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Pink sea fans (*Eunicella verrucosa*) as indicators of the spatial efficacy of Marine Protected Areas in southwest UK coastal waters

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ABSTRACT

Globally, the need to identify and establish integrated and connected systems of Marine Protected Areas (MPAs) is becoming increasingly recognised. For best practice, these networks need to be planned and assessed against multiple criteria. However, building a sound evidence base to support decision-making processes is complex, as well as fiscally and logistically challenging. Recent studies have demonstrated the utility of integrating 'citizen science' data into mainstream scientific analysis, particularly where broad-scale spatial patterns of distribution are required. In UK waters, the pink sea fan (*Eunicella verrucosa*) is a nationally protected slow growing, cold-water coral, and is a representative species of reef features that provide habitat for many other sessile species. However, this species is vulnerable to physical impact and loss of suitable substratum, and is likely highly vulnerable to bottom-towed fishing gears. In this study, data from a volunteer-based marine survey programme ('Seasearch') are analysed with the aim of describing the spatial distribution and relative abundance of pink sea fan colonies throughout southwest UK coastal waters. The congruence between pink sea fans and the extant southern UK MPA network is reported, and the current threat from Bottom-Towed Gear (BTG) to pink sea fan dominated reefs, that have historically lacked protection, is quantitatively assessed. This analysis reveals that protection of this and other benthic species has been increased by management of previously 'open access' MPAs. Nonetheless, areas of pink sea fan habitat and their host reef systems exist outside extant protected areas in southwest UK seas, and as such are potentially at risk from bottom-towed fisheries. This analysis demonstrates the utility of well-organised citizen science data collection and highlights how such efforts can help inform knowledge on broad scale patterns of biodiversity.

1. Introduction

The revised Convention for Biological Diversity (CBD) calls for 10% of coastal and marine ecosystems to be protected through an integrated and well connected system of Marine Protected Areas (MPAs) by 2020 [3]. Within the EU, the Marine Strategy Framework Directive (MSFD) aims to protect and conserve marine ecosystems, with the explicit objective of halting the loss of, and thereby maintaining, biodiversity [5]. In the UK, a growing system of inshore and offshore MPAs, under-pinned by a range of legislative measures (e.g. Council Directive 92/43/EEC (Habitats Directive) and Council Directive 79/409/EEC (Birds Directive)), provide variable protection to species and habitats of national or European importance. In the UK, the term 'MPA' may encompass, Special Protection Areas (SPAs) for seabirds, Special Areas of Conservation (SACs), Nature Conservation MPAs (Scotland), and in England and Wales, newly established inshore and offshore Marine Conservation Zones (MCZs). For conservation best practice, MPAs need to be planned and assessed against multiple criteria including spatial adequacy, management objectives and effectiveness of regulation [12,20,29,30]. However, building a sound evidence base to support decision-making processes in MPA networks is complex [18,22,36,7] and consequently may be fiscally and logistically demanding.

The on-going integration of 'citizen science' data into mainstream scientific enquiry is rapidly increasing [34] and may be an important and cost-effective means of contributing to evidence bases in marine policy decision making [14]. Furthermore, citizen science data has improved both regional and national ecological knowledge on spatial and temporal patterns of distribution on

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species of conservation interest [25,26,38]; however, the collection of these data rarely uses volunteers to conduct large, coordinated, field work [6]. Seasearch is a volunteer-based marine survey programme for recreational divers (http://www.seasearch.org.uk) that was established in the mid 1980s. Seasearch divers are trained in underwater surveying techniques that facilitate the rigorous collection of data on the presence, abundance and health of multiple marine species and their habitats through a standardised method.

The assimilation of robustly sourced data, such as those gathered from citizen science schemes, over an extended time-period, may be a key component in assessing marine ecosystem health. With an ever increasing demand for human resources, and associated degradation of natural habitats, in excess of a third of the world's oceans have experienced a high level of anthropogenic damage [10]. Ecosystems with the highest predicted cumulative impact scores (where multiple drivers of anthropogenic change are combined) include hard and soft continental shelves and rocky reefs; almost half of all coral reefs having a high, to very high damage impact score [10]. Threats to corals can include climate-induced changes such as alteration in the ocean chemistry [8,24] and impacts from trawl fisheries (Bottom-Towed Gear; BTG) [9,37].

The pink sea fan (*Eunicella verrucosa*) is a temperate to cold-water gorgonian coral. Typically found off south and west coasts of the UK through to north-west Africa and into the Mediterranean [11]. Colonies may be widely separated, or may occur as 'forests', thereby providing valuable habitats for sessile and mobile animals [4]. They are associated with 'hard ground', as their basal holdfast requires a stable substratum on which to attach [1], and are therefore associated with UK reefs [13] of geogenic origin (bedrock or stony reef resulting from geological processes). Pink sea fans are vulnerable to mechanical damage [4], sensitive to abrasion, physical disturbance and loss of suitable substratum [13]. Their slow growth rate [4,31] and preferred habitat [13] likely make recovery/re-colonisation of negatively impacted colonies slow (in the order of decades). The species is considered 'vulnerable' by the IUCN Red List [41]. Pink sea fans are listed under Schedule 5 of the UK Wildlife and Countryside Act 1981 (as amended) and are protected under sections 9(1), 9(2) and 9(5). They were originally listed as a UK BAP species; however, as a result of [3] this has now been superseded by the UK post-2010 biodiversity framework. Accordingly, they are now listed as a species of principal importance on the English section 41 list and Welsh section 42 list under the NERC Act 2006. They are also a species FOCI (Features of Conservation Importance) for MCZ designation [16]. Although not listed as an EU Habitats Directive Annex II species, pink sea fan associated habitat may be protected via SACs as an Annex I habitat (reefs). See Table 1 for summary of pink sea fan legislation applicable to English and Welsh waters.

