Fal and Helford Recreational Boating Study

Chapter 1:

Single block, sub-tidal, permanent moorings

Ecological impact on infaunal communities due to direct, physical disturbance from mooring infrastructure

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Falmouth Harbour Commissioners (FHC)

Cornwall Council (CC)

Natural England (NE)

University of Plymouth (UoP)

Environment Agency (EA)

A&P Ports (A&P)

St. Mawes Pier and Harbour Company

Truro and Penryn Harbour Authority

Duchy of Cornwall

Port Pendennis Marina

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Version 1.0	Independent sections to relevant partners for initial comment.
Version 1.1	Distributed to all Project Partners and Scientific Advisors for comment.
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Executive Summary

Study

The Fal and Helford Recreational Boating Project evolved in response to a shortage of information on the impact of recreational boating activities and associated infrastructure (e.g. mooring blocks and chains, pontoons). The development of the project was driven forward by a Project Partnership of local organisations who aimed to conduct an Environmental Assessment, mapping infrastructure and impact within the Fal and Helford estuaries. The one year Fal and Helford Study was one work package of the Project. The study was streamlined to investigate one type of mooring infrastructure but at a statistically robust level. The aims of the Fal and Helford Study were to quantify the impact of direct physical disturbance from single block, sub-tidal recreational boat moorings and to use this to estimate the level of impact across the estuaries, to make management recommendations, develop a transferable methodology and guide future study.

The Fal and Helford estuaries are highly biologically diverse, of socio-economic importance and of conservation interest as demonstrated by their designations. The two estuaries are different in character but both contain a diverse range of sub-tidal sediment habitats; both estuaries are also extremely popular for water-based recreation, offering mariners a wide range of facilities throughout the year. Recreational boating activities have the potential to influence the seabed and its associated fauna through a variety of impacts. This study addresses only direct physical disturbance resulting from the most prominent type of mooring infrastructure within the estuaries. The movement of a mooring disturbs the upper layers of sediment and creates a 'scour' through the abrasive physical action of the chain around the mooring block. Literature on this impact is skewed towards seagrass habitats and its effect on estuarine sediment habitats has not been quantified. Disturbance is a natural influential factor in marine systems and some disturbances from human sources (anthropogenic disturbances) may mimic the effect of natural disturbance; however an increased frequency of disturbance within an area can also detrimentally affect the community of organisms present. Recreational boating infrastructure has the potential to impact upon the features of interest within the Special Area of Conservation (SAC) and overlap between these features and mooring infrastructure emphasises the need for research into the potential extent of associated ecological impact.

Surveys

Brief epifaunal video surveys were completed across 4 locations; Falmouth, Mylor, St. Mawes and Durgan. Transects ran between moorings and across control areas to establish the epifauna present (epifauna being the faunal or animal life present on the surface of the seabed). The results were analysed statistically to investigate differences in the community of organisms between the different survey locations and between moorings and control (un-impacted) areas. Similarities in the community composition of samples were identified and the significance of these similarities were tested to determine the influence of survey location, survey site and the presence of mooring infrastructure in determining the epifaunal community present.

The main infaunal surveys of the study were completed across the locations of Falmouth, Mylor and St. Mawes. Infaunal sampling of Durgan (Helford) did not occur for logistical reasons. These surveys were conducted to detect potential differences in infaunal communities (infauna being the faunal or animal life present within the seabed sediment) at set distances away from the physical disturbance caused by individual moorings. Core samples were collected by divers from mooring sites and corresponding control sites. Within mooring areas the set distances corresponded to areas influenced by the thrash chain (2 metres), riser chain (5 metres) and outside the swinging reach of the mooring infrastructure (11 metres). All organisms were picked from the samples and identified to an intermediate identification level[1]. A series of standard biodiversity measures were calculated (abundance, species richness and grouped abundances) and these were analysed to determine the significance of the influence of distance on each measure. Similarities were then investigated at the community level and this data was again analysed to determine the significance of distance. Sediment samples were collected alongside the infaunal samples to determine differences in grain size and organic material. Sediments were analysed to determine the influence of mooring infrastructure on the sediments and the influence of the sediment on the infaunal community.

Results

It became apparent during analysis of the epifaunal survey output that the quality of the footage was only sufficient to consistently detect large organisms and that the abundances of these could not be quantified; therefore the results of the epifaunal survey should be treated with caution. Within this video footage 38 different groups of epifaunal organisms were identified; however no significant difference could be detected between the epifaunal communities of the mooring and control areas. An apparent separation of the different survey locations was identified, but at the level of impact (mooring area or control area) no obvious trend was detected. Analysis of the epifaunal communities present indicated significant spatial variation across locations (communities were different in different locations). Although the difference between mooring and control areas was not significant, the analysis indicated that the extent of the effect of the moorings varied across survey sites within the different locations.

Analyses of sediments indicated the distance from the mooring significantly influences the grain size, with a greater proportion of coarser sediment grains closer to the mooring blocks. On a small scale, the results indicated significant spatial variation (differences due to different sample sites), with differences present between sites within locations. Distance from the mooring infrastructure did not appear to affect the level of carbon content in the sediment; however, at small scales (at site level within the locations) spatial variation was again significant.

Within the infaunal samples 95 different groups of organisms were identified. Measures of abundance and biodiversity (species richness) of the samples were both significantly influenced by the distance from the mooring centre and also showed small-scale spatial variation (differences at site level within the locations). Combined abundances of organisms across three prominent phyla[2] indicated the influence of distance was not even; indicating that some phyla may be more susceptible to impact. Of those examined Crustacea (crabs, amphipods) showed a significant overall influence, indicating that this group may be more adversely affected than the others. Spatial variation was also influential in the abundances of the three main phyla and the different factors (the sample distance, site and location) interact in determining the abundances of these groups. Differences between locations were apparent in the community level data; therefore each survey location was also analysed separately. Within individual locations the greatest homogeneity (similarity) was apparent within the control samples and analyses indicated distance to be important in influencing the community composition. A final analysis, combining aspects of the community and sediment analyses, indicated distance from the mooring to be significant and implied distance to be responsible, alongside the sediment grain size and spatial variation, in determining the composition of infaunal communities.

Discussion

Sediment grain size was significantly influenced by the presence of mooring infrastructure on the seabed. Samples closest to the mooring consisted of coarser particles, potentially due to the re-suspension of finer sediments by the movement of the mooring chain. The difference was most prominent in Falmouth, potentially due to the highly

[1] Organisms were identified to an intermediate group or taxonomic level (usually family). This level of identification is quicker to process than species level identification but still capable of detecting of environmental impacts.
[2] Phyla (singular phylum) are broad categories that group similar organisms together. For example the phylum Crustacea groups crabs, lobsters, amphipods and isopods together based on similarities in body structure.

mixed sediment composition in this location. No significant difference was detected in organic content between the samples. The results of the sediment analysis must be interpreted with care as this was not a primary aim of the study and replication of samples was limited.

An ecological impact resulting from the physical disturbance of the mooring infrastructure was detectable within the infaunal communities; however the physical extent of this impact was variable. When considering all biodiversity measures and all locations surveyed, an ecological impact of mooring disturbance can be identified as conclusively present between 2 and 5 metres and visible at between 5 and 11 metres. This gives a strong estimate of the area of seabed significantly physically impacted per mooring of between 12.6 and 78.5 metres^2 (2–5 metre radius) and a more ecologically conservative estimate of between 78.5 and 380.1 metres^2 (5 -11 metre radius). While the area of impact per mooring is relatively small, once multiplied across the number of moorings within the estuaries this represents a considerable area of seabed. The number of permanent, single block, sub-tidal moorings within the Fal estuary is calculated to be at least 903; which gives a total impacted area in the Fal to range from at least 7.1ha (5 metre radius) to 34.3 ha (11 metre radius). This estimate can be extended to the whole SAC area, although the level of confidence in this figure is lower. This gives a potential total area of seabed impacted by permanent, single block, sub-tidal moorings within the SAC of up to 48 ha (1263 moorings). These figures do not account for at least 2615 additional moorings of different types, drying state or only seasonally deployed within the estuaries. The results also detected a differential impact on different groupings of organisms and a potential wider influence of the moorings on the seabed within the mooring areas.

The infaunal communities were significantly different between the three locations surveyed. Of the three, the fine/muddy sand sediments in St. Mawes indicated the least influence of disturbance, while the muddier, more stable sediments of Mylor and Falmouth exhibited greater significant influences. Some habitats encountered are also protected as part of the SAC and impacts within these areas should be managed to prevent adverse effects on these features. The areas of moorings studied were situated on biotope types broadly distributed throughout the estuaries; however the habitats found during the survey varied from those indicated by the biotope maps of the estuaries. Clarification of biotope distributions within the estuaries would increase the confidence in the estimation of impact and improve the success of any management outcomes. The sensitivities of habitats to abrasion and physical disturbance were identified and mapped, highlighting areas to prioritise for future study or remediation.

The Fal and Helford Study identified several areas of important research which would contribute towards sustainable future management of recreational boating infrastructure. Further study to encompass alternative mooring types and across other representative habitats would allow evidence-based consideration of infrastructure options and locations that offer the lowest ecological impact in future planning. Research into the wider suite of impacts associated with recreational boating would clarify the broader ecological picture and allow a more comprehensive estimation of ecological impact. An additional important consideration for the Fal and Helford estuaries is the comprehensive collaboration of records and survey information, supplemented by further survey in information deficient areas, to establish baseline ecological information upon which to base future studies and management. This report also considers a range of potential management measures to reduce the ecological impact of moorings which could be explored in more detail alongside practical, social and economic considerations.

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1 Introduction

1.1 Project Background

In 2007, Cornwall Council was asked to consider proposals for a significant new marina development within the Fal and Helford Special Area of Conservation (SAC), shortly after the expansion of a number of existing marinas in the area. This development proposal highlighted knowledge gaps in the extent and potential impacts of recreational boating activities and prompted acknowledgement of the need for a detailed strategic assessment of the existing scale and extent of recreational boating infrastructure within the SAC. This assessment would then provide guidance on decisions regarding future management and capacity issues for the area. This work was supported by the Fal and Helford SAC Management Scheme and planning guidance at that time.

Cornwall Council drafted a project brief for the Fal and Helford SAC Recreational Boating Environmental Assessment. A Recreational Boating Study Working Group was established, this subsequently became a Project Partnership with representatives from relevant organisations around the estuaries, including the Port of Truro and Penryn, Falmouth Harbour Commissioners, Duchy of Cornwall, Environment Agency, Natural England, A & P Falmouth, St Mawes Pier and Harbour Company and Port Pendennis marina. The project brief was refined, funding was obtained and the project partners contributed to and oversaw the delivery of the project.

Objectives *of the overall Fal and Helford SAC Recreational Boating Environmental Assessment were as follows:*

Objective 1
To ***quantify and map*** *existing recreational boating* ***infrastructure*** *within the project area, using existing and new information.*

Objective 2
To ***quantify, describe and map*** *evidence of* ***environmental impact*** *associated with recreational boating infrastructure using existing and new information.*

Objective 3
To make ***management recommendations*** *based on the best available information, aimed at minimising the impacts of recreational boating infrastructure in the project area.*

Objective 4
To develop a ***transferable methodology*** *for estimating the environmental impact of recreational boating infrastructure to guide future projects.*

Objective 5
To identify knowledge gaps in the available information and ***make recommendations*** *for further studies.*

Between 2008 and 2010 the group delivered *Objective 1* by substantially completing a strategic audit of existing recreational boating infrastructure within the estuaries, which was then visually mapped using geographical information software (GIS) by Natural England (Appendix 1). The audit used a *pro forma* developed by Cornwall Council which was completed by the Harbour Authorities and infrastructure providers for each item (or group of items) of boating infrastructure (Appendix 2). An initial scoping report of available literature on the recreational boating impacts was commissioned in 2008 (Mather, 2009). This report subsequently informed a full desk study in 2009 which described the available information on the impacts of recreational boating activities and highlighted examples of international best practise for minimising impacts (Neilly, 2011). The information identified through these reports contributes substantially to the delivery of *Objectives 1, 3* and *5*.

Various pathways for delivering the outstanding project objectives within the tight budget available were explored, including consultancy contracts and Knowledge Transfer Partnerships. Falmouth Harbour Commissioners offered to host a Project Coordinator for 1 year (July 2011 to July 2012) to deliver the remaining work, with academic support from the University of Plymouth. This was a viable model for delivery given the limited budget available. This report sets out the findings of the work carried out by the Project Coordinator.

