-down and bottom-up approaches to governance, Environ. Conserv. 39 (3) (2012) 248–258.
[32] J.-L. Solandt, P. Jones, D. Duval-Diop, A.R. Kleiven, K. Frangoudes, Governance challenges in scaling up from individual MPAs to MPA networks, Aquat. Conserv. Mar. Freshw. Ecosyst. 24 (S2) (2014) 145–152.
[33] L.M. Lieberknecht, P.J.S. Jones, From stormy seas to the doldrums: the challenges of navigating towards an ecologically coherent marine protected area network through England's Marine Conservation Zone process, Mar. Pol. 71 (2016) 275–284.
[34] D.E. Johnson, S.E. Rees, D. Diz, P.J.S. Jones, C. Roberts, C. Barrio Froján, Securing Effective and Equitable Coverage of Marine Protected Areas: an Overview of Global Efforts by the Convention on Biological Diversity and Analysis of National Efforts on Behalf of the United Kingdom, Aquatic Conservation: Marine and Freshwater Ecosystems, 2019 (Accepted paper).
[35] JNCC, UK Marine Protected Area Network Statistics, 2018. Retrieved 14.01.2019, 2019.
[36] J.-L. Solandt, T. Mullier, S. Elliott, E. Sheehan, Managing Marine Protected Areas in Europe: Moving from 'feature-Based' to 'whole-Site' Management of Sites. Marine Protected Areas: Evidence, Policy & Practice, Elsevier, 2018.
[37] HM Government, A Green Future: Our 25 Year Plan to Improve the Environment, Department for the Environment Food and Rural Affairs, London, 2018.
[38] J.-L. Solandt, T. Mullier, S. Elliott, E. Sheehan, Managing Marine Protected Areas in Europe: Moving from 'feature-Based' to 'whole-Site' Management of Sites, Elsevier, 2019.
[39] HM Government, The Natural Choice: Securing the Value of Nature, Her Majesty's Stationery Office, 2011.
[40] J.-L. Solandt, B. Stewart, A. Puritz, Perspective: What Does Brexit Mean for UK MPAs? MPA News, Open Channels, 2017. https://mpanews.openchannels.org/news/mpa-news/perspective-what-does-brexit-mean-uk-mpas. (Accessed 19 February 2019).
[41] T. Appleby, J. Harrison, Brexit and the future of Scottish fisheries, J. Water Law 25 (3) (2017) 124–132.
[42] HM Government, A Green Future: Our 25 Year Plan to Improve the Environment Annex 1: Supplementary Evidence Report 145, 2018.
[43] R.E. Ulanowicz, The balance between adaptability and adaptation, Biosystems 64 (2002) 13–22.
[44] J.D. Parrish, D.P. Braun, R.S. Unnasch, Are we conserving what we say we are? Measuring ecological integrity within protected areas, Bioscience 53 (9) (2003) 851–860.
[45] European Commission, Managing Natura 2000 Sites: the Provisions of Article 6 of the Habitats Directive 92/43/EEC, 2000, p. 73. European Commission.
[46] Her Majesty's Government, Planning Policy Guidance Note 9 (PPG9) on Nature Conservation, 1994.
[47] J. Rice, C. Arvanitidis, A. Borja, C. Frid, J.G. Hiddink, Indicators for sea-floor integrity under the European marine strategy framework directive, Ecol. Indicat. 12 (2012) 174–184.
[48] European Parliament and Council, Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 Establishing a Framework for Community Action in the Field of Marine Environmental Policy (Marine Strategy Framework Directive), vol. 22, The European Parliment, 2008.
[49] E.V. Sheehan, S.L. Cousens, S.J. Nancollas, C. Stauss, J. Royle, M.J. Attrill, Drawing lines at the sand: evidence for functional vs. visual reef boundaries in temperate Marine Protected Areas, Mar. Pollut. Bull. 76 (1) (2013) 194–202.
[50] E.V. Sheehan, T.F. Stevens, S.C. Gall, S.L. Cousens, M.J. Attrill, Recovery of a temperate reef assemblage in a marine protected area following the exclusion of towed demersal fishing, PloS One 8 (12) (2013), e83883.
[51] S. Rees, N. Foster, O. Langmead, C. Griffiths, Assessment of the Ecological Coherence of the MPA Network in the Celtic Seas: A Report for WWF-UK by the Marine Institute, Plymouth University and The Marine Biological Association of the United Kingdom, 2015, p. 167.