This study investigates the distribution of pink sea fan colonies in southwest UK coastal waters, as recorded by the Seasearch marine survey programme between 2001 and 2012, in the context of the extant UK MPA network and knowledge on inshore seabed fishing pressure. More specifically, this study: (i) describes the spatial distribution and relative abundance of pink sea fan colonies for south Wales and throughout southwest England, (ii) reports the congruence between pink sea fan occurrence and MPAs with and without legislative protection from BTG, and (iii) quantitatively assesses the threat from BTG to benthic marine species within and outside MPAs with respect to knowledge on inshore seabed fishing activities (coastal waters out to 12 nautical miles).

2. Methods

2.1. Seasearch marine surveys

The occurrence of pink sea fan colonies have been recorded by Seasearch volunteer SCUBA divers as a part of both general and species-specific surveys using a standardised methodology since 2001. The pink sea fan is an easily recordable species, having a colour and morphology unique to the species, leading to easy identification by non-specialist divers. Owing to the depth limitations of recreational SCUBA (30 m) and thus comparatively limited dive-time in deeper waters, the methodology was relatively simple. Firstly, the abundance of the species at the surveyed location was estimated using a semi-quantitative SACFOR scale (Super-abundant [numeric equivalent; 6], Abundant [5], Common [4], Frequent [3], Occasional [2] and Rare [1]). Secondly, a representative sample of pink sea fan colonies at each surveyed location was examined and various metrics (i.e. colony width/height, colour, condition, feeding status and presence of any fouling organisms, fishing gear or marine debris/litter) recorded [40]. Each volunteer was able to record approximately 15 colonies during a dive and the use of multiple recorders allowed up to 100 colonies to be surveyed at any one time.

To describe Seasearch dive density within the study area a grid comprised of hexagonal cells (200 km^2) was used to sum the total number of survey events, as recorded in the Seasearch database, within each cell for the period of the study. This total was divided by the coincident sea area (km^2) for each cell to provide mean dive density km^{-2}. The grid resolution was iteratively determined to provide the optimum cell area, being a balance between too many cells and therefore akin to the original data, and too few cells resulting in the density of the locations being over-smoothed and spatially uninformative.

To describe the relative abundance of pink sea fans the total number of unique dive sites with pink sea fan colonies present (termed Colonised Dive Sites; CDS) was summed within each cell and multiplied by the modal SACFOR score for all pink sea fan

Table 1
Summary of pink sea fan legislation applicable to English and Welsh waters.

Legislation	Status
Wildlife and Countryside Act 1981 (as amended)	Listed under Schedule 5, protected under sections 9(1), 9(2) and 9(5)
Natural Environment and Rural Communities (NERC) Act 2006[a]	
English section 41	Listed as species of principal importance
Welsh section 42	Listed as species of principal importance
Marine and Coastal Access Act 2009	Listed as designating species Features of Conservation Importance (FOCI)
Marine and Coastal Access Act 2009	May be protected as a component of the Habitat of Conservation Importance 'fragile sponge and anthozoan communities on subtidal rocky habitats' or the broad-scale habitats 'high energy circalittoral rock' and 'moderate energy circalittoral rock'
Habitats Directive (Council Directive 92/43/EEC)	May be protected via Special Areas of Conservation (SACs) as an Annex I habitat (reefs)

[a] Pink sea fans were originally listed as a UK BAP species; however, as a result of [3] this has now been superseded by the UK post-2010 Biodiversity Framework statutory lists of priority species and habitats. This in turn is legislated for under the NERC Act 2006.

colonies recorded within that cell. In this study a unique dive site represented a survey event where location coordinates (decimal degrees to 2 decimal places; approx. 1 km resolution) were not duplicated within the database. The relative abundance for each cell was divided by its coincident sea area. All spatial analyses were conducted in ArcMap 10 (ESRI, Redlands, US, http://www.esri.com) using coordinates conforming to the British National Grid (BNG) projection (metres).

2.2. Marine protected areas

To contextualise Seasearch data with the current UK MPA networks spatially referenced shapefiles of areas regulated to protect the seabed from bottom-towed fishing gears were obtained from Inshore Fisheries and Conservation Authorities (IFCAs) and the Marine Management Organisation (MMO). These organisations are responsible for regulating or providing scientific advice for the management of UK (English and Welsh) coastal and nearshore marine environments (<12 nautical miles from the coast). Observed distributions of pink sea fan colonies at CDS were then compared to this library of shapefiles to assess spatial congruency.

2.3. Fishing activity and threat analysis

To investigate the spatial overlap between areas of high pink sea fan abundance and fisheries using bottom-towed gear data on inshore fishing activity made by UK inshore fleet 2007–2009 were sourced [2]. Sightings data for vessels using trawl and dredging gear were rescaled to 0–1, and average (mean) sightings densities for both gear types were calculated for each hexagonal cell. A pink sea fan versus fisheries Relative Threat Index (RTI; arbitrary scale of 0–1; where 1 indicates greatest threat) was calculated for each hexagon grid cell as follows: pink sea fan relative abundance km^{-2}* fishing activity/max (pink sea fan relative abundance km^{-2}* fishing activity).

3. Results

3.1. Seasearch marine surveys

Seasearch surveys ($n=4482$) were conducted in nearshore waters (mostly out to 6 nautical miles) of Wales (Pembrokeshire and Swansea) and southwest England (Cornwall, Devon, Dorset, and Hampshire) for the period 2001–2012. No dives were conducted in the Bristol Channel due to poor visibility (Fig. 1a). Survey coverage varied due to dive site accessibility and logistical constraints. Concentrated survey effort occurred off Plymouth (South Devon) (2.4–3.2 dives km^{-2}). Areas that received moderate survey effort (0.9–2.4 dives km^{-2}) were: Milford Haven (Pembrokeshire), Lundy Island, Isles of Scilly, Penzance, The Manacles (Falmouth Bay), Bigbury Bay (South Devon), Brixham (South Devon) and Poole (Dorset) (Fig. 1b).