1.2 Specific Study Aims

The Fal and Helford Recreational Boating Study working group acknowledged that recreational boating within the estuaries has a wide variety of impacts which may influence habitats within the Special Area of Conservation (SAC)[c]. The original remit of the Fal and Helford SAC Recreational Boating Environmental Assessment reflected broad partnership interests and the diverse nature of recreational boating activities within the estuaries; however initial project meetings served to focus the interests of the partnership into a concise study that was realistically achievable within the 1 year project timescale. The project aimed to focus purely on the most prominent mooring infrastructure and address the wider Environmental Assessment objectives with specific regard to single block, sub-tidal, permanent moorings.

The primary aim of the Fal and Helford Study was to quantify, describe and map the environmental impact associated with single bloc, sub-tidal, permanent moorings (*Objective 2*). This was to be completed through a robust scientific study and the findings extrapolated to estimate the extent of impact at the estuary and SAC level. Secondary objectives completed within the Study included the development of a non-scientific Transferable Methodology[d] (*Objective 4*), delivering ecological Management Recommendations (*Objective 3*) and making recommendation for future study (*Objective 5*). During the course of the Study it was also necessary to supplement the infrastructure audit in further quantifying and mapping single point, sub-tidal, permanent moorings within the estuary (*Objective 1*). It is acknowledged that this study alone in no way investigates the overall effect of recreational boating and that any calculations of ecological impact are based solely the measures described and on the impact studied, which may affect the environment cumulatively and/or in combination with other impacts from recreational boating or wider human activities.

*"The Fal and Helford Study aimed to investigate **ecological impact** on community composition due to direct **physical disturbance** resulting from the presence of **recreational mooring infrastructure** on habitats within the Fal and Helford Special Area of Conservation."*

[c] These are identified in Mather, 2009 and Neilly, 2011.
[d] The Transferable Methodology is available as a separate report from the Fal and Helford Study project partners.

1.3 The Fal and Helford Estuaries

The Fal and Helford estuaries represent an area of high biodiversity, socio-economic importance, conservation interest and a wonderful natural playground. The estuaries lie within two Areas of Outstanding Natural Beauty (AONB), and the marine biodiversity, environmental and ecological importance of the area are also recognised in its designation as a Special Area of Conservation (SAC), multiple Sites of Special Scientific Interest (SSSI) designations and the inclusion of St. Mawes bank as a recommended Reference Area (rRA) in the recent Marine Conservation Zone (MCZ) project. The SAC boundary encompasses both estuaries, with an outer boundary extending between Manacle Point on the Lizard and Zone Point on the Roseland peninsula. It was designated under the EU Habitats Directive to protect a number of habitats and interest features, including the large shallow inlets and bays, sub-tidal sandbanks, intertidal mudflats and saltmarshes (Moore, Smith, & Northern, 1999).

The Fal estuary is located on the south coast of Cornwall, close to the western entrance of the English Channel. The main body of the estuary, the Carrick Roads, contains a deep natural channel extending down to some 30m CD, bordered on either side by extensive shallow sub-tidal banks. Off the main body of water are smaller inlets, fed by several rivers and numerous creeks. The upper reaches and inlets contain extensive areas of intertidal and sub-tidal mudflats, but the mid to lower reaches contain a diverse range of marine habitats. These include a mix of sub-tidal sediments types, maerl beds, seagrass beds and areas of sub-littoral rock supporting diverse communities, bordered by rock and shingle shores of varying exposures (Moore et al., 1999). The Helford estuary cuts westward into the Lizard and is smaller, narrower and shallower throughout. Just inside the estuary mouth are diverse sub-tidal habitats including sand and gravel sediments, maerl beds, bedrock and extensive seagrass beds. Further up the estuary muddy sands and mixed sediments dominate with a large intertidal spit of mixed sediment. At the far reaches sub-tidal and intertidal estuarine mud flats are interspersed with areas of sheltered littoral rock (Moore et al., 1999).

The Fal estuary has a long history of human use and anthropogenic impact, with some areas subject to heavy human influence. It is a historical port, with a current commercial docks established in the 1860's. The presence of the commercial docks is identified in the site characterisation as a major source of TBT (Tributyltin) which is still present in some sediments and considered to cause impoverished faunal communities in some habitats (Langston et al., 2003). Passenger ferries operate throughout the estuary. A relatively small number of fishing vessels are based in the estuary and a traditional native oyster fishery operates in Carrick Roads. The catchment area for the estuary has been subject to prolific mining in the past, with copper and tin wastes permeating through the western creeks and china clay wastes in the eastern rivers. Historically, mining wastes have had considerable detrimental effects within the estuary, however mine wastes are now subject to stringent treatment and the current environmental quality of the area is considered to be high. Whilst the Helford is primarily a playground for recreational activities, there are several notable commercial influences. A large boatyard still exists at Gweek Quay, marine geotechnical contractors and fisheries influences, including an oyster farm, operate within its waters. The Helford estuary is a Voluntary Marine Conservation Area (VMCA)[e], a designation which aims to engage local communities and encourage sustainable exploitation of natural resources[f]. The VMCA currently operate a voluntary no anchor zone within the large seagrass bed between Durgan and Toll Point.

1.4 Recreational Boating Infrastructure within the Fal and Helford Estuaries

The diversity and natural beauty the Fal and Helford estuaries make the area extremely popular for water-based leisure and recreation. The area is host to numerous local sailing clubs and offers exceptional day sailing, a destination or extended stop off for coastal sailors and, due to Falmouth's geographical location as one of the most

[e] Further information on the Helford VMCA is available from helfordmarineconservation.co.uk.
[f] Information on the role of Voluntary Marine Conservation Areas (VMCAs) within Cornwall is available from the Cornwall Wildlife Trust at www.cornwallwildlifetrust.org.uk/conservation/livingseas/yourshore/voluntary_marine_conservation_areas_in_cornwall.

southerly estuaries in the British Isles, an important port of call for cross channel sailing. A wide range of facilities are available year round for visiting and resident vessels, with a strong seasonal influx between April and October (Lloyd Pond, pers. comm.). An audit within the Fal and Helford estuaries identified primary recreational boating infrastructure including over 3878 full-time, seasonal and visitor moorings, marker buoys, 23 marinas and pontoon systems, 69 public and private slipways, 8 boat parks and storage areas, 34 small tender haul-outs and beach launch areas, 36 jetties and quays and several designated anchorage areas (Appendix 1). Most recreational mooring infrastructure is concentrated into several large areas within the estuaries.

Within the Fal and Helford estuaries there are 2 broad types of recreational mooring infrastructure in use – single point moorings and trot moorings. Single point moorings are independent moorings; a large block (usually granite within the Fal and Helford) is deployed on the seabed. Attached to this block is a central eye bolt, from which a large 'thrash' chain and a lighter 'riser' chain rise to join a main buoy and pickup buoy at the surface (Appendix 3). Trot moorings are deployed in rows of multiple, connected moorings. A large ground chain is laid along the seabed and anchored at each end, to which multiple 'riser' chains are attached at regular distances. No truly unanimous standards for mooring configurations exist, however moorings within an area tend to be installed and maintained by a pool of specialised moorings operators and mooring configurations tend to converge through operational necessity (Izzard, 2010). Of the two types of infrastructure, single point moorings are the most widely distributed within the estuaries.

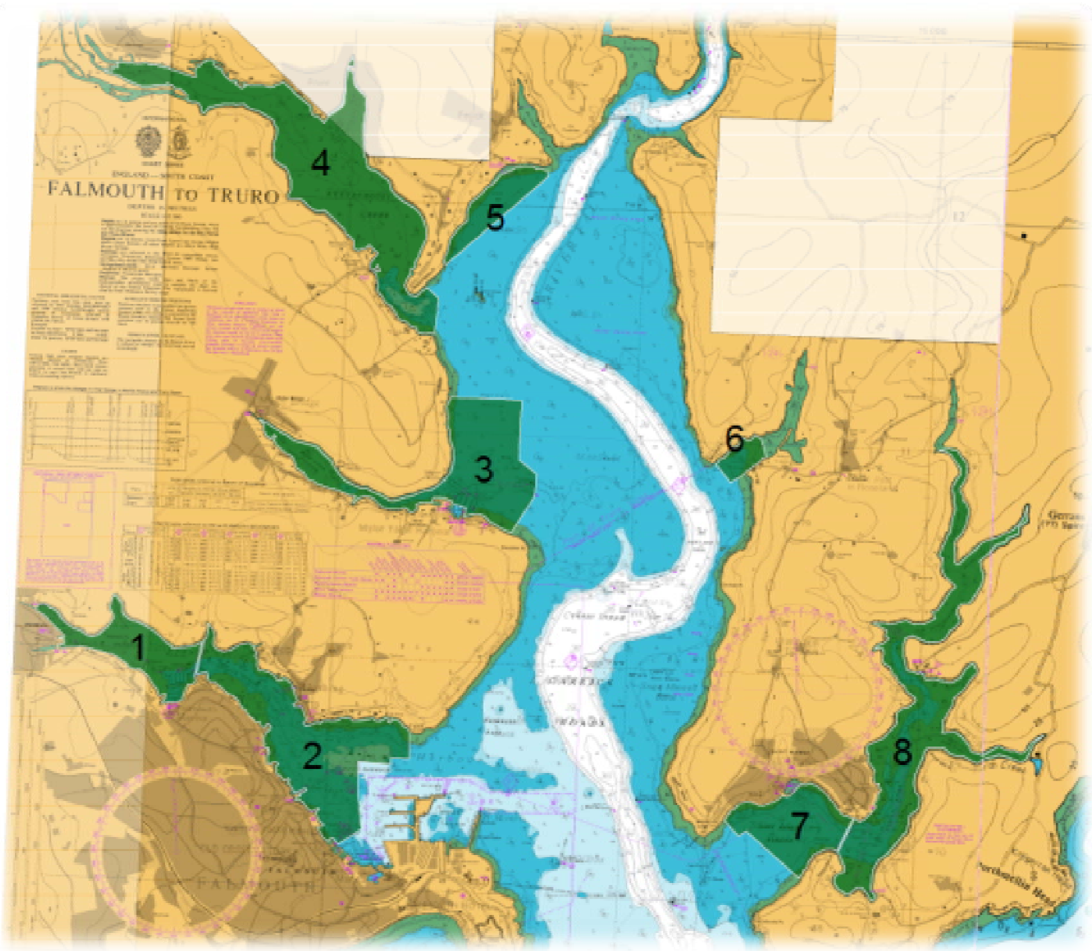

Figure 1 GIS output showing the main areas of recreational mooring infrastructure within the Fal estuary. Areas of mooring infrastructure are identified by green polygons with white outlines. Areas: 1 = Penryn, 2 = Falmouth, 3 = Mylor, 4 = Restronguet (largest concentration present at the creek mouth), 5 = Loe beach, 6 = St. Just (no mooring numbers were available for this area), 7 = St. Mawes, 8 = Percuil river.

