Title

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Main Heading

Abstract Heading

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Coastal and inshore areas of the marine environment have historically been overexploited and subjected to high levels of pressure. These pressures have had large impacts on coastal marine resources and ecosystems, and as such, many different management tools have been implemented to negate these impacts. One widely used tool is the implementation of marine protected areas (MPAs) (Cleguer et al. 2015; Gallacher et al. 2016). Objectives of MPAs have focused primarily on commercial fishing stocks (Roberts, Hawkins, and Gell 2005), yet increasingly there has been a shift towards ecosystem based management (Halpern et al. 2007).

Within ecosystem based management objectives, recovery or maintenance of ecosystem functioning and services is often a high priority. Ecosystem function can be thought of as a complex system of interactions or individual functions, which combine to sustain the system as a whole through multiple different processes (Jax 2005). Services provided by ecosystem functions can then be thought of as the outcome in respect to another organism, such as the function of an oyster reef, which provides services to humans by enhancing water quality and stabilising the shoreline (Grabowski et al. 2012).

Even as more importance is set on ecosystem functioning and the services that these functions provide, species or taxonomy based diversity is frequently being used to monitor MPAs (Soykan and Lewison 2015; Starr et al. 2015; Ferreira et al. 2017). However, large changes in taxonomic based biodiversity do not necessarily imply equally large changes to the ecosystem function (Solan et al. 2004; Törnroos and Bonsdorff 2012; Wong and Kay 2019), especially when an ecosystem contains high levels of functional redundancy or overlap of functions (Micheli and Halpern 2005; Guillemot et al. 2011). Hence, the use of functional or biological traits has been suggested to have potential for both monitoring and management (King and McFarlane 2003; Tillin et al. 2006; Bremner 2008; Wiedmann et al. 2014; Rijnsdorp et al. 2016), as the functional diversity of a system will dictate the ecosystem functioning (Díaz and Cabido 2001; Perović et al. 2018). The utility of biological traits or Biological Trait Analysis (BTA) in community ecology, similar to many disciplines, primarily started within terrestrial and freshwater environments (Bonada, Dolédec, and Statzner 2007; Statzner and Bêche 2010; Fountain-Jones, Baker, and Jordan 2015; Bello et al. 2016) but has increased in recent years in the marine environment (Berthelsen, Hewitt, and Taylor 2015; Coleman et al. 2015; Juan et al. 2015).

Marine Biological Trait Analysis (BTA) is overwhelmingly utilised to assess either fish or benthic invertebrate communities (Beauchard et al. 2017). Benthic invertebrates are well known as bio-indicators of ecosystem health, disturbance or biogeochemical processes (De-La-Ossa-Carretero et al. 2012; Belley and Snelgrove 2016; Parmar, Rawtani, and Agrawal 2016; Munroe et al. 2018) and fish assemblages have been used to assess fishing and climate change impacts (Benoit et al. 2013; Benoıt and Swain 2008), yet neither will give a full picture of all the functions nor services that an ecosystem is providing. Likewise, when just analysing fish species, the analysis is limited to one taxonomic group and higher range trophic levels, even though it is a functionally diverse group. Subsequently, to create a full picture of the functional space of an ecosystem and how that ecosystem is changing with time or impact, sampling methods which maximise trophic levels sampled should be employed (Deraison et al. 2015; Nordstrom et al. 2015; Thackeray et al. 2016; Perović et al. 2018). This, in turn, will lead to more specific and thus effective management regimes (Pedersen et al. 2017).