[52] S.E. Rees, M. Ashley, L. Evans, S. Mangi, L. Rodwell, M. Attrill, O. Langmead, E. Sheehan, A. Rees, An Evaluation Framework to Determine the Impact of the Lyme Bay Marine Protected Area and the Activities of the Lyme Bay Consultative Committee on Ecosystem Services and Human Wellbeing, A report to the Blue Marine Foundation by research staff the Marine Institute at Plymouth University, Exeter University and Cefas, 2016, p. Pp139.
[53] A.D. Olds, R.M. Connolly, K.A. Pitt, S.J. Pittman, P.S. Maxwell, C.M. Huijbers, B. R. Moore, S. Albert, D. Rissik, R.C. Babcock, T.A. Schlacher, Quantifying the conservation value of seascape connectivity: a global synthesis, Global Ecol. Biogeogr. 25 (1) (2016) 3–15.
[54] E.B. Barbier, Marine ecosystem services, Curr. Biol. 27 (11) (2017) R507–R510.
[55] S.J. Pittman, C.A. Lepczyk, L.M. Wedding, C. Parrain, Chapter 12: Advancing a Holistic Systems Approach in Applied Seascape Ecology. Seascape Ecology. Pittman SJ, Wiley & Sons Ltd, 2018, pp. 367–389.
[56] S.E. Rees, E.V. Sheehan, E.L. Jackson, S.C. Gall, S.L. Cousens, J.-L. Solandt, M. Boyer, M.J. Attrill, A legal and ecological perspective of 'site integrity' to inform policy development and management of Special Areas of Conservation in Europe, Mar. Pollut. Bull. 72 (1) (2013) 14–21.
[57] POST, UK Fisheries Management. The Parliamentary Office of Science and Technology, 2018. POSTnotes POST-PN-0572.
[58] J.P. Kritzer, M.-B. DeLucia, E. Greene, C. Shumway, M.F. Topolski, J. Thomas-Blate, L.A. Chiarella, K.B. Davy, K. Smith, The importance of benthic habitats for coastal fisheries, Bioscience 66 (4) (2016) 274–284.
[59] B.D. Stewart, L.M. Howarth, Quantifying and Managing the Ecosystem Effects of Scallop Dredge Fisheries, in: S.E. Shumway, G.J. Parsons (Eds.), Scallops: Biology, Ecology, Aquaculture and Fisheries, Developments in Aquaculture and Fisheries Science, 40, Elsevier, 2016, pp. 585–609.
[60] S.A.M. Elliott, A.D. Sabatino, M.R. Heath, W.R. Turrell, D.M. Bailey, Landscape effects on demersal fish revealed by field observations and predictive seabed modelling, PloS One 12 (12) (2017), e0189011.
[61] M. Zupan, F. Bulleri, J. Evans, S. Fraschetti, P. Guidetti, A. Garcia-Rubies, M. Sostres, V. Asnaghi, A. Caro, S. Deudero, R. Goñi, G. Guarnieri, F. Guilhaumon, D. Kersting, A. Kokkali, C. Kruschel, V. Macic, L. Mangialajo, S. Mallol, E. Macpherson, A. Panucci, M. Radolovic, M. Ramdani, P.J. Schembri, A. Terlizzi, E. Villa, J. Claudet, How good is your marine protected area at curbing threats? Biol. Conserv. 221 (2018) 237–245.
[62] P. Breen, K. Vanstaen, R.W.E. Clark, Mapping inshore fishing activity using aerial, land, and vessel-based sighting information, ICES (Int. Counc. Explor. Sea) J. Mar. Sci. 72 (2) (2015) 467–479.
[63] D. Vaughan, Fishing effort displacement and the consequences of implementing Marine Protected Area management – an English perspective, Mar. Pol. 84 (2017) 228–234.
[64] T. Appleby, The public right to fish: is it fit for purpose? J. Water Law 16 (6) (2005) 4.
[65] R. Clark, J. Humphreys, J.-L. Solandt, C. Weller, Dialectics of nature: the emergence of policy on the management of commercial fisheries in English European Marine Sites, Mar. Pol. 78 (2017) 11–17.
[66] Scottish Government, Priority Marine Features, 2019. Retrieved 11.01.19, 2019, from, https://www2.gov.scot/Topics/marine/marine-environment/mpanetwork/PMF.
[67] T. Appleby, J. Harrison, Taking the pulse of environmental and fisheries law: the common fisheries policy, the habitats directive and brexit, J. Environ. Law 31 (3) (2019) 443–464, in press.
[68] C.W. Armstrong, J. Falk-Petersen, Habitat–fisheries interactions: a missing link? ICES (Int. Counc. Explor. Sea) J. Mar. Sci. 65 (6) (2008) 817–821.
[69] R.D. Seitz, H. Wennhage, U. Bergström, R.N. Lipcius, T. Ysebaert, Ecological value of coastal habitats for commercially and ecologically important species, ICES (Int. Counc. Explor. Sea) J. Mar. Sci. 71 (3) (2014) 648–665.