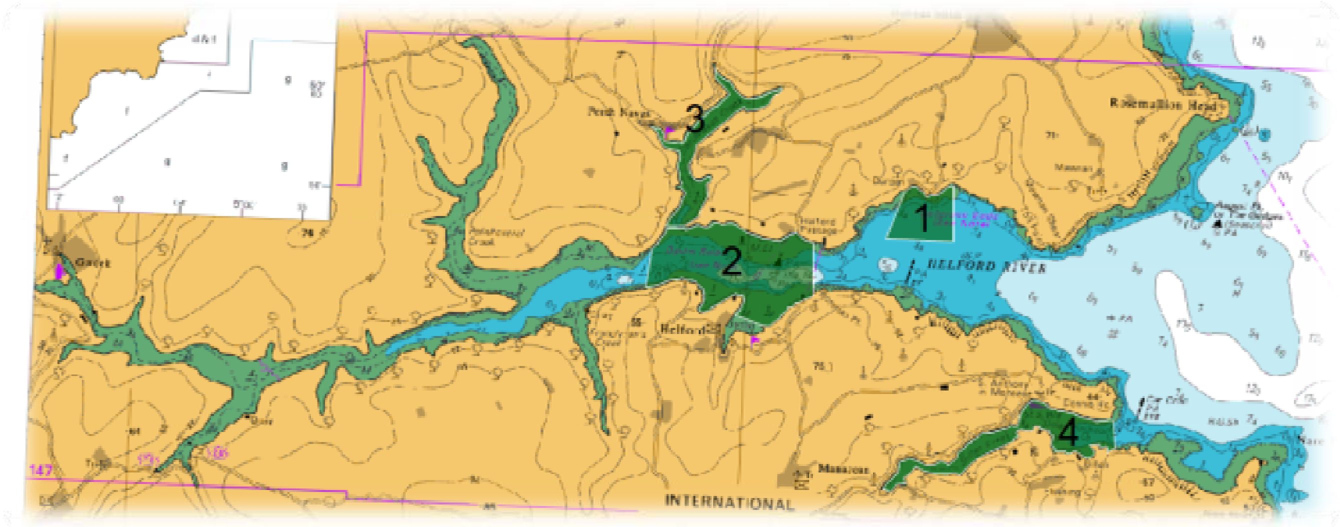

Figure 2 Geographical Information System (GIS) output showing the main areas of recreational mooring infrastructure within the Helford estuary. Areas of mooring infrastructure are identified by green polygons with white outlines. Areas: 1 = Durgan, 2 = Main River (this polygon represents the main area of moorings, the numbers given for Main River also include scattered moorings higher up the estuary towards Gweek), 3 = Porth Navas and Calamansac, 4 = Gillian Creek (no mooring numbers were available for Gillian Creek).

Recreational boating activities and associated infrastructure are considered to have the potential to impact water-based processes within the marine features identified in the Fal and Helford SAC (Saunders et al., 2000). Key SAC features with the potential to suffer negative impacts as a result of recreational mooring infrastructure include the sub-tidal mud communities, mixed muddy sediment communities, sandbank communities, seagrass beds, gravel and sand communities and mixed sediment communities. Moorings within the Fal and Helford estuaries are primarily located on areas of muddy sediment, sand and mixed sediments; however there are moorings within areas of seagrass bed and a limited number of moorings overlapping with areas of live maerl.

Coastal activities are a source of major economic, environmental and social benefit within Cornwall and it is acknowledged that deterioration of the marine ecosystem and surrounding environment would have adverse consequences on tourism and leisure activities, including recreational boating (Roberts, 2007). The established core principles of sustainable tourism are also equally applicable to sustainable recreation and a suitable balance of all three aspects – economy, society and environment – is required to achieve long-term sustainability (Kopke, Mahony, Cummins, & Gault, 2008). From an ecological perspective this means 'making optimal use of environmental resources that constitute a key element in tourism development, maintaining essential ecological processes and helping to conserve natural heritage and biodiversity'[g]. Coastal tourism and recreational activities are generally considered to have a lower environmental impact when compared to more traditional coastal activities (e.g. fisheries, shipping) (Kopke et al., 2008) however with growth in coastal activities the potential to impact the marine environment is becoming increasingly evident.

The carrying capacity of an area is broadly defined as the upper limit that an area can sustain without environmental degradation. Despite widespread acceptance of the potential for anthropogenic impact and a limit of the ecological carrying capacity, little work has been conducted to establish a baseline assessment of the scale and impacts of recreational boating infrastructure. Recent research work to establish the carrying capacity of selected estuaries has focussed primarily on user perceptions and available infrastructure rather than ecological impacts (Natural England, 2011; Roberts, 2007). Within the Fal and Helford estuaries there are currently no plans for drastic expansion of

[g] This definition is given on the World Tourism Organisation website at http://sdt.unwto.org/en/content/about-us-5.

mooring areas, with most large managed areas currently remaining relatively static in number. Increasing demand for moorings has been identified (Roberts, 2007) and moorings waiting lists continue to be oversubscribed, however it has been suggested that current economic conditions have slowed this somewhat (Lloyd Pond, pers. comm.).

1.4.1 Fundus, Licensing and Moorings Management

The ownership and management of moorings and seabed (fundus) within estuaries can be complex. The paragraphs below aim to give a broad overview of some of the complexities within the Fal and Helford estuaries. A large proportion of the UK seabed out to 12 nautical mile territorial limit is owned by the Crown Estate[h], however within the Fal and Helford estuaries the foreshore, fundus and management of moorings within falls under several different organisations. Licensing for new moorings now lies with the Marine Management Organisation[i] (MMO) and new moorings are subject to the consent of a marine license, although exceptions to this requirement are in place for Harbour Authorities.

Within Falmouth Inner Harbour waters the majority of the fundus is owned by Falmouth Harbour Commissioners (FHC). Within this FHC operate and maintain most of the moorings within the Inner Harbour area although some privately owned moorings are present, where the mooring is installed by FHC and the owner provides the infrastructure and rents the swinging room of the mooring. Between Flushing New Quay and the FHC boundary at Penryn, the fundus is privately owned and the moorings are privately managed. In St. Just, also within FHC waters, the fundus is leased to a third party who then operates and leases the moorings.

The fundus within Port of Truro and Penryn waters is owned by the Port of Truro and Penryn Harbour Authority. The Harbour Authority operates some areas of moorings directly and leases some areas of fundus on to third parties. Additionally, in the creeks, for example Restronguet, there is no Harbour Authority and the fundus and foreshore is owned by a myriad of third parties. Within St. Mawes Harbour the fundus is owned by the Duchy of Cornwall, on authority lease to the St. Mawes Pier and Harbour Company who also control the water. The moorings within this are split (approximately 50:50) between privately owned with leases for the mooring swinging room and moorings owned and operated by the St. Mawes Pier and Harbour Company. Upwards of Amsterdam Point, within the Percuil River, the fundus was ceded to the Duchy by the Crown Estate, this is on long term lease to the Place Estate and sub-leased to Percuil River Moorings. Percuil River Moorings license moorings, but do not provide infrastructure or maintenance.

The Helford estuary does not have a statutory Harbour Authority and Cornwall Council's involvement is limited to a speed limit bylaw legacy within the area from its predecessor, Kerrier District Council. The foreshore and fundus within the Helford is in multiple third party ownership, including the Duchy of Cornwall and private individuals. Within the Duchy of Cornwall area the mooring rights are leased to Helford River Moorings, who own, operate and license the moorings in the main body of the river (except an area between Helford and Helford Passage), Port Navas Creek and around Durgan.

1.5 Spatial Variation and Natural Disturbance

Soft sediment marine habitats are a three-dimensional habitat with animals living on the sediment surface, the epifauna, and occupying space within the sediment beneath, the infauna. For the purpose of biological studies these organisms are separated into size groupings – meiofauna (organisms that will pass unharmed through a 0.5mm sieve mesh), macrofauna (organisms retained on a 0.5mm sieve mesh) and megafauna (organisms >1cm). Despite the initial uniform appearance of marine sediments, the abundances of the infaunal organisms within are variable at a

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[h] Further information on the Crown estates as a fundus owner and its role in licensing moorings and marinas is available at www.thecrownestate.co.uk/marine/moorings-and-marinas. Site accessed June 2012.

[i] Further information on the MMO and licensing is available from www.marinemanagement.org.uk/licensing/marine.htm. Site accessed June 2012.

range of spatial scales. Organism abundances may vary at scales of a metre up to several kilometres (Morrisey, Howitt, Underwood, & Stark, 1992). The ideological, uniform spacing of benthic organisms within sediments is only apparent at very small scales (centimetres), above which non-random patterns dominate, with clumped distributions most commonly identified (Thrush, 1991). Studies on coastal soft sediment have assessed spatial patterns of distribution and inferred the processes behind such distributions, indicating the influence of large scale abiotic factors (sediment characteristics) and biotic factors (life history and organism interaction processes), including competition, motility, predation, reproductive cycles, territoriality and interference interactions (Thrush, 1991).

This study investigated ecological impact in terms of disturbance. Disturbance is commonly referred to within ecological systems but it is notoriously hard to clearly define and various working definitions of disturbance have been discussed at length within the scientific literature (Pickett, Kolasa, Armesto, & Collins, 1989; White & Jentsch, 2001). For the purpose of this work, disturbance is defined as any discrete event which causes disruption and alters resource availability or the physical environment (Pickett & White, 1985). This includes anthropogenic (human source) impacts and fluctuations and destructive events perceived as normal within a natural system. Natural disturbances within soft sediment habitats may be physical in nature, typically large-scale events such as storms, tidal scouring and temperature fluxes, or biological events, usually on a smaller scale and including activities such as burrowing and bottom-feeding of animals within the environment (Probert, 1984). Anthropogenic disturbances may be physical, chemical or biological in nature and include activities such as dredging, pollution and the introduction of non-native species. In some cases, particularly physical disturbance, the direct effect on the seabed may be the same regardless of whether the source of the disturbance is natural or anthropogenic. Disturbance is a perfectly normal influence within the marine environment, it is important in defining the structure of many types of marine ecosystems including soft sediment seabeds (Thistle, 1981), and has been identified as an important reproductive cue in the life cycles of some sedimentary marine organisms (Barry, 1989).

Intermediate disturbance hypothesis (IDH) suggests that greatest biodiversity will be found when an ecosystem is affected by a moderate level of disturbance, such that a mosaic of patches of varying successional maturity are present within an ecosystem (Wilson, 1994). In ecosystems subject to very low levels of disturbance the community contains limited species richness and consists primarily of competitively dominant organisms, given the prevailing conditions. Similarly, in ecosystems subject to very high levels of disturbance the instability within the environment is only tolerable to a limited number of specifically adapted species which can survive under such conditions. Throughout the lifespan of a distinct patch variation in the level of resources available and a sequential favourability of life history strategies will occur, resulting in colonisation and displacement responses within the community that reflect the local environment at that point in time (Thistle, 1981).

Recovery of an area of seabed can considered to have occurred when the community present post-disturbance resembles that present pre-disturbance. This re-colonisation of a disturbed area occurs across a number of timescales, ranging from hours to months (Thistle, 1981). For the smallest organisms, the meiofauna, studies have indicated recovery to be relatively rapid with re-colonisation occurring within one week following experimental bait-digging activities (Lee, Lee, & Connolly, 2011). At the macrofaunal level, re-colonisation can take weeks or months within the disturbed sediments and doesn't always occur as it may be predicted (Ferns, Rostron, & Siman, 2000). Recovery and the pattern of succession within post-disturbance patch is indicated to be influenced by factors including disturbance scale, local water currents, the surrounding faunal communities, the season, the level of larval input into the area and immigration of adults from local patches (Probert, 1984). The frequency with which disturbance occurs is also highlighted as significant and in areas of constant or frequent disturbance communities may not have the opportunity to recover to the pre-disturbance state. A frequency of disturbance which reoccurs regularly within an organism's lifespan is likely to select for short-term fitness, as to be successful an organism must grow quickly and reproduce prior to the next disturbance (Probert, 1984). Disturbance occurring very frequently, on an hourly or daily basis, would select even further for organisms that can tolerate the level of disturbance encountered. Alternatively disturbance may occur at a level insufficient to completely kill or remove the fauna from the area, but sufficient to alter feeding regimes and impact the fitness of the organisms in a sub-lethal manner (Lee et al., 2011). Such an effect would be likely to reduce the abundance of such species as only the fittest individuals would survive.

A detrimental effect within an ecosystem could be considered to be experienced when the level of disturbance within the environment reaches a level at which species richness and community composition is reduced. However, in areas of low disturbance, a detrimental effect could be considered to be a significant alteration to the community, as the disturbance may cause an increase in the number of species but alter the status quo of the community and change an important habitat. The loss of overall biodiversity or of specific, functionally important species can significantly influence the ecological functioning of ecosystems through a network of complex interactions, which may act in way disproportionally larger than their cumulative effect (Worm & Duffy, 2003). As disturbance can be both natural and anthropogenic, background natural disturbance should be included when assessing the cumulative effect of potential human impacts on an environment.

1.6 Anthropogenic Disturbances – Impacts of Recreational Mooring Infrastructure

As part of the wider Fal and Helford Recreational Boating Study a literature review (Neilly, 2011) and a review of international evidence and best practice (Mather, 2009) was compiled to outline current knowledge of the wider potential impacts of recreational boating infrastructure. Potential impacts identified from areas of recreational boating infrastructure are numerous and diverse, including sewage and grey water inputs, litter input, oil pollution, reduced water quality, raised metal concentrations (from sacrificial anodes), inputs of toxic chemicals (from antifoulants), altered light levels, water disturbance and erosion, increased turbidity, seabed abrasion and scour, modification of sediment composition and loss of habitat (Mather, 2009).