Pink sea fan colonies ($n=2823$) were recorded for the period 2001–2012 at 303 CDS. Concentrated, but isolated colonies of pinks sea fans were recorded off the Pembrokeshire peninsula, and the islands of Lundy and the Isles of Scilly. Colonies also occurred along the north coast of Cornwall and throughout the southern coast of England (Fig. 1c). The relative abundance of pink sea fan colonies varied. The greatest relative abundance of pink sea fans

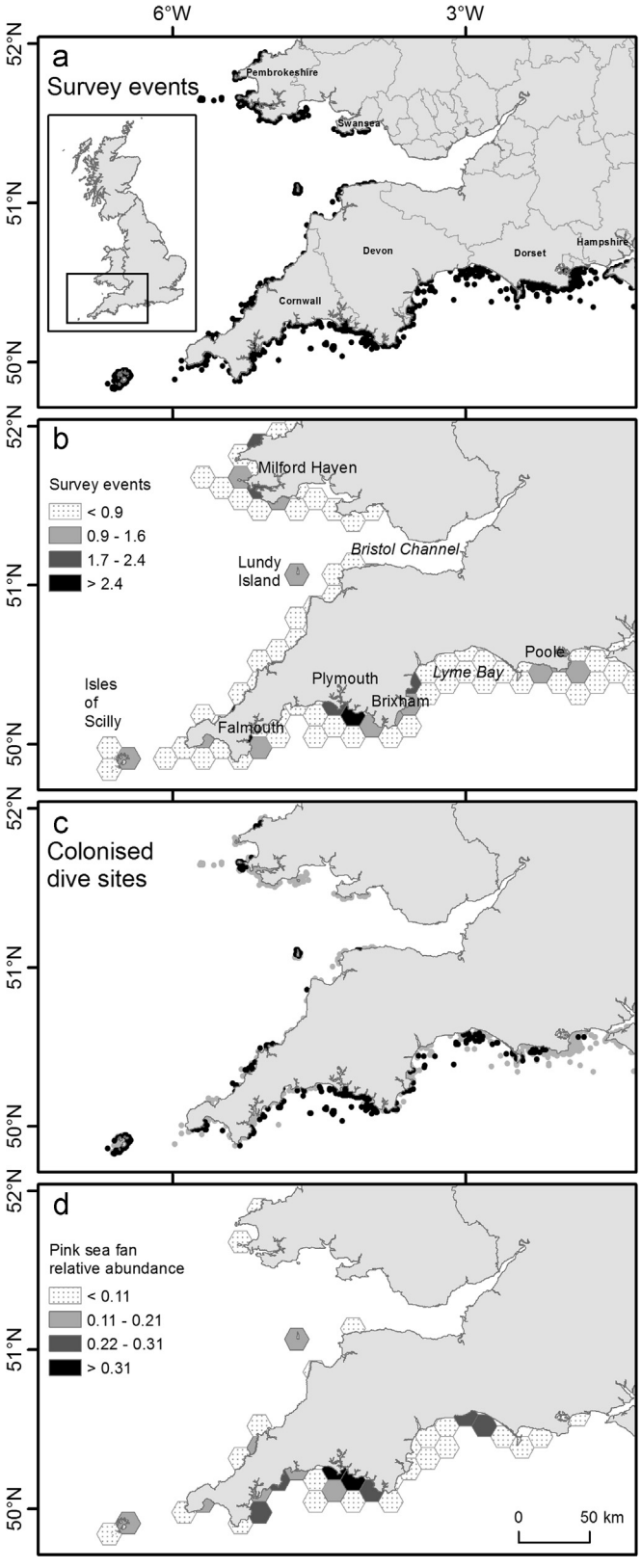

Fig. 1. Seasearch survey events and unique dive sites with pink sea fan colonies present (Colonised Dive Sites (CDS)) within the study area, 2001–2012. (a) Seasearch survey events ($n=4482$). (b) Survey events were summed by hexagon polygon sampling grid (200 km^2) and the resulting densities corrected for coincident sea surface area. Survey densities km^{-2} are represented by monochrome shading using a four class equal interval classification as detailed in the. (c) Seasearch survey events ($n=4482$), overlain with CDS ($n=303$, black circles). (d) Relative abundance of pink sea fans. Each hexagon grid is the product of the sum of CDS multiplied by the pink sea fan modal SACFOR score for that hexagon, corrected for coincident sea surface area. The relative abundance km^{-2} is represented by monochrome shading using a four class equal interval classification as detailed in the figure legend. All parts are drawn to the same spatial scale. Map drawn to Projected Coordinate System: British National Grid Transverse Mercator.

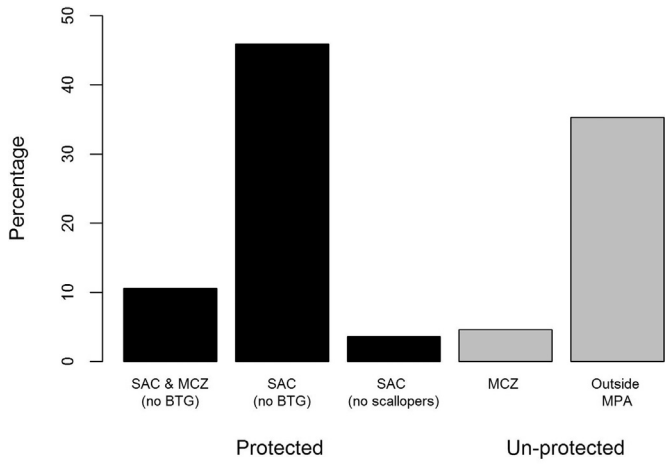

Fig. 2. Percentage coincidence of unique Colonised Dive Sites (CDS) and Marine Protected Areas (MPAs). Bars are labelled as follows; SAC & MCZ (no BTG): CDS within a Special Area of Conservation (SAC) with no access to Bottom-Towed Gear (BTG) and within a Marine Conservation Zone (MCZ). SAC (no BTG): CDS within a SAC with no access to BTG. SAC (no scallopers): CDS within a SAC closed to scallop dredgers (Welsh waters). MCZ: CDS within a MCZ. Outside MPA: CDS that are located outside of a MPA. Black bars, CDS with protection from bottom-towed gear, grey bars CDS without protection from bottom-towed gear.

occurred off Plymouth. Moderate abundances (0.1–0.3 relative abundance) occurred around the island of Lundy, the Isles of Scilly, The Manacles (Falmouth Bay), Bigbury Bay and Lyme Bay (Fig. 1d). Pink sea fan relative abundance was limited in other places, even where Seasearch survey effort was moderate i.e. Pembrokeshire, Brixham and Poole.