[70] P.S. Levin, T.E. Essington, K.N. Marshall, L.E. Koehn, L.G. Anderson, A. Bundy, C. Carothers, F. Coleman, L.R. Gerber, J.H. Grabowski, E. Houde, O.P. Jensen, C. Möllmann, K. Rose, J.N. Sanchirico, A.D.M. Smith, Building effective fishery ecosystem plans, Mar. Pol. 92 (2018) 48–57.
[71] UK Government, Marine and Coastal Access Act, 2009.
[72] L.W. Botsford, J.C. Castilla, C.H. Peterson, The management of fisheries and marine ecosystems, Science 277 (5325) (1997) 509–515.
[73] F.P. Chavez, C. Costello, D. Aseltine-Neilson, D. Doremus, J.C. Field, S.D. Gaines, Readying California Fisheries for Climate Change, California Sea Grant College Program, UC San Diego, 2017. Retrieved from, https://escholarship.org/uc/item/2kr7839k.
[74] A.M. Cisneros-Montemayor, T. Cashion, D.D. Miller, T.C. Tai, N. Talloni-Álvarez, H.W. Weiskel, U.R. Sumaila, Achieving sustainable and equitable fisheries requires nuanced policies not silver bullets, Nat. Ecol. Evol. (2018).
[75] S.E. Lester, B.S. Halpern, K. Grorud-Colvert, J. Lubchenco, B.I. Ruttenberg, S. D. Gaines, S. Airamé, R.R. Warner, Biological effects within no-take marine reserves: a global synthesis, Mar. Ecol. Prog. Ser. 384 (2009) 33–46.
[76] G.J. Edgar, Marine protected areas need accountability not wasted dollars, Aquat. Conserv. Mar. Freshw. Ecosyst. 27 (1) (2017) 4–9.
[77] K. Jantke, K.R. Jones, J.R. Allan, A.L.M. Chauvenet, J.E.M. Watson, H. P. Possingham, Poor ecological representation by an expensive reserve system: evaluating 35 years of marine protected area expansion, Conserv. Lett. (2018), e12584, 0(0).
[78] M. Hockings, S. Stolton, F. Leverington, , D.N., J. Courrau, Evaluating Effectiveness. A Framework for Assessing Management Effectiveness of Protected Areas. Gland, IUCN, Switzerland & Cambridge, UK, 2006.
[79] J. Claudet, P. Guidetti, Improving assessments of marine protected areas, Aquat. Conserv. Mar. Freshw. Ecosyst. 20 (2) (2010) 239–242.
[80] E. Reuchlin-Hugenholtz, E. McKenzie, Marine Protected Areas: Smart Investments in Ocean Health, WWF, Gland, Switzerland, 2015.
[81] G.N. Ahmadia, L. Glew, M. Provost, D. Gill, N.I. Hidayat, S. Mangubhai, Purwanto, H.E. Fox, Integrating impact evaluation in the design and implementation of monitoring marine protected areas, Phil. Trans. Biol. Sci. 370 (1681) (2015) 20140275.
[82] B.S. Halpern, C.J. Klein, C.J. Brown, M. Beger, H.S. Grantham, S. Mangubhai, M. Ruckelshaus, V.J. Tulloch, M. Watts, C. White, H.P. Possingham, Achieving the triple bottom line in the face of inherent trade-offs among social equity, economic return, and conservation, Proc. Natl. Acad. Sci. Unit. States Am. 110 (15) (2013) 6229–6234.
[83] T.A. Wilding, A.B. Gill, A. Boon, E. Sheehan, J.C. Dauvin, J.-P. Pezy, F. O'Beirn, U. Janas, L. Rostin, I. De Mesel, Turning off the DRIP ('Data-rich, information-poor') – rationalising monitoring with a focus on marine renewable energy developments and the benthos, Renew. Sustain. Energy Rev. 74 (2017) 848–859.