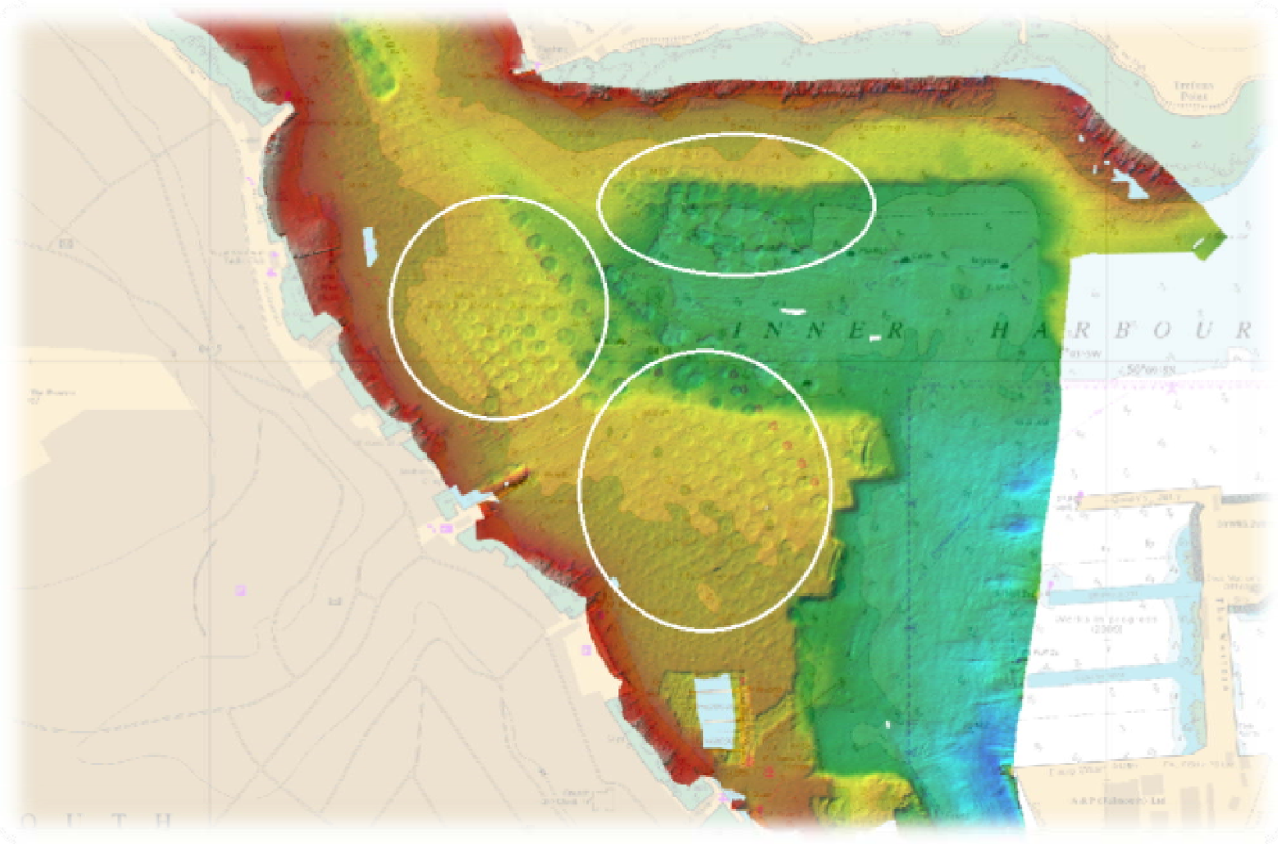

Figure 3 Detailed bathymetric data of the Falmouth Inner Harbour mooring areas shows clear circular depressions (20-40cm depth) around the locations of the moorings. The main areas of mooring scour are highlighted by white rings. Source: 2010 Falmouth Harbour Commissioners commissioned Coastwise bathymetric survey.

The mooring infrastructure associated with recreational boating activities has several potential influences on the seabed and its associated fauna. The block itself has a physical footprint, approximately 1.5m^2, in which it covers the sediment surface removing the water-sediment interface. The presence of the mooring block also introduces hard substratum into a primarily soft sediment habitat, offering new substrata for species to colonise. The mooring chain (thrash and riser) moves relative to the movement of the vessel above and is influenced by tidal, wind and water conditions. The subsequent movement of the mooring chain across the seabed can rake the sediment surface, mixing and disturbing the top layers of sediment (pers. obs.). This disturbance of the sediment can re-suspend fine sediment particles into the water column, changing the sediment composition in the vicinity of the mooring (Herbert, Crowe, Bray, & Sheader, 2009). This scouring movement creates a depression in the sediment surrounding the mooring block. The depth of this scour may be relatively shallow, around 0.5m (Walker, Lukatelich, Bastyan, & Mccomb, 1989), but is sufficient to be clearly visible in bathymetric survey data (Figure 3). The scale of these disturbances is likely to vary with the size and structure of the mooring, the seabed type, the vessel size and hull design and the exposure of the mooring to wind and tide.

Literature searches specific to the physical impact of vessel moorings returns a skewed result with reference to the habitats previously investigated. The impacts of moorings infrastructure on seagrass beds are well documented and the presence of a physical impact of mooring chains on seagrass is clearly described and established by studies within the UK and further afield. Studies in the late 1980's were already documenting the loss of ecologically important seagrass habitats and calculating the impacted areas of recreational vessel moorings in seagrass beds (Walker et al., 1989). Studies within extensive Australian seagrass beds documented impacts including loss of seagrass area, increases in the exposed edge of the seagrass beds, coalescence of multiple mooring scours and bed fragmentation in heavily used areas (Hastings, 1995). Boat mooring scours and anchoring scars within seagrass beds are indicated to differ from undisturbed seagrass bed in several biological and physical features, including reduced sediment cohesion, organic material content, silt fraction, infaunal species abundance and diversity (Collins, Suonpaa, & Mallinson, 2010).

Removal of seagrass habitats from the search criteria gives a much reduced collection of literature. Instances of impact studies for mooring infrastructure conducted on less charismatic but more relevant mud, sand and mixed sediment seabeds give a limited return. When looking specifically for the impacts of mooring infrastructure on estuarine and soft sediment infaunal communities only a handful of studies were identified. Previous studies have generally been of relatively small scale and have usually focused on a specific mooring niche: intertidal recreational moorings (Herbert et al., 2009), sub-tidal commercial moorings (Smith, 2000) and eco-mooring trials (Kendall, McNeill, Needham, & Fileman, 2006).

Herbert et al. (2009) investigated the disturbance of intertidal soft sediment estuarine assemblages in response to the presence of recreational boat moorings. The study investigated initial differences in assemblage structure between impacted sites (with mooring buoys) and non-impacted sites (without mooring buoys) and followed the effect of the removal of the mooring buoys to establish if indications of 'recovery' could be detected. The results revealed significantly altered community composition and an increase in particle size within the influence of the moorings, despite no obvious disturbance visible on the mud surface. The study also indicated that although the removal of the mooring buoys appeared to initiate a response in the assemblage structure, no convergence of impacted and non-impacted appeared within the 15 months of the experimental sampling timescale. Herbert et al. 2009 concluded recreational mooring buoys clearly impact spatial and temporal variation, but suggested other factors may at times have a greater impact on the composition of the infaunal assemblage. The assemblage structure was only investigated within and outside the impact radius of the buoy and as such only investigates the effect of the presence or absence of the impact not any graduation of impact.

The study by Smith (2000) specifically investigated compositional changes in sub-tidal mud sediment infaunal communities in relation to distance from a disturbance, with faunal compositions sampled from multiple, graduated distances around 3 commercial-scale Naval moorings within Plymouth Sound. Although the data showed large amounts of spatial variation, Smith, 2000 were able to identify significant changes in some biodiversity measures at sampling sites closest to the disturbance. While this study was conducted at a commercial-scale of mooring infrastructure, the physical impact of the mooring on the seabed would, to a certain degree, be expected to be similar when scaled down to recreational vessel moorings.

Initial comparisons have compared traditional, recreational mooring infrastructure with alternative ‘eco’ mooring systems (Kendall et al., 2006). This study was conducted within muddy estuarine sediments, in an area also studied as part of this project. This study did suggest potentially greater homogeneity around the SEAFLEX® moorings used in the study at some sampling points throughout the trial, however operational difficulties and safety concerns resulting in unplanned exchange of the moorings prevented a truly conclusive outcome (Kendall et al., 2006). An overview of the management of the Porth Dinllaen seagrass bed (North Wales, UK) and an investigation into the benefits and limitations of alternative mooring systems within seagrass habitats has also been previously reviewed (Egerton, 2011).

2 Location Selection

The initial four study locations selected reflected the interests of the project partners and the four main areas of comparable recreational boating infrastructure within the Fal and Helford estuaries, as identified through the recreational boating infrastructure audit (Natural England, 2011), remote visual assessment of the estuaries and through communication with project partners and mooring operators. The areas chosen were all operated by commercial moorings operators offering reliable, accurate information on the mooring numbers, locations and types. The habitats within these four locations were broadly grouped into two types; mud and gravel sediments in Falmouth and Mylor and fine sand sediments with variable seagrass coverage in St. Mawes and Durgan. Mooring data (types and locations) was collated with available bathymetric data within Cadcorp (Cadcorp SIS Map Modeller Version 7.1, Computer Aided Development Corporation (CADCORP) Ltd., UK[j]) to identify areas of moorings within the locations with comparable depth ranges of between 2 and 4 metres. At each of the four locations two comparable sites were identified, allowing investigation of intra-location variation within the samples.

3 Initial Scoping Surveys

In order to confirm habitat types and ground-truth available habitat data, scoping surveys were conducted in advance of the core project work. These surveys took place throughout July and August 2011 in the areas of prolific mooring infrastructure within Falmouth, St. Mawes and the Helford and across three initial marina locations of Falmouth Yacht Haven, Port Pendennis marina and Mylor Yacht Harbour. A SCUBAR remote video survey system (IM-SCU-01 SCUBAR Underwater Scope, Iris Marine Surveillance Ltd., UK[k]) was used to determine broad habitat types within the Falmouth mooring area. At the depths of the moorings (4-5m) it was possible to distinguish habitat types, but the equipment was very difficult to control and direct. The Remotely Operated Vehicle (ROV) (Video Ray Pro4, Atlantas Marine Ltd., UK[l]) to be used for the epifaunal survey was available for one day to conduct preliminary scoping surveys within the Helford and St. Mawes. This availability also offered limited time to develop and trial potential epifaunal transect methodologies ahead of the full survey. While the detail of habitat coverage initially anticipated was not achievable, the scoping survey work was beneficial in supplementing the available habitat data and allowing the study sites to be selected using the best available habitat information.

4 Methodology

4.1 Broad-scale Epifaunal Survey

Remote underwater videography offered a cost-effective means of recording the broad epifaunal communities present within the survey areas. Due to the nature of harbour environments a system was required which could manoeuvre independently amongst the moorings infrastructure with minimal risk of entanglement. Video footage was captured using a Remotely Operated Vehicle (ROV) (Video Ray Pro4, Atlantas Marine Ltd., UK,) supplied by the University of Plymouth. The ROV was retrofitted with two laser pointers (Apinex.com Inc. BALP-LG05-B105 green laser) to provide a constant scale on the video footage and a negatively buoyant tether (Atlantas Marine Ltd., UK[m]) kept the tether on the seabed, minimising the need for additional surface cover and aiding in ease of use within busy harbour areas.

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j Further information available from www.cadcorp.com/products_geographical_information_systems/map_modeller.htm. Site accessed June 2012.

[k] Further information is available from Iris Innovations Ltd. www.boat-cameras.com. Site accessed June 2012.

[l] Further information on Video Ray ROVs is available through www.atlantasmarine.com/htm/product/details/videoray_pro_4. Site accessed May 2012.

[m] Details of the negative tethers are available online at www.atlantasmarine.com/htm/product/details/extension_tether. Site accessed May 2012.