3.2. Marine protected areas

Sixty percent (60%) of CDS occurred within MPAs (SACs and designated MCZs) that offered protection to species from bottom-towed gear, 5% of CDS occurred within MPAs that currently offer no protection to benthic species and 35% of CDS occurred outside MPAs (Fig. 2).

Pink sea fan colonies coincident with MPAs, but without protection from bottom-towed gear, primarily occurred within the MCZs of The Manacles, Skerries Bank and Surrounds, Chesil Beach and Stennis Ledges, Whitsand Bay and Looe Bay; there were also isolated colonies coincident with the MCZs of Torbay and Padstow Bay and Surrounds (Fig. 3).

This analysis identified five key areas where pink sea fan colonies occurred outside the protection of the MPA network; north of the Pembrokeshire 'no scallopers' SAC, northeast and southwest of the Padstow Bay and Surrounds MCZ, Land's End to Penzance (east of the Land's End and Cape Bank SAC), Falmouth to St. Austell Bay (east of the Falmouth and Helford SAC) and west of Lyme Bay (Figs. 1 and 3).

3.3. Fishing activity and threat analysis

Relative threat to pink sea fan colonies from fishing vessels operating bottom-towed gears (2007–2009) was primarily concentrated along the south coast of Cornwall and Devon. Moderate to greatest threat (≥ 0.25 RTI, based on the arbitrary division of the RTI by quartiles (<0.25:low, $\geq 0.25 - \leq 0.75$: moderate, >0.75: high)) from trawls occurred around Falmouth Bay (The Manacles), and for trawls and dredges, south of Plymouth (including the Eddystone Reef complex), and Lyme Bay. There was low threat (<0.25 RTI) throughout the majority of southwest coastal waters for both gear types, with isolated areas along the north Cornish coast and Pembrokeshire (Fig. 4b and c).

4. Discussion

At present, approximately 16% of UK waters are designated as MPAs [17]. However, until 2014, there was no statutory underpinning on a UK-wide basis to protect vulnerable reef habitat from bottom-towed fishing gears within MPAs. Isolated sites were protected in a piecemeal fashion primarily as a result of local campaigns, e.g. Falmouth Bay [35], and Lyme Bay [27]. In 2010 all Welsh SACs were protected from bottom-towed scallop dredges under the Welsh Scallop (2010) Order. Between November 2013 and May 2014 byelaws introduced by Inshore Fisheries and Conservation Authorities (IFCAs) and the Marine Management Organisation (MMO) saw much of the remainder of reef habitat in southwest England SACs protected from all bottom-towed fishing gears.

This study reveals that within southwest UK coastal waters, the MPA network confers protection to approximately 60% of known pink sea fan colonies by way of either EU-level Special Areas of Conservation (SACs), or more recently under national legislation, through 'Marine Conservation Zones' (MCZs) under the Marine and Coastal Access Act (2009). Although not listed as an EU Habitats Directive Annex II species, pink sea fan associated habitat may be protected via SACs as an Annex I habitat (reefs); or via MCZs as a component of the Habitat of Conservation Importance 'fragile sponge and anthozoan communities on subtidal rocky habitats' or the broad-scale habitats 'high energy circalittoral rock' and 'moderate energy circalittoral rock' [23]. Since the first tranche of twenty seven MCZs were designated in 2013, pink sea fans have been directly considered as a designating (species) feature (Feature of Conservation Importance) for protection within some MCZs [12] both for its own intrinsic value, and as this species is generally considered a useful surrogate for the presence of 'hard ground', be that artificial or natural reef, as their basal 'holdfasts' must recruit onto solid substratum. Its presence on some areas of veneers of loose sediment around consolidated reefs has even resulted in an evidence base to support wide-scale buffers for protection against bottom-towed fishing gears around hard reef areas [28,32].

All SACs in this analysis contain 'reef' habitat of some kind (either bedrock or stony) as part of their designated features (see site applicable formal advice under Regulation 33/35 of The Conservation of Habitats and Species Regulations 2010 (as amended): http://publications.naturalengland.org.uk/category/3212324). Pink sea fans were recorded throughout the study area, with the exception of parts of the South Pembrokeshire, Gower peninsula, the Bristol Channel, North Cornwall and Bideford Bay in Devon. In the cases of South Pembrokeshire and the Gower Peninsula suitable rocky habitats occur but pink sea fans were not present probably due to the turbidity of coastal waters. Similarly, turbidity and lack of suitable habitats may preclude pink sea fans from colonising Bideford Bay and the Bristol Channel. In the case of North Cornwall, pink sea fans are potentially present in suitable habitats, but survey effort within the area is relatively low, or non-existent in some areas (Fig. 1a and c) because the coast is exposed and has limited diving infrastructure. There were no dive records for the Cape Bank and Land's End SAC (to the west and northwest of Land's End) (Fig. 3c). This is because these locations are too exposed and costly to access for recreational diving. However, underwater video and camera surveys of these sites by Natural England have confirmed the presence of pink sea fan colonies in both the inner and outer parts of the site [21]. Pink sea fans have not been recorded in the South Dorset MCZ to the south of Portland (Fig. 3e), probably because the conservation features here are coarse sediment and chalk reef and therefore potentially unable to support pink sea fans.