[84] S.A.M. Elliott, R.J. Milligan, M.R. Heath, W.R. Turrell, D.M. Bailey, Disentangling habitat concepts for demersal marine fish management, in: R.N. Hughes, D. J. Hughes, I.P. Smith, A.C. Dale (Eds.), Oceanography and Marine Biology: an Annual Review, vol. 54, CRC Press, 2016.
[85] E.V. Sheehan, S. Vaz, E. Pettifer, N.L. Foster, S.J. Nancollas, S. Cousens, L. Holmes, J.-V. Facq, G. Germain, M.J. Attrill, An experimental comparison of three towed underwater video systems using species metrics, benthic impact and performance, Methods Ecol. Evol. 7 (7) (2016) 843–852.
[86] L. Howarth, C. Roberts, J. Hawkins, D. Steadman, B.D. Beukers-Stewart, Effects of ecosystem protection on scallop populations within a community-led temperate marine reserve, Mar. Biol. 162 (2015) 823–840, https://doi.org/10.1007/s00227-015-2627-7.
[87] T.J. Arciszewski, K.R. Munkittrick, G.J. Scrimgeour, M.G. Dube, F.J. Wrona, R. R. Hazewinkel, Using adaptive processes and adverse outcome pathways to develop meaningful, robust, and actionable environmental monitoring programs, Integrated Environ. Assess. Manag. 13 (5) (2017) 877–891.
[88] R. Przeslawski, S. Foster, Field Manuals for Marine Sampling to Monitor Australian Waters, Version 1. 2018. Report to the National Environmental Science Programme, Marine Biodiversity Hub, National Environment Science Programme Marine Biodiversity Hub, Canberra, Australia, 2018, p. 212.
[89] G.J. Edgar, A.E. Bates, T.J. Bird, A.H. Jones, S. Kininmonth, R.D. Stuart-Smith, T. J. Webb, New approaches to marine conservation through the scaling up of ecological data, Ann. Rev. Mar. Sci. 8 (1) (2016) 435–461.
[90] S.D. Foster, P.K. Dunstan, F. Althaus, A. Williams, The cumulative effect of trawl fishing on a multispecies fish assemblage in south-eastern Australia, J. Appl. Ecol. 52 (1) (2015) 129–139.
[91] N.A. Hill, S.D. Foster, G. Duhamel, D. Welsford, P. Koubbi, C.R. Johnson, Model-based mapping of assemblages for ecology and conservation management: a case study of demersal fish on the Kerguelen Plateau, Divers. Distrib. 23 (10) (2017) 1216–1230.
[92] T.F. Stevens, E.V. Sheehan, S.C. Gall, S.C. Fowell, M.J. Attrill, Monitoring benthic biodiversity restoration in Lyme Bay marine protected area: design, sampling and analysis, Mar. Pol. 45 (2014) 310–317, 0.
[93] L. Henly, Assessing Functional Recovery Trends within the UK Marine Protected Area Network. Masters of Research Thesis, University of Plymouth, Faculty of Science and Engineering, 2017.
[94] J.A.G. Charton, I.D. Williams, A.P. Ruzafa, M. Milazzo, R. Chemello, C. Marcos, M.S. Kitsos, A. Koukouras, S. Riggio, Evaluating the ecological effects of Mediterranean marine protected areas: habitat, scale and the natural variability of ecosystems, Environ. Conserv. 27 (2) (2002) 159–178.