Within the moorings areas all possible transects between moorings were identified and 3 transects were selected at random, identifying a start mooring and target compass bearing. For the control zones, bearings were selected at random 10^o intervals, allowing for inaccuracies in ROV operation. Each ROV transect covered 30m of seabed. This distance was standardised and measured using a marked ROV tether, with additional tether deployed relative to the depth of water in which the ROV was operating. Laser alignment was checked and calibrated regularly, at minimum prior to deployment at each new site or following any knocks or contact with the seabed. The ROV was deployed down the mooring chains within moorings sites or descended freely to the seabed in control zones. The ROV autopilot compass maintained a constant heading throughout the video transect. Video footage was collected from all mooring and control sites between the 24th August and 20th September 2011, with fieldwork completed from a number of harbour and survey vessels including the Port of Truro and Penryn harbour authority launch “J. A. Barriger”, the Cornwall Inshore Fisheries and Conservation Agency survey and patrol vessel “Kerwyn” and the Falmouth Harbour Commissioners patrol vessel “Killigrew”.

All ROV footage was processed using VLC media player (VideoLAN, Boston, USA) allowing playback of the footage at 0.8x actual speed. All identifiable epifaunal organisms present were recorded from the start of the video transect, standardised as the point at which the ROV aligned to the transect heading, until the end of the video transect, the point at which the ROV turns to follow the umbilical back to the vessel. All organisms were recorded to family level where resolution was sufficient; for some organisms a greater level of taxonomic detail was recorded, but only in cases where regular reliable identification was possible across the locations. Organisms that were not reliably identifiable, not conclusively alive (for example shells with no visible occupant) and any macroalgae obviously drifting or decaying were not recorded. All taxonomic groups were recorded as present or absent on the transect.

4.2 Infaunal Samples

To distinguish potential differences in infaunal community structure at relatively small spatial scales samples were collected *in situ* using a team of scientific divers. This allowed samples to be taken accurately at pre-specified distances within relatively little variance in distance around the intended sample point. Infaunal samples were collected from the mooring survey sites at Falmouth, Mylor and St. Mawes between the 5th and the 9th September 2011. The infaunal dive surveys were organised and completed in conjunction with Natural England from the dive vessel “Patrice II”.

Infaunal core samples were collected from two mooring sites and two control zones for each mooring location (Falmouth, Mylor and St. Mawes). The sites contained areas of permanent, single block, sub-tidal moorings at depths of between 2 and 4 metres (CD). The technical specifications of all moorings were comparable, consisting of a granite block, 2-3 metre thrash chain and 9 metre riser chain. All potential moorings within the study site were numbered and 3 replicate moorings were identified at random. At the control zones, a start position was identified for the dive and divers were given random bearings and a minimum distance of 10m to separate the three groups of replicates. Infaunal cores were collected on transects leading outwards from the centre of the mooring block. Each transect consisted of a 30m tape measure attached to central eye bolt on the block and transect direction was allocated randomly to the divers prior to each dive. Divers used a plastic corer (120mm deep, 100mm ∅) to collect three replicate samples at each distance (2 metres, 5 metres and 11 metres) away from the central eye of the mooring. Cores were transferred *in situ* to large, heavy duty plastic bags and secured with labelled cable ties. All samples were then transferred to a mesh ‘dive bag’ bag and sent to the surface using a lifting bag. At each distance divers were instructed to haphazardly distribute the cores, avoiding areas visibly unrepresentative of the surrounding seabed and carefully removing any significantly large amounts of surface macroalgae.

Once on the surface, the samples were recovered to the vessel for immediate primary processing. All infaunal samples were elutriated 5 times over a 0.5mm sieve mesh, with care taken not to damage or lose any organisms. The remaining sediment was checked briefly for larger, heavy organisms (for example bivalves) which may not be extracted by elutriation. The retained sample was transferred to a 100ml sample pot, preserved and stored in 75%

IMS solution and grouped into location bundles. As identification was only required to intermediate taxonomic level, Rose Bengal stain was used to facilitate sorting by increasing the visibility of infaunal organisms. This was added to the samples at least 24hrs prior to processing.

Due to the time limitations for this project an initial trial was completed to assess the viability of sub-sampling the infaunal samples to speed up processing. Multivariate analyses were employed to determine a size of subsample representative of the whole sample equivalent (*sensu* Sheehan, Coleman, Thompson, & Attrill, 2010). Organism abundances were recorded for successively smaller sub-samples (1, $^1/_2$, $^1/_4$, $^1/_{16}$) of five random infaunal samples. These datasets were then compared using the RELATE routine in PRIMER 6. Consistent patterns in organism abundance were present at sub-sample sizes of a quarter ($^1/_4$) or above (4th root transformation; ρ>0.74, P< 0.01). The dataset was presence/absence transformed and reanalysed to compare taxonomic composition of the subsamples, which indicated that taxonomic patterns were consistent at a half sub-sample and above (ρ>0.8, P<0.01). This results of the RELATE test indicated that a sub-sample of ½ was reliable in representing the faunal content of the whole sample.

The infaunal samples were re-sieved over a 0.5mm mesh prior to sub-sampling and processing. Organisms were picked to family group on a sub-divided petri dish using a binocular microscope. All identified specimens were stored in sample specific glass vials in 75% IMS solution. A compound microscope was also used to check identification features on smaller specimens.

4.3 Particle Size and Organic Content Samples

100ml sediment cores were collected alongside the infaunal samples to determine the sediment particle (grain) size and organic content. One sediment sample was collected at each distance away from the mooring block (2m, 5m and 11m) and from each group of replicates within the controls. All sediment samples were frozen on the day of collection. The collection of samples followed guidelines outlined by the National Marine Biological Analytical Quality Control (NMBAQC) Coordinating Committee (Mason, 2011). The main deviations from the guidance with regard the collection of sediment samples were imposed as a restriction of the sampling equipment available for this study.

Analysis of particle size was completed in accordance with procedures recommended in the NMBAQC guidance (Mason, 2011). As the samples contained mixed sediments a combination of two techniques, a wet split over a 1mm mesh and laser diffraction (of the <1mm fraction), were used to produce a comprehensive particle size distribution. To wet split the sample approximately 40ml of sediment was separated over a 1mm sieve mesh. The <1mm fraction is sieved into a pre-weighed beaker. The sediment was oven dried (minimum of 24hours at 105^{o}C) and the <1mm fraction was reweighed in the beaker. The greater than 1mm fraction was dry sieved through a stacked series of sieves (16mm-1.0mm at half ϕ intervals) and the resulting fractions retained weighed. Laser diffraction samples were prepared by sieving approximately 2ml of sediment through a 1mm mesh into a test tube. The laser diffraction was performed on a Malvern Mastersizer 2000 (Software version 5.6, Malvern Instruments Ltd., UK). Appropriate standard operating procedures were identified as a general analysis model with enhanced sensitivity and irregular particle shape (SOP Natural Sediments- Autosampler- No Blue- Fulltilt- 1 Wash) and an assumed refractive index of 1.53 and a light absorption of 0.01 (pers. comm. Richard Hartley). This was used on all sediment samples. The unit completes 30,000 red laser measurements on 3 replicates for each sediment sample.

To determine organic content approximately 5 grams (dry weight) of sediment from each sample was transferred into pre-weighed crucibles and oven dried (minimum of 24 hours at 105^{o}C). The crucibles of dried sediment were re-weighed, transferred to a muffle furnace and burnt (450^{o}C for 4 hours). After cooling all samples were re-weighed and the carbon content, as a percentage of the sample weight, was calculated. Balance calculation software automatically recorded and calculated weight reductions and organic content percentages (pers. comm. Richard Hartley).

4.4 Analysis

4.4.1 Epifaunal Video Analysis

An initial visual analysis of the dataset looked for the presence of obvious trends in the raw data. Multivariate statistics were performed using PRIMER 6 with the PERMANOVA extension (PRIMER 6 version 6.1.13, PERMANOVA+ version 1.0.3, PRIMER-E, Plymouth, UK) to investigate any community level differences between locations or moorings and control areas. Data was input as presence/ absence and a Bray-Curtis resemblance matrix was created. Non-metric multi-dimensional scaling (MDS) plots were used to visualise similarities within the infaunal community assemblage data. A three factor PERMANOVA design then was used, with the levels location, site (nested within location) and treatment (mooring area versus control area). Location and treatment were fixed factors, site within location was random. PERMANOVA was run in a Type III (partial SS) approach using unrestricted permutation of the raw data and 10,000 permutations. This analysis was completed a second time on a partial dataset, omitting the highly motile taxonomic groups which may unduly influence the results.

4.4.2 Sediment Analysis

Sediment composition is considered to be an important factor influencing the distribution of infaunal organisms within the seabed, potentially through influences on locomotion or burrowing activities (Frost, Attrill, Rowden, & Foggo, 2004; Probert, 1984; Sanders, 1958). The outputs from the laser data and the sieve data were recombined to give final adjusted size (µm) values and basic granulometry statistics were calculated for each sample using an Excel template (pers. comm. Richard Hartley). Mean method of moments (logarithmic ϕ) is generally considered the most accurate sediment parameter as it employs the entire sample population (Blott & Pye, 2001). For this reason, the mean method of moments (logarithmic ϕ) was considered the best representative measure of the particle size distribution to use for analysis. The combined data was analysed using GRADISTAT (Version 14.0) to give the mean method of moments (logarithmic ϕ) for all samples (Blott & Pye, 2001; Mason, 2011). The organic carbon samples weights were input through a balance reader program which automatically calculated the organic carbon content as a percentage of the sample (pers. comm. Richard Hartley).

Disturbance of the seabed in the vicinity of the mooring is postulated to disturb the silt fragment of seabed, thus altering the overall composition of the sediment (Collins et al., 2010). In light of this the sediment data, particle size and organic carbon content, were initially analysed independent of the infaunal dataset to establish any significant trends within the sediment composition which may also be influential in the distribution of organisms. Analysis of the organic carbon content and sediment granulometry was completed using univariate analysis of variance (ANOVA) within SPSS 19 (IBM, New York).

4.4.3 Analysis of Biodiversity Measures

To assess the impact of the moorings infrastructure on infaunal biodiversity the following matrices were calculated. Abundance (N), the total number of organisms in each sample, and species richness (S), the total number of taxa represented in the sample were calculated using the DIVERSE routine (PRIMER6). Further measures of biodiversity were calculated, to interrogate abundances of the main taxonomic groups represented in the infaunal samples. This included total abundances for phylum Annelida, sub-phylum Crustacea and phylum Mollusca. Further statistical analyses were completed for some families within these phyla.

The influence of locations, sites and distances on the biodiversity measures outlined above was assessed using generalised linear models (GLM) within SPSS 19 (IBM, New York). Univariate analysis of variance (ANOVA) was used to identify the significance of the various factors (distance, site, location) in determining abundances and species richness of samples. To compare the influence of distance on the biodiversity measures at different spatial scales, a series of a priori contrasts were used, based upon estimated marginal means and Tukey's least significant difference

(LSD). Standardised residuals were checked subsequent to all analyses to ensure all analytical assumptions for the GLM model were upheld.

4.4.4 Multivariate Community Analysis

All multivariate statistics were performed using PRIMER 6 with the PERMANOVA extension (PRIMER 6 version 6.1.13, PERMANOVA+ version 1.0.3, PRIMER-E, Plymouth, UK). Non-metric multi-dimensional scaling (MDS) plots were used to visualise similarities between the infaunal communities using PRIMER. Datasets were square root or fourth root transformed to reduce the effect of occasional, highly abundant species within the assemblage. Bray-Curtis resemblance matrices were then constructed on the transformed data. These were used to create MDS plots of the whole data set and of each location individually. Analyses of similarities (ANOSIM) were conducted to interrogate the significance of apparent similarities present at different levels (location, site, distance). Within individual locations pairwise comparisons were conducted to identify significance within distance combinations. Replicates for each distance in each location were averaged within PRIMER, fourth root transformed and a Bray-Curtis resemblance matrix was created. An MDS plot was created to visualise patterns of similarity within distance across the different locations.