Although approximately 60% of known pink sea fan CDS are now within MPAs with protection from BTG, over 40% are not

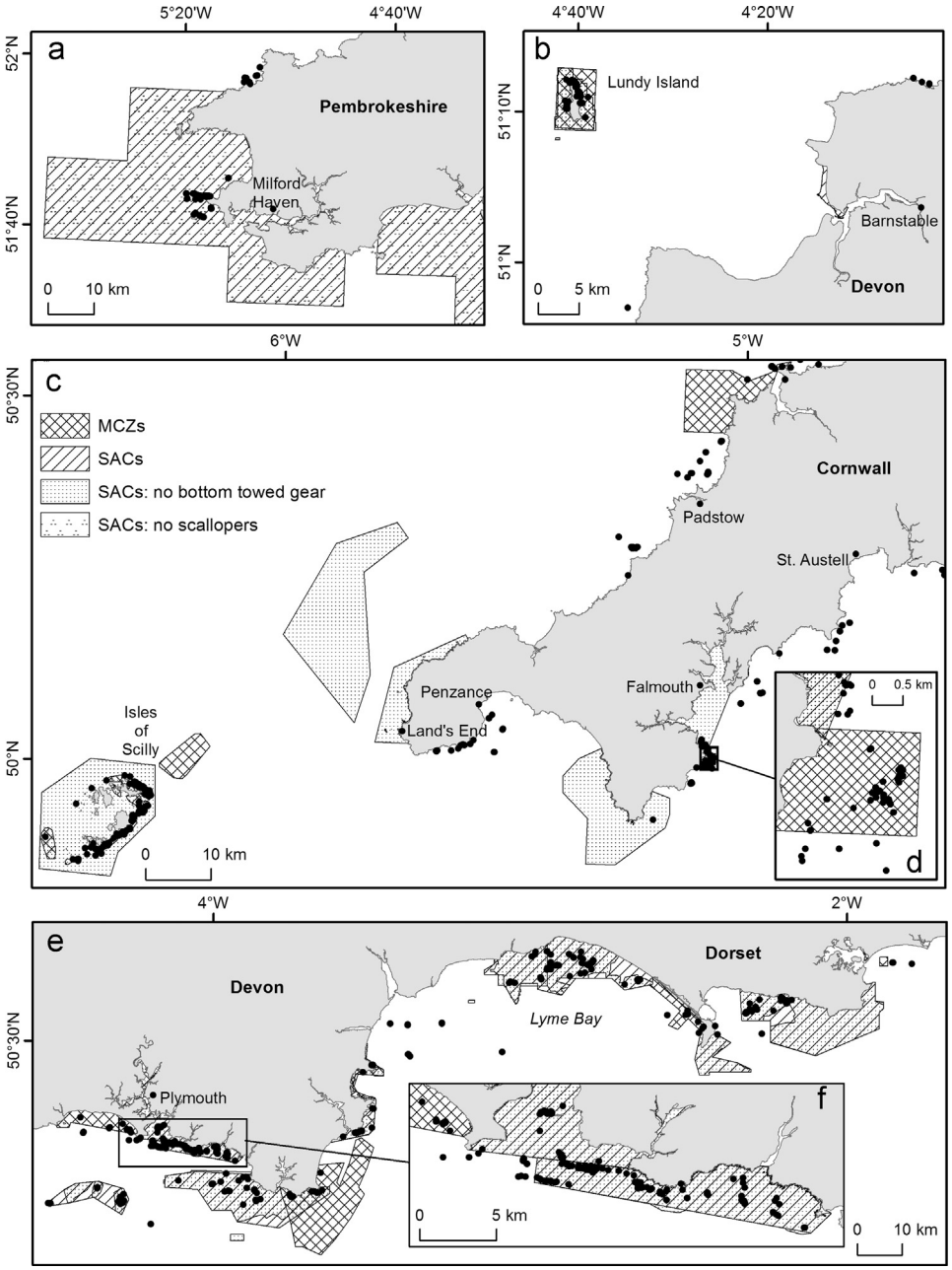

Fig. 3. Pink sea fan colonies ($n=2823$, black circles) as recorded by Seasearch survey events ($n=4482$, 2001–2012) with Marine Protected Areas (MPAs). MPAs are drawn in accordance with the legend detailed in part (c). Differing spatial scale used throughout all parts. Maps drawn to Projected Coordinate System: British National Grid Transverse Mercator.

coincident with protected areas. These locations occur outside of the MPA network; or, if situated within an MPA, byelaws do not exist to protect them from BTG. However, it is likely that established rocky reefs at some of these locations, e.g. The Manacles, provides *de facto* protection, as fishing gear would likely become trapped if it were to be towed over the site due to the vertical nature of the bedrock. Nonetheless, fisheries are likely to operate to the very limits of these features and so while these areas may be protected by their very nature they may become isolated and lack connectivity to surrounding habitats. Some habitats surrounding reefs also recruit and support pink sea fans and other species associated with hard geogenic structures [32]; as such, expansion of protection measures that surround reefs, into more sedimentary habitat, may provide wider ecosystem benefits [28].

Areas of unprotected pink sea fan habitat, with moderate to low risk of damage from bottom-towed gear occurred within, and adjacent to, the MCZ of The Manacles, within the MCZ of Whitsand and Looe Bay, and throughout areas of Falmouth and St. Austell Bay. Restricting access to bottom-towed gear inside established MPAs (i.e. The Manacles, Whitsand and Looe Bay) would result in a 'quick win' for protection of pink sea fan dominated habitat within these already designated areas. Deliberation could also be given to extending existing boundaries of MCZs/SACs (with appropriate protection) into adjacent waters where pink sea fan habitat exist (as identified within this study), as well as establishing MPAs in areas already colonised by pink sea fans. However, this is unlikely to be a practical consideration given that current MPA designations are based on multiple criteria and not solely focused on the distribution of a single species. Furthermore, implementation of additional legislative measures needs to accurately account for the possible displacement of fisheries effort to other habitats and species, as well as the social and economic implications that these