[95] F. Vandeperre, R.M. Higgins, J. Sanchez-Meca, F. Maynou, R. Goni, P. Martin-Sosa, Effects of no-take area size and age of marine protected areas on fisheries yields: a meta-analytical approach, Fish Fish. 12 (2011).
[96] T.A. Oliver, K.L.L. Oleson, H. Ratsimbazafy, D. Raberinary, S. Benbow, A. Harris, Positive catch & economic benefits of periodic Octopus fishery closures: do effective, narrowly targeted actions 'catalyze' broader management? PloS One 10 (6) (2015), e0129075.
[97] L.M. Howarth, H.L. Wood, A.P. Turner, B.D. Beukers-Stewart, Complex habitat boosts scallop recruitment in a fully protected marine reserve, Mar. Biol. 158 (2011) 1767–1780, https://doi.org/10.1007/s00227-011-1690-y.
[98] L.M. Howarth, S.E. Pickup, L.E. Evans, T.J. Cross, J.P. Hawkins, C.M. Roberts, B. D. Stewart, Sessile and mobile components of a benthic ecosystem display mixed trends within a temperate marine reserve, Mar. Environ. Res. 107 (2015) 8–23, https://doi.org/10.1016/j.marenvres.2015.03.009.
[99] L.M. Howarth, P. Dubois, P. Gratton, M. Judge, B. Christie, J.J. Waggitt, J. P. Patricia Hawkins, C.M. Roberts, B.D. Stewart, Trade-offs in marine protection: multi-species interactions within a community-led temperate marine reserve, ICES J. Mar. Sci. 74 (1) (2016) 263–276, https://doi.org/10.1093/icesjms/fsw166.
[100] N.L. Gutiérrez, R. Hilborn, O. Defeo, Leadership, social capital and incentives promote successful fisheries, Nature 470 (2011) 386.
[101] A. Di Franco, P. Thiriet, G. Di Carlo, C. Dimitriadis, P. Francour, N.L. Gutiérrez, A. Jeudy de Grissac, D. Koutsoubas, M. Milazzo, M.d.M. Otero, C. Piante, J. Plass-Johnson, S. Sainz-Trapaga, L. Santarossa, S. Tudela, P. Guidetti, Five key attributes can increase marine protected areas performance for small-scale fisheries management, Sci. Rep. 6 (2016) 38135.
[102] R. Haines, C. Hattam, M. Pantzar, D. Russi, Study on the Economic Benefits of MPAs. Luxembourg, European Commission, 2018, p. 93.
[103] M. Ashley, S.E. Rees, A. Cameron, North Devon Marine Pioneer Part 1: State of the Art Report of the Links between the Ecosystem and Ecosystem Services in the North Devon Marine Pioneer, A report to WWF-UK by research staff the Marine Institute at Plymouth University, 2018, p. 103.
[104] S.E. Rees, M. Ashley, A. Cameron, North Devon Marine Pioneer Report 2: A Natural Capital Asset and Risk Register A SWEEP/WWF-UK Report by Research Staff the, Marine Institute at Plymouth University, 2019.
[105] H.E. Fox, M.B. Mascia, X. Basurto, A. Costa, L. Glew, D. Heinemann, L.B. Karrer, S. E. Lester, A.V. Lombana, R.S. Pomeroy, C.A. Recchia, C.M. Roberts, J. N. Sanchirico, L. Pet-Soede, A.T. White, Reexamining the science of marine protected areas: linking knowledge to action, Conserv. Lett. 5 (1) (2012) 1–10.
[106] T. Hooper, M. Ashley, T. Börger, O. Langmead, O. Marcone, S. Rees, O. Rendon, N. Beaumont, M. Attrill, M. Austen, Application of the natural capital approach to the marine environment to aid decision-making, in: Report Prepared for the Department for Environment Food and Rural Affairs (Project Code ME5115), 2018, p. 109.