The Marine Protected Area in Lyme Bay was primarily a voluntary closure of a few small reef areas, then subsequently a much larger portion of the bay, 206km2, was designated as a Statutory Instrument (SI) in 2008, which banned all forms of mobile demersal fishing activity (trawling and scallop dredging). The area was protected for the large amounts of fragile, ecologically important rocky reef habitat (Hiscock and Breckels 2007), which can be severely damaged by mobile fishing gear, which was historically used throughout the bay. Finally, protection was extended by the implementation of a Special Area of Conservation (SAC) in 2010, which increased protection at the eastern and western edges of the SI. The SAC limits demersal towed gear on specific reef areas, with other activities requiring specific permits. To keep to the objectives of the protected area, a monitoring scheme was set up by researchers from the University of Plymouth, starting in 2008, with the aim of studying the protected area in a non-invasive and non-extractive way (Sheehan, Stevens, et al. 2013; Stevens et al. 2014). Underwater videography, in the form of a flying towed array (Sheehan, Stevens, and Attrill 2010) has been deployed annually since the protected areas inception.

The data produced provide the perfect opportunity to study the functional changes happening throughout the protected area, as well as recovery of the once heavily exploited ecosystem. Functional Divergence (FDiv), Functional Richness (FRic) and Functional Evenness (FEve), which are unaffected by difference in the type of abundance values used (e.g. biomass, count, percentage cover or density; Villeger, Mason, and Mouillot (2008)), were used to assess Functional Diversity. The combination of these three indices (FDiv, FRic and FEve) is thought to be a comprehensive assessment of Functional Diversity (Villeger, Mason, and Mouillot 2008).

The aim of this work was to utilise functional diversity measures derived from Biological Trait Analysis to assess health and overall ecosystem functioning of Lyme Bay MPA. It was hypothesised that the older and higher levels of protection would increase in Functional Diversity relative to the younger and lower level protection areas.

Four hypotheses were set out to assess the functional diversity across the four different protection levels:

1. Functional diversity will be highest in areas of highest protection;
2. Functional diversity will be highest in older areas of protection;
3. Functional redundancy will be highest in areas of highest protection;
4. Functional redundancy will be highest in older areas of protection.

## Materials and Methods

### Study Location

The MPA is located inside Lyme Bay, an embayment stretching from Portland Bill at the eastern end to Start Point at the western end on the south coast of the UK, covering 206km2 of seabed south of Lyme Regis (Figure 1). The closure includes rocky reef habitats (bedrock, boulders and cobbles), pebbly sand and soft muddy sediments (Sheehan, Stevens, et al. 2013). Sampling was carried out across the whole MPA with sites in four different categories: Previous Voluntary Closure (PVC); Statutory Instrument (SI); Special Area of Conservation (SA) and Open Control (OC).