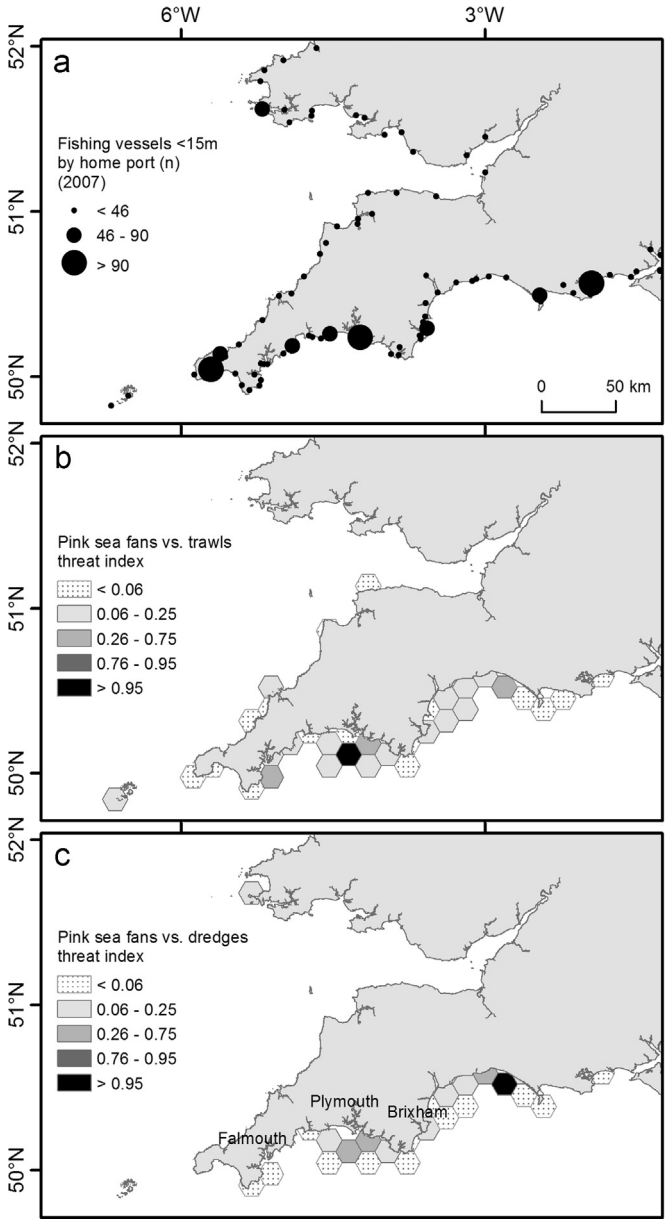

Fig. 4. (a) Fishing vessels < 15 m by home port (2007) (http://www.geostore.com/environment-agency/WebStore?xml=environment-agency/xml/ogcDataDownload.xml). Black circles represent total vessels (*n*) registered by home port as detailed in the figure legend. Relative Threat Index (RTI) for pink sea fans vs. (b) trawls and (c) dredges. Each hexagon grid is calculated as follows: pink sea fan relative abundance km^{-2} * fishing activity / max (pink sea fan relative abundance km^{-2} * fishing activity), and is represented by a five class classification as detailed in the figure legend. All parts are drawn to the same spatial scale. Maps drawn to Projected Coordinate System: British National Grid Transverse Mercator.

measures may have on targeted fisheries. Cost-benefit analysis including the potential recovery of ecosystem goods and services to the environment and associated human goods should also be factored in to any management measures [19]. It is important to recognise that this analysis focuses on the single threat of bottom-towed gear to a sessile benthic species. As such, other impacts associated with the growing pace of human development in the sea, including activities such as anchoring of shipping or civil engineering projects (e.g. renewable energy developments [15]; [39]) are not considered, all of which may disturb and potentially permanently alter benthic habitats.

Several caveats must be considered when interpreting the findings from this study. Using a citizen science approach to data collection no doubt poses some issues regarding species identification; however, the pink sea fan has a morphology and colour unique to the species (Fig. 5 and Supplementary material, Fig. S1), leading to a low likelihood of false positive detection, allowing confidence that the available data present a useful representation of pink sea fan distribution. The spatial coverage of the Seasearch pink sea fan dataset is necessarily limited by the depth range of recreational SCUBA and the level of effort invested by the Seasearch volunteers; as such, some areas within the study area have received more attention than others. Yet, in the absence of wide-scale and comprehensive government-funded surveys of south-west UK seabed biodiversity, the Seasearch programme provides an unrivalled spatial and temporal coverage. It is clear that knowledge on pink sea fan distribution in waters deeper than 30 m and for areas inaccessible to safe recreational SCUBA would complement this analyses; such knowledge could be gained from a focused campaign of novel rapid data collection using surface operated seabed survey equipment [33]. This sampling approach could extend knowledge in unsurveyed areas and validate extant data at randomly selected sites previously surveyed by Seasearch.

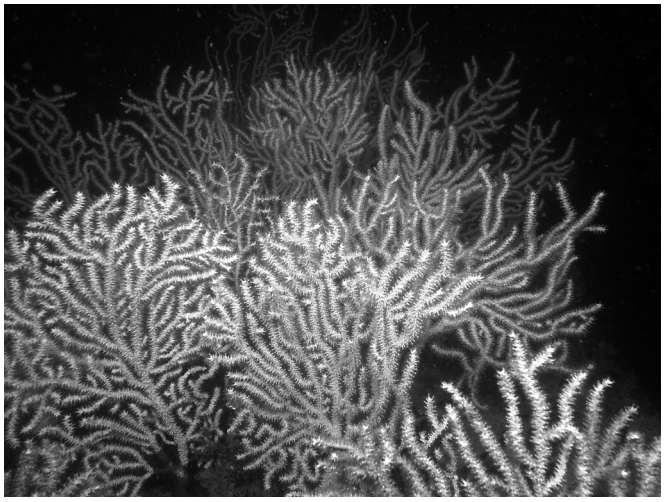

Fig. 5. Pink sea fan colony at Litte Wrea, The Manacles. The pink sea fan has a morphology and colour unique to the species. See Supplementary material, Fig. S1 for colour version. Image courtesy of C. Wood, Seasearch.