[107] T. Hooper, T. Börger, O. Langmead, O. Marcone, S. Rees, O. Rendon, N. Beaumont, M. Attrill, M. Austen, Applying the Natural Capital Approach to Decision Making for the Marine Environment, Ecosystem Services 36 (2019), 100947.
[108] N.L. Foster, M. Sciberras, E. Jackson, B. Ponge, V. Toison, S. Carrier, S. Christiansen, A. Lemasson, E. Wort, M. Attrill, Assessing the ecological coherence of the channel MPA network, in: Report Prepared by the Marine Institute for the Protected Area Network across the Channel Ecosystem (PANACHE) Project, INTERREG programme France (Channel) England funded project, 2014, p. 156.
[109] N.L. Foster, S.E. Rees, O. Langmead, C. Griffiths, M.J. Attrill, Assessing the ecological coherence of a marine protected area network in the Celtic Seas, Ecosphere 8 (2) (2017), e01688.
[110] C. House, D. Redmond, M.R. Phillips, An assessment of the efficiency and ecological representativity of existing marine reserve networks in Wales, UK, Ocean Coast Manag. 149 (2017) 217–230.
[111] M. Spalding, I. Meliane, A. Milam, C. Fitzgerald, L. Hale, Protecting marine spaces: global targets and changing approaches, Ocean Yearb. 27 (2013) 213–248.
[112] R. Hilborn, Counterpoint to sala and giakoumi, ICES (Int. Counc. Explor. Sea) J. Mar. Sci. 75 (3) (2018) 1169–1170.
[113] CBD, Convention on Biological Diversity. Strategic Plan for Biodiversity 2011-2020, Including Aichi Biodiversity Targets, 2010.
[114] Natural Capital Committee, Towards a Framework for Defining and Measuring Changes in Natural Capital. Working Paper 1. March 2014, Natural Capital Committee, 2014, p. 21.
[115] E.G. Drakou, L. Pendleton, M. Effron, J.C. Ingram, L. Teneva, When ecosystems and their services are not co-located: oceans and coasts, ICES (Int. Counc. Explor. Sea) J. Mar. Sci. 74 (6) (2017) 1531–1539.
[116] G.M. Mace, R.S. Hails, P. Cryle, J. Harlow, S.J. Clarke, REVIEW: towards a risk register for natural capital, J. Appl. Ecol. 52 (3) (2015) 641–653.
[117] HM Government, UK Marine Policy Statement, Crown Copyright, London, 2011, p. 47.
[118] P.J.S. Jones, L.M. Lieberknecht, W. Qiu, Marine spatial planning in reality: introduction to case studies and discussion of findings, Mar. Pol. 71 (2016) 256–264.
[119] P. Unai, P. Ignacio, M.A. William, M.A.C. Kai, M.D. Tim, G. Eneko, G.-B. Erik, S.d. G. Rudolf, M.M. Georgina, M.-L. Berta, P. Jacob, Off-stage ecosystem service burdens: a blind spot for global sustainability, Environ. Res. Lett. 12 (7) (2017), 075001.
[120] CBD, Protected Areas and Other Effective Area-Based Conservation Measures, 2018. UNEP/CBD/COP/DEC/XiV/8.
[121] D. Diz, D. Johnson, M. Riddell, S. Rees, J. Battle, K. Gjerde, S. Hennige, J. M. Roberts, Mainstreaming Marine Biodiversity into the SDGs: the Role of Other Effective Area-Based Conservation Measures (SDG 14.5), Marine Policy, 2017.