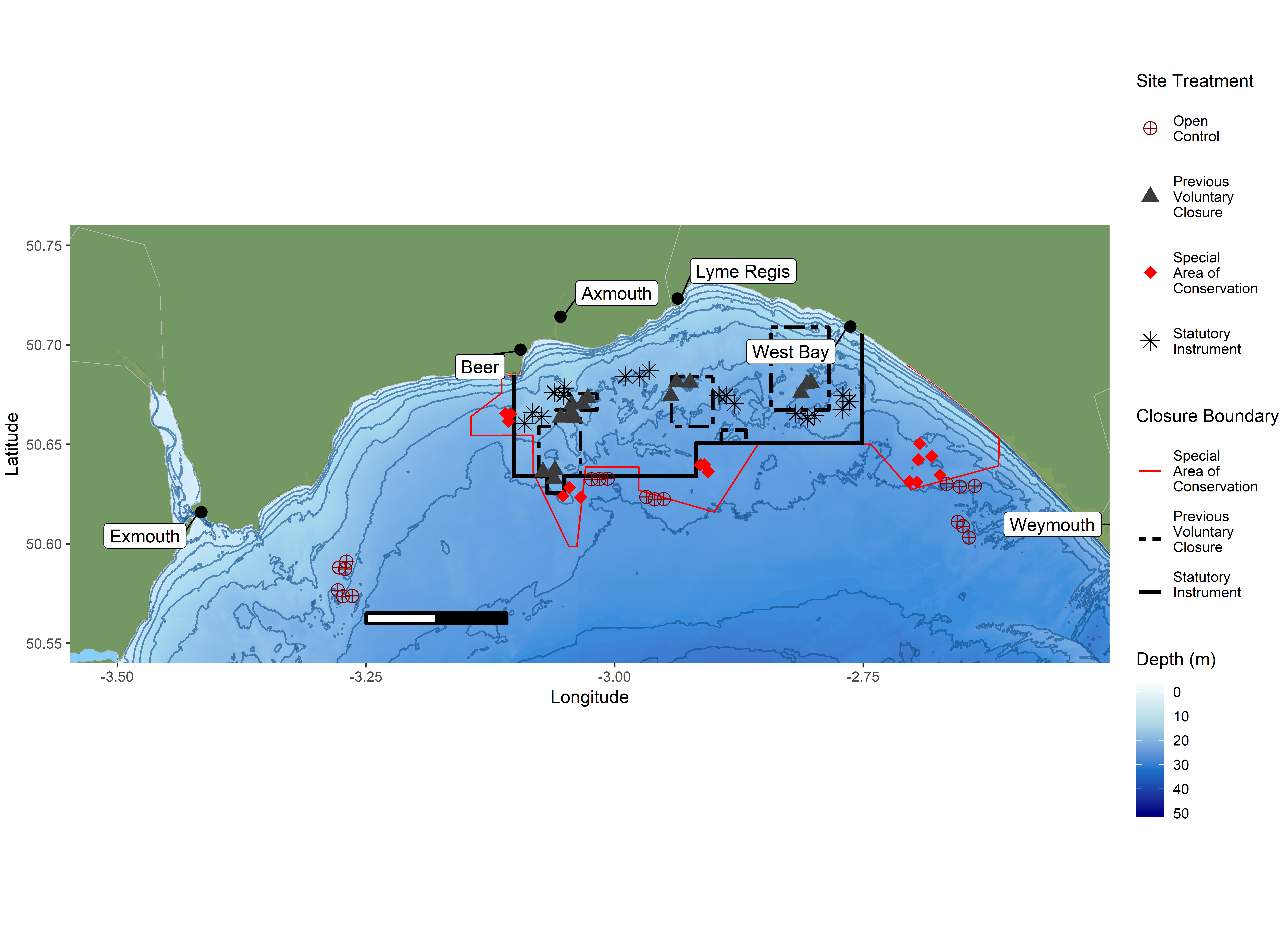


Figure 1

### Data Collection

#### Towed Flying Array

The Towed Flying Array is a way of performing 200 metre long by 0.5 metre wide High Definition (HD) video transects over heterogeneous and fragile benthic ecosystems (Sheehan, Stevens, and Attrill 2010). The array is a bespoke rig mounted with: a HD video camera (Surveyor-HD-J12 colour zoom titanium, 720p); LED lights (Bowtech Products limited, LED-1600-13); two green lasers (Z-bolt Scuba-1) and a mini CTD profiler (Valeport ltd). The camera is connected to a Bowtech System power supply/control unit by an umbilical cord, which allows control of the lights, camera aperture and camera focus in real time. The camera and the lasers are positioned at a 45 angle to the seabed, with the lasers parallel with a known distance. This allows the quantification of the field of view.

#### Video Analysis

Videos were analysed in two ways. Firstly, all inconspicuous or infrequent fauna were counted from watching the entire video at normal speed, enumerating all individuals that passed through the ‘gate’ made by the lasers. Secondly, frame grabs were extracted from the video (Cybertronix frame extractor) and a digital 0.25m2 quadrat overlaid. Frame grabs were only analysed if they met certain criteria of habitat, focus of camera, laser placement and visibility with 30 frames calculated to be the most appropriate (Sheehan, Cousens, et al. 2013; Stevens et al. 2014). All species were identified to the highest possible taxonomic level. However, morphologically similar species were grouped, as they would be too difficult to be confident of species level classification. Numbers of towed videos were 47 in 2008 to 2010 (15 SI tows, 13 PVC tows and 13 OC tows) and 66 in 2011-2018 (18 SI tows, 15 PVC tows, 15 SAC tows and 18 OC tows). Species were enumerating using one methodology then converted to relative abundance to create a Site x Species matrix of relative abundance and combined for both methodologies.