To determine if the overall infaunal community was affected by the moorings infrastructure an analysis of covariance (ANCOVA) was employed. This accounts for influence of sediment particle size (mean method of moments logarithmic ϕ) on the infaunal community composition. Infaunal abundance data replicates were averaged to the level of the particle size data and square root transformed, before being used to calculate a similarity matrix based upon the Bray Curtis similarity coefficient (Anderson, Gorley, & Clarke, 2008). Covariate PERMANOVA was used to examine the effect of location, site and distance after sediment particle size in determining infaunal community composition. A three factor PERMANOVA design was created using the factors location, site (nested within location) and distance. PERMANOVA was run in a Type I (sequential SS) approach using permutation of residuals under a reduced model and 10,000 permutations. During the analysis model simplification was adopted where viable and analytical terms with the lowest P-values were pooled with the lowest compatible term. Pooling can be considered to make the analysis more conservative as the subsequent pooled term better represents the significant spatial variation in the assemblage response. PERMANOVA non-parametric tests have none of the constraining assumptions found in GLM models, but it was also not possible to perform planned pairwise contrasts in a directly comparable fashion to those performed on the univariate data using estimated marginal means.

5 Results

5.1 Epifaunal Video

A total of 38 taxonomic groupings across 11 phyla were recorded within the ROV footage. Phyla recorded included Porifera (sponges), Annelida (segmented worms), Mollusca (molluscs), Cnidaria (sea anemones, corals, jellyfish), Echinodermata (starfish, sea urchins, sea cucumbers), Arthropoda (crustaceans), Chordata (vertebrates), Chlorophyta (green algae), Rhodophyta (red algae), Ochrophyta (brown algae) and Tracheophyta (seagrasses). A full table of the taxonomic groups recorded is included in the Appendix (Appendix 4). When processing the ROV footage it became apparent that there was insufficient resolution to confidently and accurately detect any potential differences between the surveyed areas, therefore the results given below should be used tentatively and further study would be required to conclusively assess any epifaunal differences.

The locations show clear separation, visible on the MDS plot as separate sample groupings with relatively little overlap (Figure 4). At the level of impact, mooring area versus control area, the results were well mixed (Figure 5) showing no obvious grouping or trend. Community level analysis (PERMANOVA) of the epifaunal data indicated no significant difference between transects within the mooring sites and the control zones (P=0.1131). A significant difference was visible at the level of location (P=0.0093) and site within location (P=0.0001) suggestion significant spatial variation is present. The interaction of sites within locations and mooring versus control transects (Table 1) was also identified as significant, suggesting that any effect of treatment (mooring versus control) was variable between sites within locations. The removal of the large, highly motile organisms (cuttlefish and fish) from the PERMANOVA analysis did not change the pattern of significance.

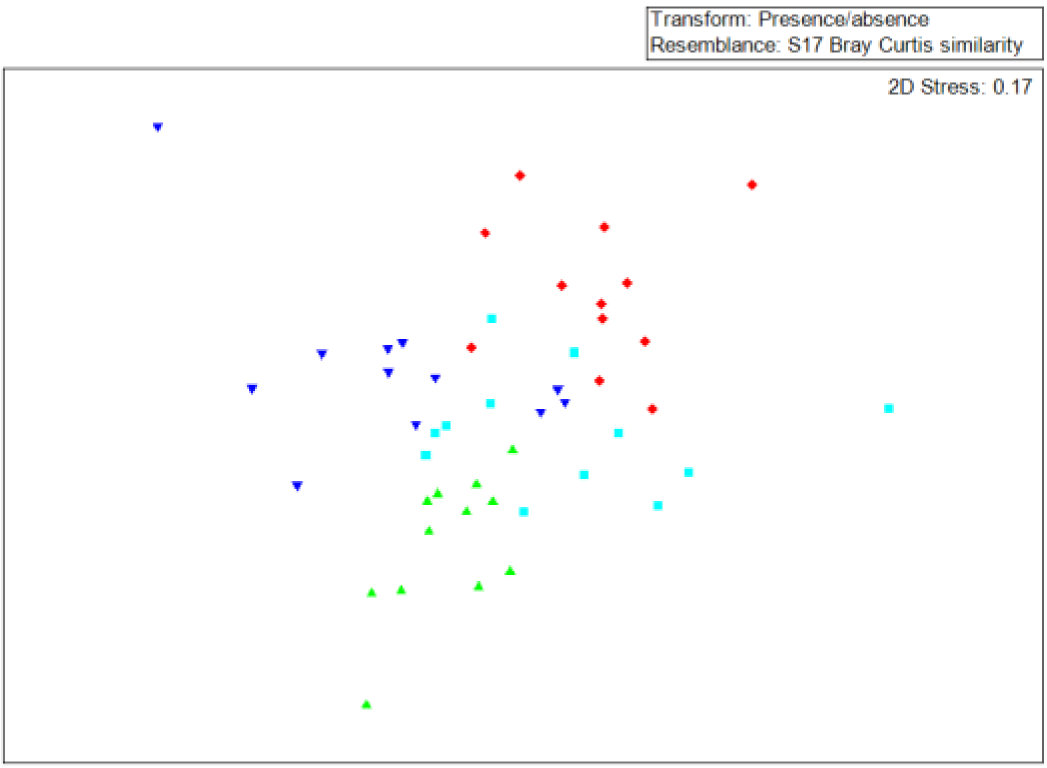

Figure 4 MDS plot illustrating differences in the epifaunal community assemblages (within mooring areas and control areas) at the four moorings locations (**green triangles** = Falmouth, **blue triangles** = Mylor, **light blue squares** = St. Mawes, **red diamonds** = Durgan). The epifaunal communities at the four locations are significantly different from each other.

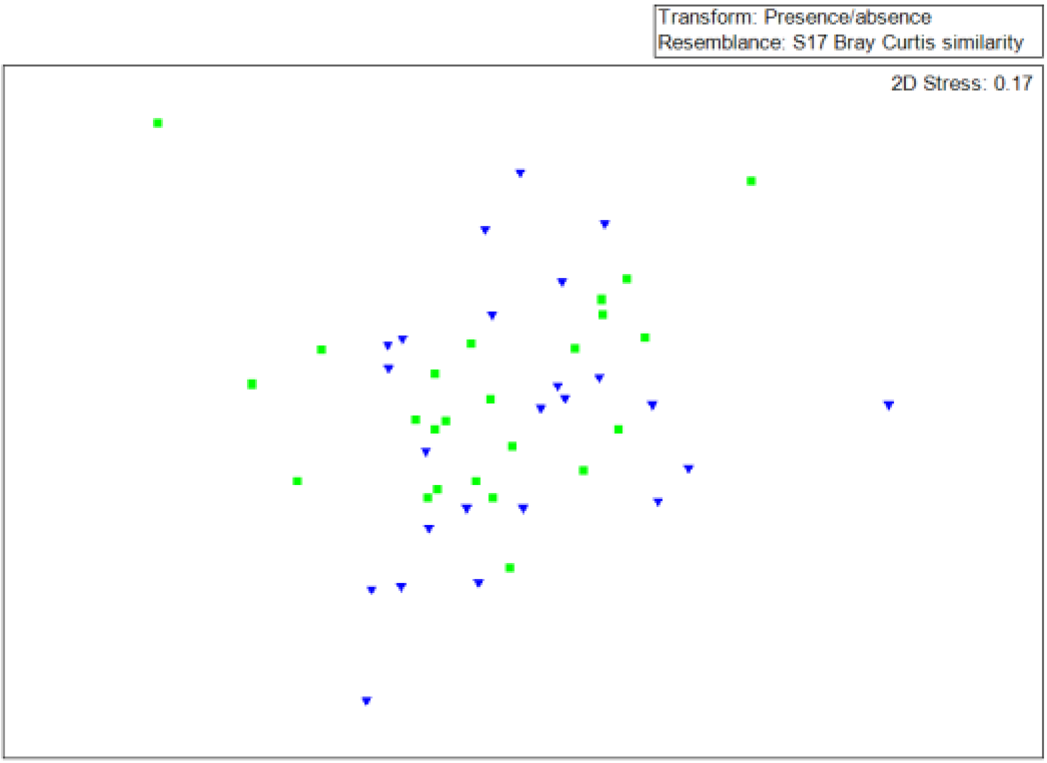

Figure 5 MDS plot illustrating similarities between the epifaunal communities of the transects within the moorings (**green squares**) and the control zones (**blue triangles**) across all four locations. At this level (presence/absence) there is no significant difference between the epifaunal communities within the mooring areas and outside the mooring areas (control zones).

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Location	3	26031	8676.9	3.7158	0.0093	105
Mooring/Control	1	2674.6	2674.6	1.8909	0.1131	9937
Site(Location)	4	9340.5	2335.1	4.6079	0.0001	9920
LoxMo	3	6782.7	2260.9	1.5985	0.1371	9929
Site(Location)xMRG/CTZ	4	5657.7	1414.4	2.7911	0.0003	9902
Res	32	16217	506.77			
Total	47	66703				

Table 1 The PERMANOVA table of results indicates no significant difference between the epifaunal communities within the mooring areas and the control zones (Mooring/Control). Significant differences (highlighted by grey bars) are identified between the different locations and the sites within those locations. The interaction between the site (within each location) and the treatment (mooring area or control zone) was also significant (grey bar).

5.2 Sediment Analysis

Statistical analysis (ANOVA) of the organic carbon content identified no significant influence of distance (P=0.687) (Figure 6) or location (P=0.105) on the amount of organic carbon present in the samples. A significant difference was apparent at the level of sites within the locations (P=0.001), suggesting there is substantial spatial variation present between the different sites at each location. No significant differences were identified within the interactions between locations and distances (P=0.779) or distances and sites within the locations (P=0.615).

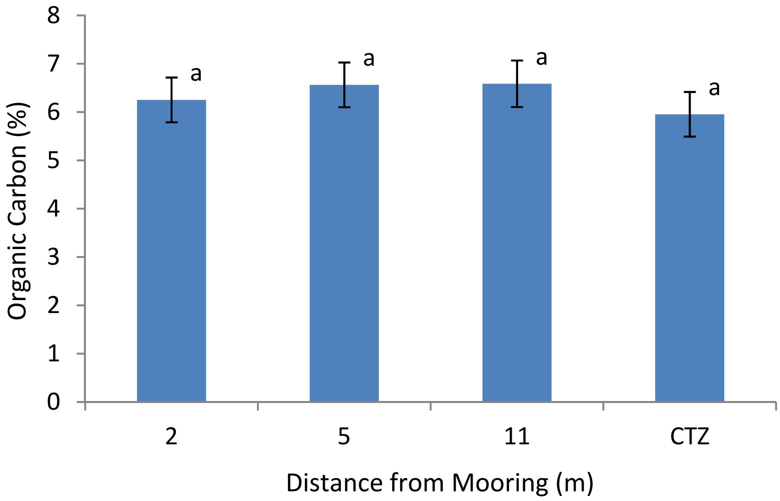

Figure 6 Graphical representation the percentage of organic carbon content of the samples (estimated marginal means) across the distances away from the mooring (2, 5 and 11 metres) and the control zone (CTZ). No significant difference is present between any of the distances or the distances and the controls (a).

Analysis of the sediment granulometry indicated significant influences of several factors on the particle sizes present within the samples. The distance of the sample from the mooring was identified as a significant source of variation within the samples (P=0.024) indicating the presence of the mooring does influence particle size. The study sites within the locations were also statistically significant (P=0.006), however the difference between the locations was not (P=0.192) suggesting that small scale variation is an important source of variation (Table 2). Pairwise comparisons of distances indicate significant differences present between 11m samples and the 2m and 5m samples, while the control zone (CTZ) samples were significantly different to the 5m samples only (Figure 7, Appendix 5). Pairwise comparisons at the level of location (Falmouth, Mylor, St. Mawes) indicates this significance is primarily driven by the Falmouth samples (Appendix 6).

Tests of Between-Subjects Effects

Dependent Variable: MeanMethMom

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
DISTANCE	Hypothesis	10.789	3	3.596	5.104	.024
	Error	6.388	9.065	.705[b]		
LOCATION	Hypothesis	34.652	2	17.326	3.012	.192
	Error	17.257	3.000	5.752[c]		
SITE(LOCATION)	Hypothesis	17.262	3	5.754	8.166	.006
	Error	6.391	9.069	.705[d]		
LOCATION * DISTANCE	Hypothesis	11.508	6	1.918	2.721	.086
	Error	6.365	9.031	.705[e]		
DISTANCE * SITE(LOCATION)	Hypothesis	6.345	9	.705	1.117	.370
	Error	29.028	46	.631[f]		

Table 2 Table of results from the analysis of variance (ANOVA) for particle size (mean method of moments logarithmic ϕ). Distance from the mooring was identified as a significant source of variation in the samples. Sites within locations were also identified as significant; this suggests small-scale spatial variation is present within the locations.