[122] S.E. Rees, S.C. Mangi, C. Hattam, S.C. Gall, L.D. Rodwell, F.J. Peckett, M.J. Attrill, The socio-economic effects of a Marine Protected Area on the ecosystem service of leisure and recreation, Mar. Pol. 62 (2015) 144–152.

[123] A.A. Rosenberg, M. Fogarty, A. Cooper, M. Dickey-Collas, N. GutiÚrrez, K. Hyde, C. Minte-Vera, Developing New Approaches to Global Stock Status Assessment and Fishery Production Potential of the Seas, Food and Agriculture Organization of the United Nations (FAO), Rome, Italy, 2014.

[124] G.J. Edgar, T.J. Ward, R.D. Stuart-Smith, Rapid declines across Australian fishery stocks indicate global sustainability targets will not be achieved without an expanded network of 'no-fishing' reserves, Aquat. Conserv. Mar. Freshw. Ecosyst. (2018) 1–14.

[125] S.J. Hall, B. Mainprize, Towards ecosystem-based fisheries management, Fish Fish. 5 (1) (2004) 1–20.

[126] J.S. Link, M. Dickey-Collas, M. Rudd, R. McLaughlin, N.M. Macdonald, T. Thiele, J. Ferretti, E. Johannesen, M. Rae, M. Handling, Mitsutaku, Clarifying mandates for marine ecosystem-based management, ICES (Int. Counc. Explor. Sea) J. Mar. Sci. (2018) fsy169-fsy169.

[127] P.J.S. Jones, Equity, justice and power issues raised by no-take marine protected area proposals, Mar. Pol. 33 (5) (2009) 759–765.

[128] B.D. Stewart, B.C. O'Leary, Post-Brexit Policy in the UK: A New Dawn? Fisheries, Seafood and the Marine Environment, University of York, 2017. https://www.york.ac.uk/media/yesi/yesioldwebsite/researchoutputs/Brexit%20Fisheries%20Brief.pdf. (Accessed 19 February 2019).

[129] M. Acreman, E. Maltby, A. Maltby, P. Bryson, N. Bradshaw, Wholescape Thinking: towards Integrating the Management of Catchments, Coast and the Sea through Partnerships – a Guidance Note. Report to the Natural Capital Committee, January 2018, 2018.

[130] M. Lockwood, J. Davidson, A. Curtis, E. Stratford, R. Griffith, Governance principles for natural resource management, Soc. Nat. Resour. 23 (10) (2010) 986–1001.

[131] Plymouth City Council, Plymouth Sound National Marine Park. Creating the UKs First National Marine Park: A Prospectus, 2018, p. 14.

[132] S. Pittman, L. Rodwell, R. Shellock, M. Williams, M. Attrill, J. Bedford, K. Curry, S. Fletcher, S. Gall, J. Lowther, A. McQuatters-Gollop, K. Moseley, S. Rees, Marine Parks for Coastal Cities: A Concept for Enhanced Community Well-Being, Prosperity and Sustainable City Living, Marine Policy **in press**, 2019.

[133] B.D. Stewart, C. Burns, A.P. Hejnowicz, V. Gravey, B.C. O'Leary, K. Hicks, F. M. Farstad, S.E. Hartley, Making Brexit work for the environment and livelihoods: Delivering a stakeholder informed vision for agriculture and fisheries, People and Nature 1 (4) (2019) 442–456, https://doi.org/10.1002/pan3.10054.