### Functional Traits

#### Trait Acquisition

In total, 10 functional traits were used with a cumulative 60 modalities in total (Table 1). They were selected for importance for the benthic environment and its coupling with other environments in the ecosystem (e.g. Pelagic/Neritic), as well as availability of information (MarLIN 2006; Shojaei et al. 2015; Beauchard et al. 2017; Froese and Pauly 2019; Palomares and Pauly 2019). Trait data were taken from multiple different sources: MarLIN BIOTIC; Fishbase and Sealifebase. When appropriate trait information wasn’t available from these three repositories, literature was searched. If trait data for close taxonomic relatives were available (Genus/Family) they were used for species with limited trait information. Fuzzy coding was used to quantify traits where individuals may follow multiple modalities of a single trait (Chevenet, Dolédec, and Chessel 1994). All modalities within each individual trait sum to equal 1 so that a trait with more modalities would not be weighted higher than another (Laliberté and Legendre 2010). This created a Trait by Species matrix for the Towed Flying Array.

#### Functional Diversity

The Trait x Species and Site x Species matrices were input into the R package ‘FD’, which calculates multiple different functional diversity indices using Euclidean distance (Laliberté and Legendre 2010; Laliberté, Legendre, and Shipley 2014). Functional Divergence (FDiv), Functional Richness (FRic) and Functional Evenness (FEve) were calculated for each tow.

#### Functional Redundancy

To calculate functional redundancy, the same Trait x Species matrices were input alongside the Species x Site matrices for all methodologies into the R package ‘funrar’. ‘Distinctiveness’ from this package calculates how functionally rare each species is at each site, returning a value from 0 (not rare) to 1 (fully distinct), meaning many close to 0 values imply high redundancy. ‘Uniqueness’ from this package calculates how functionally rare each species is across the whole matrix, returning a value from 0 (not rare) to 1 (fully distinct), meaning many close to 0 values imply high redundancy.

#### Statistical Analysis

Permutational Analysis of Variance (PERMANOVA) was used to test differences in Functional Diversity between years and treatments, with Year and Treatment as fixed factors. The factors had eleven and four levels respectively (Year: 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017 and 2018; Treatment: PVC, SI, SA and OC). The statistical significance of the variance components were tested using 9999 permutations under a reduced model (Anderson 2001; Anderson and Braak 2002). Unless stated otherwise, all multivariate analyses were done on the basis of a Euclidean distance matrix calculated from the Index values (PERMANOVA+) (Anderson, Gorley, and Clarke 2008; Clarke and Gorley 2015): Primer v7:(Clarke and Gorley 2015). Significant interactions (p<0.05) of fixed terms were tested using PERMANOVA pairwise tests (Sheehan, Cousens, et al. 2013).

## Results

### Functional Diversity

There were similar levels of functional divergence across all treatments, whereas functional evenness was lower in the higher protected areas in comparison to the OC. The reverse pattern can be seen in the functional richness with OC as the lowest of all treatments. Regardless of treatment, functional divergence steadily decreases with time. Functional Evenness shows no change with time, whereas functional richness increases after three years, decreases in 2014 then stays relatively constant.

All three functional indices, when combined, show separation between the OC and the other treatments after the first three years of protection (Distance to Centroid MDS). This is primarily being driven by the functional richness, which is higher in the PVC and SI treatments (Distance to Centroid MDS Vector, correlation of 0.97).

### Functional Distinctiveness

Functional distinctiveness did not change with increased time but did showed lower levels of distinctiveness in the higher levels of protection in comparison with the OC.

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