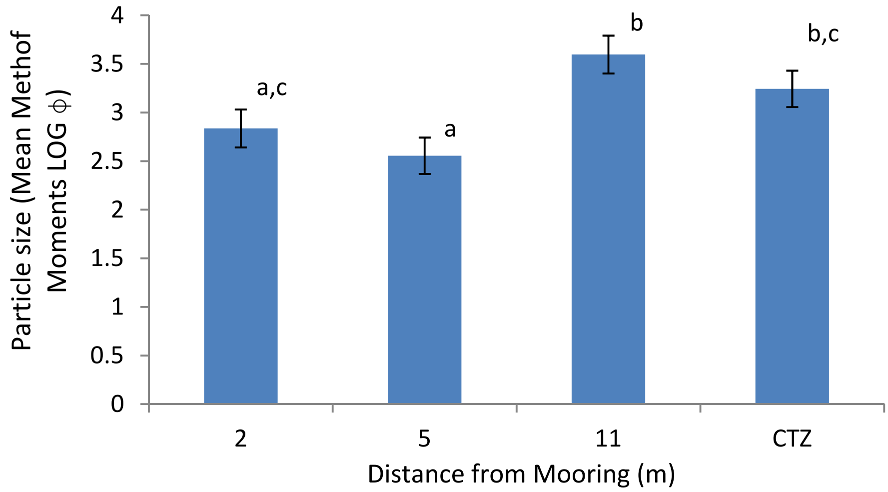

Figure 7 Changes in granulometry (particle size distribution) at varying distances from mooring and at the control zones (CTZ) (estimated marginal means of the mean method of moments logarithmic ϕ). The particle sizes at 2 metres and 5 metres are significantly different to those at the 11 metre distance. The control zone (CTZ) is not significantly different to the 2 metre and 11 metre samples, but is significantly different to the 5 metre sediment samples.

5.3 Summary of Infaunal Taxa

Within the infaunal samples, a total of 95 taxa were recorded across 11 phyla (Nematoda, Nemertea, Platyhelminthes, Chaetognatha, Annelida, Phoronida, Arthropoda, Echinodermata, Cnidaria, Mollusca and Chordata). Organisms within Nematoda (nematode worms) and Nemertea (nemertean worms) were recorded at phylum level only. Within Annelida (segmented worms), organisms were identified to 24 families, with the sub-class Oligochaeta recorded separately. Within the Arthropoda, organisms were split across 8 orders containing 30 families. Echinodermata included 3 classes. Cnidaria only included one order Actinaria (sea anemones). Mollusca (molluscs) predominantly split to the classes Bivalvia (bivalves) and Gastropoda (gastropods), with limited representatives from Opisthobranchia (sea slugs) and Polyplacophora (chitons). Bivalvia was represented by 14 families; Gastropoda by 6 families. Phylum Chordata (chordates) contained only one representative, Ascidiidae (sea squirts). Full details of the families recorded are available in the Appendix (Appendix 7).

The mean abundance of organisms per sample across all locations was 181. Within locations, the highest mean abundance of organisms was in St. Mawes (230 organisms/ sample) and the lowest in Mylor (123 organisms/ sample). The most abundant phylum across all locations was Annelida, with a mean abundance of 100 organisms per sample. The dominant phyla varied with location, phylum Annelida had the highest mean abundance at Mylor (mean abundance = 89) and Falmouth (mean abundance = 160) but within St. Mawes the dominant phylum was Arthropoda with a mean abundance of 107 organisms per sample (mean abundance of Annelida = 51). The mean abundances of the majority of phyla were low, with phyla Nemertea, Platyhelminthes, Chaetognatha, Echinodermata, Cnidaria and Chordata all below 1 when considered across all locations.

The majority of the families recorded fall within three main phyla – Annelida, Arthropoda and Mollusca. When considered across all locations, within the phylum Annelida the dominant family is Cirratulidae (mean abundance = 42). Within the locations, this holds true for Falmouth (mean abundance = 83) and Mylor (mean abundance = 39. St. Mawes has a much reduced mean abundance of Cirratulidae (4) and the greatest mean abundance within this phylum lies in the sub-class Oligochaeta (14). Amongst the Arthropoda the family Apseudidae have the greatest mean abundance, 25 organisms per sample, when considered across all locations. This is driven by the high numbers present within the St. Mawes samples (mean abundance = 74), with the mean abundance for both other locations less than 1. Within the molluscs (Mollusca) mean abundances were low. Across all locations, the highest mean abundance, 3 organisms per sample, was for the family Rissoidae. This family represented the largest mean abundances across Falmouth (4 organisms/ sample) and St. Mawes (2 organisms/ sample).

The taxa identified in the Mylor samples were generally concordant with the species identified in a recent moorings study conducted within this area (Kendall et al., 2006). Within St. Mawes, the taxa reflect those previously identified, including taxa specific to this location most notably *Echinocardium* (heart urchins) (J. J. Moore et al., 1999).

5.4 Biodiversity Measures

The total number of organisms present within the samples, the abundance (N), was identified by analysis of variance (ANOVA) as being significantly influenced by the distance of the sample from the mooring infrastructure (P=0.023). Sites within locations (P=0.020) and the interaction of distance and site within location (P=0.000) (Table 3) were also indicated to contribute significantly to the total abundances within the samples. This indicates small scale spatial variation, the distance from the mooring and the site within the location that the sample was collected from, play a significant role in determining the number of organisms present. The significance of the distance and site interaction suggests that the distance response was inconsistent across sites. No significant difference was present between the survey locations (P=0.490) or in the interaction between distance and location (P=0.989).

Tests of Between-Subjects Effects

Dependent Variable: N

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
DISTANCE	Hypothesis	659867.741	3	219955.914	5.278	.023
	Error	375089.306	9	41676.590		
LOCATION	Hypothesis	423418.694	2	211709.347	.914	.490
	Error	695051.917	3	231683.972		
SITE(LOCATION)	Hypothesis	695051.917	3	231683.972	5.559	.020
	Error	375089.306	9	41676.590		
LOCATION * DISTANCE	Hypothesis	32443.898	6	5407.316	.130	.989
	Error	375089.306	9	41676.590		
DISTANCE * SITE(LOCATION)	Hypothesis	375089.306	9	41676.590	4.658	.000
	Error	1717790.444	192	8946.825		

Table 3 Table of results from the analysis of variance ANOVA of the abundance (N) of organisms within the infaunal samples. Distance, site within location and the relationship between distance and site within location were all identified as significant factors influencing the number of organisms present within the samples (significance highlighted by grey rows).

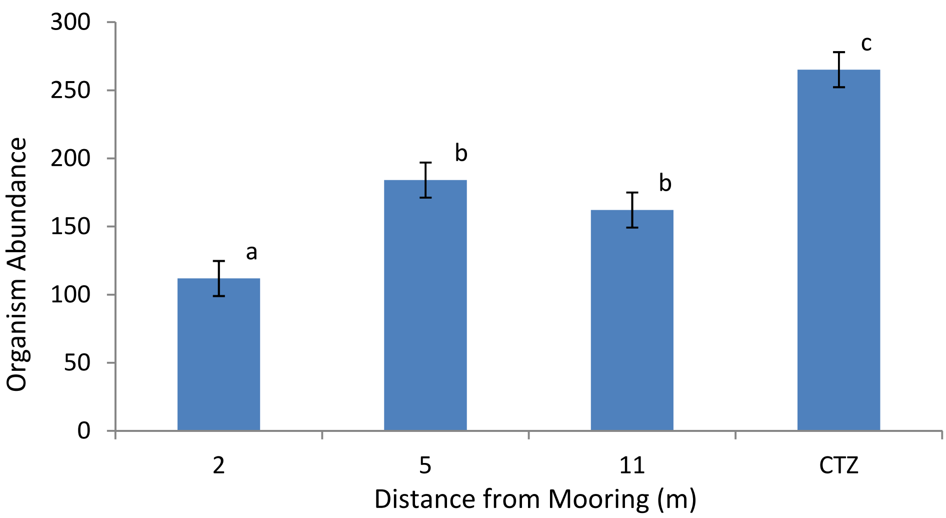

Figure 8 Graphical representation of the total abundance of organisms across the varying distances and control zones (CTZ), showing an overall increase in abundance between the samples closest to the moorings and the control zones (CTZ). 2 metre samples are significantly different from all other distances and the controls (a). Error bars indicate standard deviation.

An overall increase in the number of species is visible between the 2 metre and the control (CTZ) samples (Figure 8). Pairwise comparisons of the different distances show significant differences between multiple distance pairs, with reduced abundances in the 2 metre samples and increased abundances in the control (CTZ) samples both statistically significant different from the 5 and 11 metre samples (Figure 8). A pairwise comparison of distances, at the spatial scale of locations, indicates the significance differences arising are largely present across all 3 study locations (Appendix 8).

When considering the species richness (S) of the samples, distance from the mooring infrastructure was again indicated by the analysis of variance (ANOVA) to be a significant influencing factor (P=0.011). Small scale variation was also evident with the influence of sites within locations indicated to be highly significant (P=0.000). This indicates that both the distance from the mooring and the site within the location that the sample was collected from were significant factors in determining the number of different taxa present in the sample. No significant difference was present at the larger spatial scale of survey locations (Falmouth, Mylor, St. Mawes) (P=0.473) or in the interactions between location and distance (P=0.479) and between distance and site within location (P=0.497) (Table 4).

Tests of Between-Subjects Effects

Dependent Variable:S

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
DISTANCE	Hypothesis	652.407	3	217.469	6.820	.011
	Error	286.972	9	31.886		
LOCATION	Hypothesis	1507.787	2	753.894	.970	.473
	Error	2332.583	3	777.528		
SITE(LOCATION)	Hypothesis	2332.583	3	777.528	24.385	.000
	Error	286.972	9	31.886		
LOCATION * DISTANCE	Hypothesis	191.731	6	31.955	1.002	.479
	Error	286.972	9	31.886		
DISTANCE * SITE(LOCATION)	Hypothesis	286.972	9	31.886	.934	.497
	Error	6554.222	192	34.137		

Table 4 Table of results from the analysis of variance (ANOVA) for the species richness (S) within the infaunal samples. Distance from mooring and the interaction of sites within locations were both identified as significant influencing factors (significance highlighted by grey rows).

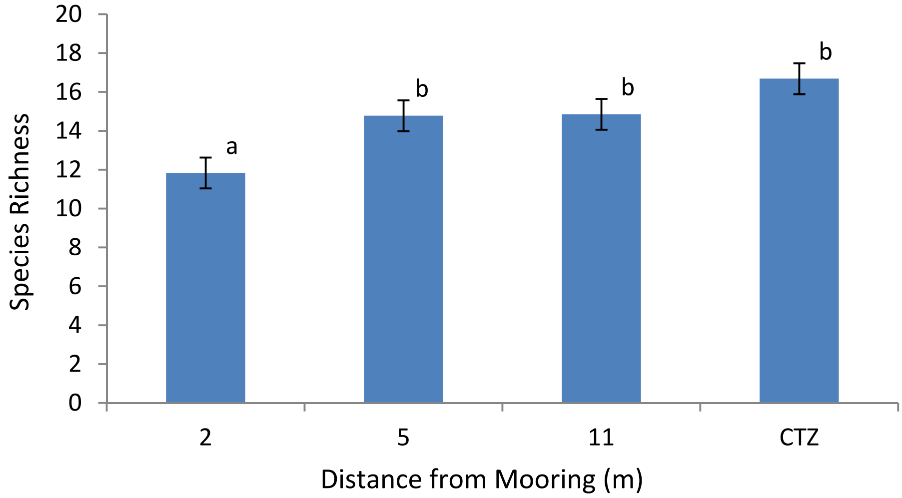

Figure 9 Graphical representation of the total number of taxa present (species richness) of the infaunal samples across the different distances from the moorings and the control zones (CTZ). The 2 metre samples were significantly different to all other distances and controls (a). Error bars indicate standard deviation.

A continuous increase is visible in the species richness across the 2 metre, 5 metre, 11 metre and control (CTZ) samples (Figure 9). Pairwise comparisons of distances show a significant difference to be present between the 2 metre samples and all other distances (5m, 11m and CTZ) (Figure 9). Further pairwise comparisons within each of the study locations suggest that these distance differences are primarily driven by Mylor and St. Mawes (Appendix 9).