This study reveals that within southwest UK coastal waters the current MPA network is affording moderate protection to pink sea fan habitat that in turn, may confer protection to other associated benthic species. Nonetheless, deficiencies in spatial coverage and legislative protection exist that allows tracts of ecologically important, and sensitive benthos, to be unprotected from fisheries using bottom-towed gear. It is likely that adoption of recommendations made within this study would result in further integration and connectivity of the UK's developing system of MPAs, which could confer protection to multiple benthic species, including associated habitat buffering the edge of rocky subtidal reefs. Whilst our analysis focuses on a single species, the presented methodology could likely be applied to other benthic species to help build knowledge of distribution and threat, that in turn may further the knowledge base required to support policy making. Further, the work highlights the utility of well organised citizen science and how such efforts can inform marine spatial planning whether it be for conservation, fisheries or other marine developments such as for marine renewable energy. Indeed, with the inclusion of the need for monitoring programs under the MSFD to allow for ongoing assessment of the marine environment, the formal integration of citizen science collected data could have a valuable contribution to play in future appraisals of the environmental status of the marine ecosystem.

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Appendix A. Supplementary materials

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.marpol.2015.10.010.

References

[1] Pink sea-fan (*Eunicella verrucosa*), Species Action Plan, in: UK Biodiversity Group. Tranche 2 Action Plans English Nature for the UK Biodiversity Group, Peterborough, 1999.
[2] P. Breen, K. Vanstaen, R.W.E. Clark, Mapping inshore fishing activity using aerial, land, and vessel-based sighting information, ICES J. Mar. Sci.: J. du Conseil 72 (2015) 467–479.
[3] CBD, The strategic plan for biodiversity 2011 – 2020 and the Aichi biodiversity targets, in: Proceedings of the Conference of Parties 10, Decision X/2, Strategic Plan for Biodiversity 2011–2020, pp. 111–123. Tenth meeting of the Conference of the Parties to the Convention on Biological Diversity, Nagoya, Japan. ⟨www.cbd.int/doc/decisions/cop-10/full/cop-10-dec-en.pdf⟩, 18–29 October 2010.
[4] R. Coz, V. Ouisse, C. Artero, A. Carpentier, A. Crave, E. Feunteun, J.-M. Olivier, B. Perrin, F. Ysnel, Development of a new standardised method for sustainable monitoring of the vulnerable pink sea fan *Eunicella verrucosa*, Mar. Biol. 159 (2012) 1375–1388.
[5] 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). European Parliament and Council of the European Union. Official Journal of the European Union, 164, 2008, pp. 19–40.
[6] J.L. Dickinson, B. Zuckerberg, D.N. Bonter, Citizen science as an ecological research tool: challenges and benefits, Annu. Rev. Ecol. Evol. Syst. 41 (2010) 149–172.
[7] K.S. Gormley, L.H. McWhinnie, J.S. Porter, A.D. Hull, T.F. Fernandes, W. G. Sanderson, Can management effort be predicted for marine protected areas? New considerations for network design, Mar. Policy 47 (2014) 138–146.
[8] J.M. Guinotte, J. Orr, S. Cairns, A. Freiwald, L. Morgan, R. George, Will human-induced changes in seawater chemistry alter the distribution of deep-sea scleractinian corals? Front. Ecol. Environ. 4 (2006) 141–146.
[9] J.M. Hall-Spencer, P.G. Moore, Scallop dredging has profound, long-term impacts on maerl habitats, ICES J. Mar. Sci.: J. du Conseil 57 (2000) 1407–1415.
[10] 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 (2008) 948–952.
[11] P. Hayward, R. Ryland, Handbook of the Marine Fauna of North-West Europe, Oxford University Press, Oxford, 1995.
[12] J. Hill, B. Pearce, L. Georgiou, J. Pinnion, J. Gallyot, Meeting the MPA Network Principle of Viability: Feature Specific Recommendations for Species and Habitats of Conservation Importance, Natural England Commissioned Reports, NECR 043, 2010.
[13] K. Hiscock, *Eunicella verrucosa*. Pink sea fan. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme [on-line], Marine Biological Association of the United Kingdom, Plymouth, 2007.
[14] K. Hyder, B. Townhill, L.G. Anderson, J. Delany, J.K. Pinnegar, Can citizen science contribute to the evidence-base that underpins marine policy? Mar. Policy 59 (2015) 112–120.
[15] R. Inger, M.J. Attrill, S. Bearhop, A.C. Broderick, W. James Grecian, D.J. Hodgson, C. Mills, E. Sheehan, S.C. Votier, M.J. Witt, B.J. Godley, Marine renewable energy: potential benefits to biodiversity? An urgent call for research, J. Appl. Ecol. 46 (2009) 1145–1153.
[16] JNCC, Marine Conservation Zone Features. ⟨http://jncc.defra.gov.uk/page-4527⟩, 2015a.
[17] JNCC, Contributing to a Marine Protected Area Network. ⟨http://jncc.defra.gov.uk/page-4549⟩, 2015b.
[18] P. Jones, A. Carpenter, Crossing the divide: the challenges of designing an ecologically coherent and representative network of MPAs for the UK, Mar. Policy 33 (2009) 737–743.
[19] J.O. Kenter, R. Bryce, A. Davies, N. Jobstvogt, V. Watson, S. Ranger, J-L. Solandt, C. Duncan, M. Christie, H. Crump, The value of Potential Marine Protected Areas in the UK to Divers and Sea Anglers, UNEP-WCMC, Cambridge, 2013.
[20] E.F. Kostylev, F.P. Tkachenko, I.P. Tretiak, Establishment of 'Zernov's Phyllophora field' marine reserve: protection and restoration of a unique ecosystem, Ocean Coast. Manag. 53 (2010) 203–208.
[21] Natural England, Fal and Helford SAC-UK0013112-Land's End & Cape Bank candidate Special Area of Conservation Formal advice under Regulation 35 (3) of The Conservation of Habitats and Species Regulations 2010. ⟨http://publications.naturalengland.org.uk/publication/3048654?category=3212324⟩, 2012.
[22] Natural England, Natural England's advice to Defra on proposed Marine Conservation Zones for designation in 2013. ⟨http://publications.naturalengland.org.uk/publication/5717839965061120⟩, 2013.
[23] Natural England and the Joint Nature Conservation Committee, The Marine Conservation Zone Project: Ecological Network Guidance. ⟨http://jncc.defra.gov.uk/pdf/100705_ENG_v10.pdf⟩, 2010.
[24] J.C. Orr, V.J. Fabry, O. Aumont, L. Bopp, S.C. Doney, R.A. Feely, A. Gnanadesikan, N. Gruber, A. Ishida, F. Joos, R.M. Key, K. Lindsay, E. Maier-Reimer, R. Matear, P. Monfray, A. Mouchet, R.G. Najjar, G.-K. Plattner, K.B. Rodgers, C.L. Sabine, J. L. Sarmiento, R. Schlitzer, R.D. Slater, I.J. Totterdell, M.-F. Weirig, Y. Yamanaka, A. Yool, Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms, Nature 437 (2005) 681–686.
[25] S.K. Pikesley, B.J. Godley, S. Ranger, P.B. Richardson, M.J. Witt, Cnidaria in UK coastal waters: description of spatio-temporal patterns and inter-annual variability, J. Mar. Biol. Assoc. UK 94 (2014) 1401–1408.
[26] S.K. Pikesley, M.J. Witt, T. Hardy, J. Loveridge, J. Loveridge, R. Williams, B. J. Godley, Cetacean sightings and strandings: evidence for spatial and temporal trends? J. Mar. Biol. Assoc. UK 92 (2012) 1809–1820.
[27] S.E. Rees, M.J. Attrill, M.C. Austen, S.C. Mangi, J.P. Richards, L.D. Rodwell, Is there a win–win scenario for marine nature conservation? A case study of Lyme Bay, England, Ocean Coast. Manag. 53 (2010) 135–145.
[28] 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 (2013) 14–21.
[29] C.M. Roberts, J.P. Hawkins, J. Fletcher, S. Hands, K. Raab, S. Ward, Ward Guidance on the size and spacing of Marine Protected Areas in England Natural England, Commissioned Report NECR037, 2010.
[30] C. Rondinini, F. Chiozza, Quantitative methods for defining percentage area targets for habitat types in conservation planning, Biol. Conserv. 143 (2010) 1646–1653.
[31] S. Sartoretto, P. Francour, Bathymetric distribution and growth rates of *Eunicella verrucosa* (Cnidaria: Gorgoniidae) populationsalong the Marseilles coast (France), Sci. Mar. 76 (2011) 349–355.
[32] E. Sheehan, S. Cousens, S. Nancollas, C. Stauss, J. Royle, M. Attrill, Drawing lines at the sand: evidence for functional vs. visual reef boundaries in temperate Marine Protected Areas, Mar. Pollut. Bull. 76 (2013) 194–202.
[33] E.V. Sheehan, T.F. Stevens, M.J. Attrill, A quantitative, non-destructive methodology for habitat characterisation and benthic monitoring at offshore renewable energy developments, PLoS One 5 (2010) e14461.
[34] J. Silvertown, A new dawn for citizen science, Trends Ecol. Evol. 24 (2009) 467–471.
[35] J-L. Solandt, T. Appleby, M. Hoskin, Up Frenchman's creek: a case study on managing commercial fishing in an English special area of conservation and its implications, Environ. Law Manag. 25 (2013) 133–139.
[36] 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 (2014) 145–152.
[37] S.F. Thrush, P.K. Dayton, Disturbance to marine benthic habitats by trawling and dredging: implications for marine biodiversity, Annu. Rev. Ecol. Syst. (2002) 449–473.
[38] M.J. Witt, T. Hardy, L. Johnson, C.M. McClellan, S.K. Pikesley, S. Ranger, P. B. Richardson, J-L. Solandt, C. Speedie, R. Williams, Basking sharks in the northeast Atlantic: spatio-temporal trends from sightings in UK waters, Mar. Ecol. Prog. Ser. 459 (2012) 121–134.
[39] M.J. Witt, E.V. Sheehan, S. Bearhop, A.C. Broderick, D.C. Conley, S.P. Cotterell, E. Crow, W.J. Grecian, C. Halsband, D.J. Hodgson, P. Hosegood, R. Inger, P. I. Miller, D.W. Sims, R.C. Thompson, K. Vanstaen, S.C. Votier, M.J. Attrill, B. J. Godley, Assessing wave energy effects on biodiversity: the Wave Hub experience, Philos. Trans. Royal Soc. A: Math. Phys. Eng. Sci., 370, (2012) 502–529.
[40] C. Wood, Pink sea fan survey 2001/2. A report for the Marine Conservation Society, 2003.
[41] World Conservation Monitoring Centre. *Eunicella verrucosa.* The IUCN Red List of Threatened Species.Version 2014.3. ⟨www.iucnredlist.org⟩, 1996.

Glossary

BNG: British National Grid;

BTG: Bottom-Towed Gear;
CBD: Convention for Biological Diversity;
CDS: Colonised Dive Sites;
EU: European Union;
FOCI: Features of Conservation Importance;
IFCA: Inshore Fisheries and Conservation Authorities;
IUCN: International Union for Conservation of Nature;
MCZ: Marine Conservation Zones;
MMO: Marine Management Organisation;
MPA: Marine Protected Area;
MSFD: Marine Strategy Framework Directive;
NERC: Natural Environment Research Council;
NGO: Non Governmental Organisation;
RTI: Relative Threat Index;
SAC: Special Areas of Conservation;
SACFOR: Super-abundant Abundant Common Frequent Occasional Rare;
SCUBA: Self-contained Underwater Breathing Apparatus;
SPA: Special Protection Areas;
UK: United Kingdom.