Analysis of variance (ANOVA) of the abundance of organisms within the phylum Annelida indicated no significant effect of the distance from the mooring on the abundance of organisms within this group (P=0.055), but did indicate significant small-scale spatial variation at the level of sites within location (P=0.005) and significance of the interaction between distance and site within location (P=0.000). No significant difference was present between locations (P=0.298) or in the interaction between location and distance (P=0.570) indicating larger-scale variation to be less influential (Table 5). Analysis of the Polychaeta, omitting Oligochaeta from the analysis, gave the same pattern of significance (Appendix 10).

Tests of Between-Subjects Effects

Dependent Variable: ANNELIDA

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
DISTANCE	Hypothesis	152331.315	3	50777.105	3.723	.055
	Error	122758.222	9	13639.802		
LOCATION	Hypothesis	441393.778	2	220696.889	1.859	.298
	Error	356244.778	3	118748.259		
SITE(LOCATION)	Hypothesis	356244.778	3	118748.259	8.706	.005
	Error	122758.222	9	13639.802		
LOCATION * DISTANCE	Hypothesis	68657.741	6	11442.957	.839	.570
	Error	122758.222	9	13639.802		
DISTANCE * SITE(LOCATION)	Hypothesis	122758.222	9	13639.802	3.869	.000
	Error	676852.667	192	3525.274		

Table 5 Table of results from the analysis of variance (ANOVA) for Annelida (segmented worms) within the infaunal samples. Significant factors influencing the abundance of Annelid worms were identified as the sites within the locations and the interaction of distance and the site within the location (significance identified by grey rows).

The abundance of organisms within the sub-phylum Crustacea (amphipods, cumaceans and tanaids) indicated highly significant effects of distance (P=0.000), location (P=0.008) and of the interaction between location and distance (P=0.001) when analysed using ANOVA. Sites nested within locations are also indicated to be significant (P=0.039) (Table 6). This indicates that the distance from the mooring infrastructure, large- and small-scale spatial variation all influence the abundance of Crustacea present in the samples. The significance of the interaction between location and distance also indicates that the effect of distance varies with the location of the sample.

An overall increase in the abundance of Crustacea is present between the 2 metres and control (CTZ) samples, although this is not consistent across subsequent distances (Figure 10). Overall pairwise comparisons indicate significant differences between the control zones (CTZ) and samples from all other distances (2, 5 and 11 metres). 2 metre samples are significantly different from those at 5 metres, but not significantly different to the 11 metre samples (Figure 10). Pairwise comparisons at the level of the study locations indicate the significance between the distances to be primarily driven by St. Mawes (Appendix 11). An analysis of variance (ANOVA) of the order Amphipoda, removing the influence of large numbers of tanaids and rare occurrences of organisms in the phyla Pycnogonida and Isopoda, gives an output that closely mirrors that of Crustacea, although the influence of location becomes non-significant (P=0.190) (Appendix 12).

Tests of Between-Subjects Effects

Dependent Variable: CRUSTACEA

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
DISTANCE	Hypothesis	74314.384	3	24771.461	17.983	.000
	Error	12397.153	9	1377.461		
LOCATION	Hypothesis	437554.565	2	218777.282	37.086	.008
	Error	17697.569	3	5899.190		
SITE(LOCATION)	Hypothesis	17697.569	3	5899.190	4.283	.039
	Error	12397.153	9	1377.461		
LOCATION * DISTANCE	Hypothesis	105188.324	6	17531.387	12.727	.001
	Error	12397.153	9	1377.461		
DISTANCE * SITE(LOCATION)	Hypothesis	12397.153	9	1377.461	.472	.892
	Error	559972.000	192	2916.521		

Table 6 Table of results for the analysis of variance (ANOVA) of the abundance of Crustacea within the infaunal samples. The analysis identified distance but also location, site within location and the interaction of location and distance as having significant effects on crustacean abundances (significance indicated by grey rows).

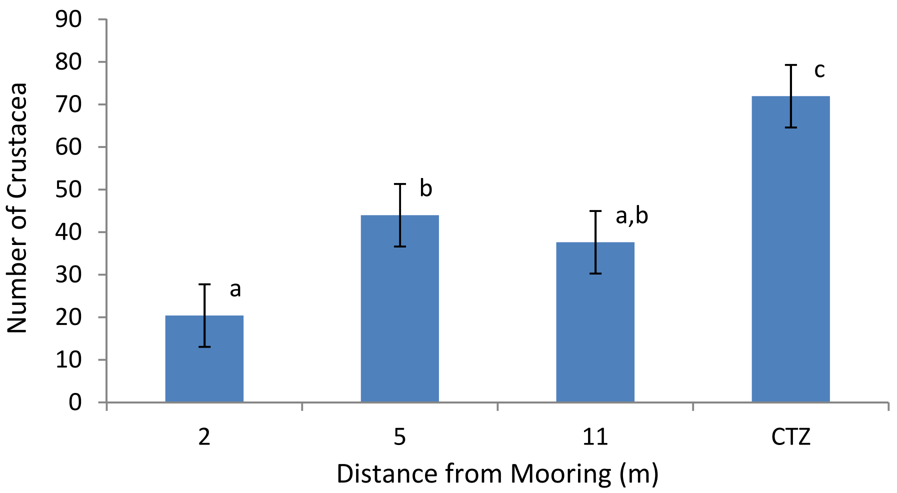

Figure 10 Graphical representation of Crustacea abundances across the different distances and control zone (CTZ). Within the distances (2, 5 and 11 metres) the number of Crustacea present peak at 5 metres, this value is significantly different to the abundance at 2 metres but not to that at 11 metres (a,b). The abundance of Crustacea in the control zone (CTZ) samples was significantly greater than that of all distances (c). Error bars indicate standard deviation.

Analysis of variance (ANOVA) of the abundance of organisms within the phylum Mollusca indicates sites within location as the only significant factor (Table 7), suggesting that small-scale spatial variation is influential. A further ANOVA of bivalve (Bivalvia) abundance again only indicated a significance effect of site within location on the abundances within the samples (Appendix 13). Neither analysis, at phylum or class level, detected an effect of the distance from the mooring infrastructure on abundance.

Tests of Between-Subjects Effects

Dependent Variable: MOLLUSCA

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
DISTANCE	Hypothesis	557.574	3	185.858	1.161	.377
	Error	1441.083	9	160.120		
LOCATION	Hypothesis	1395.009	2	697.505	.791	.530
	Error	2644.583	3	881.528		
SITE(LOCATION)	Hypothesis	2644.583	3	881.528	5.505	.020
	Error	1441.083	9	160.120		
LOCATION * DISTANCE	Hypothesis	1109.954	6	184.992	1.155	.406
	Error	1441.083	9	160.120		
DISTANCE * SITE(LOCATION)	Hypothesis	1441.083	9	160.120	1.607	.116
	Error	19133.111	192	99.652		

Table 7 Table of results of the analysis of variance (ANOVA) for the abundance of Mollusca within the infaunal samples. No significant influence of distance was identified (significant factors identified by grey rows).

5.5 Community Analysis

Non-metric multi-dimensional scaling (MDS) provides two-dimensional visualisation of the similarity of the infaunal communities between samples and groups of samples. While univariate analysis of the biodiversity measures generally indicated location to be a non-significant factor, an MDS plot of the square root transformed infaunal data shows some overlap of in the similarity of Mylor and Falmouth samples, but clearer isolation of St. Mawes (Figure 11). This data indicates the locations to be significantly different (P=0.001) when analysed with an analysis of similarity (ANOSIM) at the level of community composition, indicating large-scale spatial variation to be present in the samples.

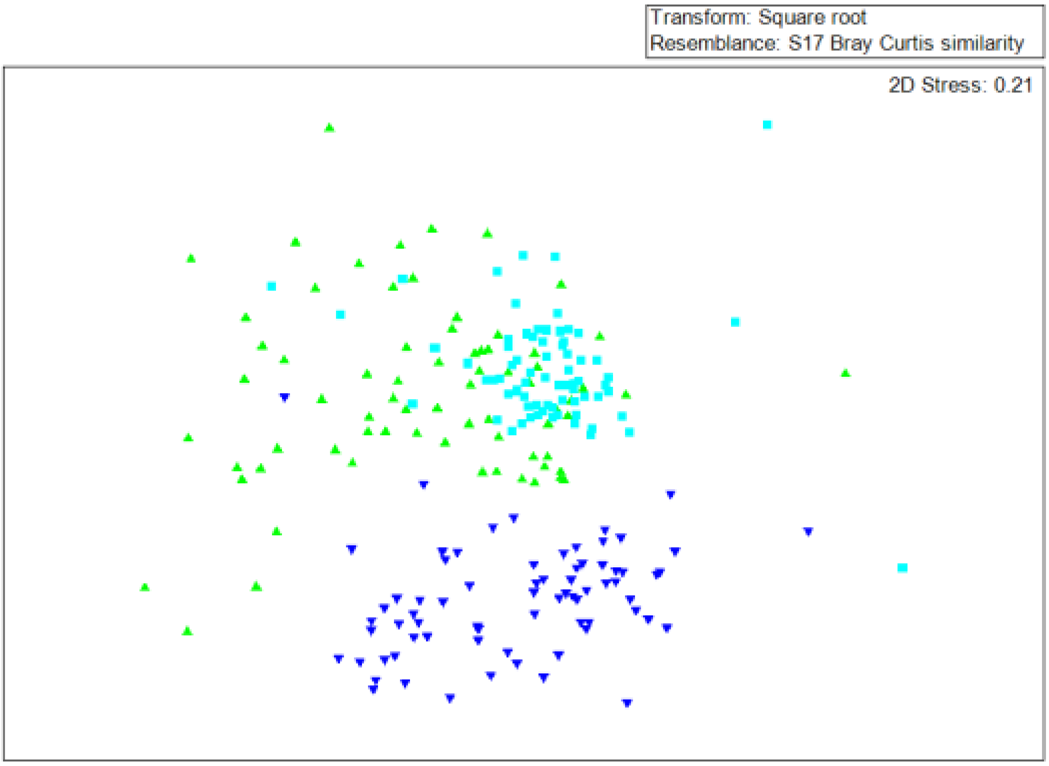

Figure 11 Multi-dimensional scaling (MDS) plot of the similarity of the infaunal communities across the different locations (**light blue squares** = Falmouth, **green triangles** = Mylor, **blue triangles** = St. Mawes). Although considerable overlap of the locations is apparent, an ANOSIM analysis identified the locations as significantly different (P=0.001).

MDS plots of each of the locations generally show greater similarities of samples within the control (CTZ) samples when compared to those within the mooring area (2 metres, 5 metres, 11 metres) (Appendix 14). Dis-similarity of samples is generally acknowledged to be an indicator of disturbance within a community (Warwick & Clarke, 1993). The greater level of similarity amongst the control zones suggests that these areas are subject to a lower level of disturbance. Independent ANOSIMs on each of the locations, conducted on 4th root transformed data, identified distance from the mooring infrastructure to be a significant factor influencing the community composition at all locations (Falmouth R=0.234, P=0.001; St. Mawes R=0.169, P=0.001; Mylor R=0.26, P=0.001). Pairwise comparisons were used to identify which distances were significantly different. Within Falmouth this revealed significant differences across all distance combinations (P=0.001) with the exception of the 2 metre, 5 metre comparison (P=0.431). This shows the 2 metre and 5 metre samples to be statistically significant from 11 metre and controls, suggesting an impact on community composition out to at least 5 metres. At St. Mawes the pairwise tests only identified differences between the mooring distances (2 metres, 5 metres and 11 metres) and the control (CTZ) samples (P=0.001). Pairwise tests at Mylor again identified significant differences between the mooring distances (2 metres, 5 metres and 11 metres) and the control samples (CTZ) (P=0.001). The pairwise tests also identify significance between the 2m and 11m samples. Full pairwise test results are included in the Appendix (Appendix 14).

Averaging of the infaunal data to distance within the 3 locations allows broad illustration of the similarities of community compositions at each location. Within each location the 11m and 5m sample groups are consistently closest to the control (CTZ) sample groups, with the 2m sample group furthest from the control within each location on the MDS plot (Figure 12).

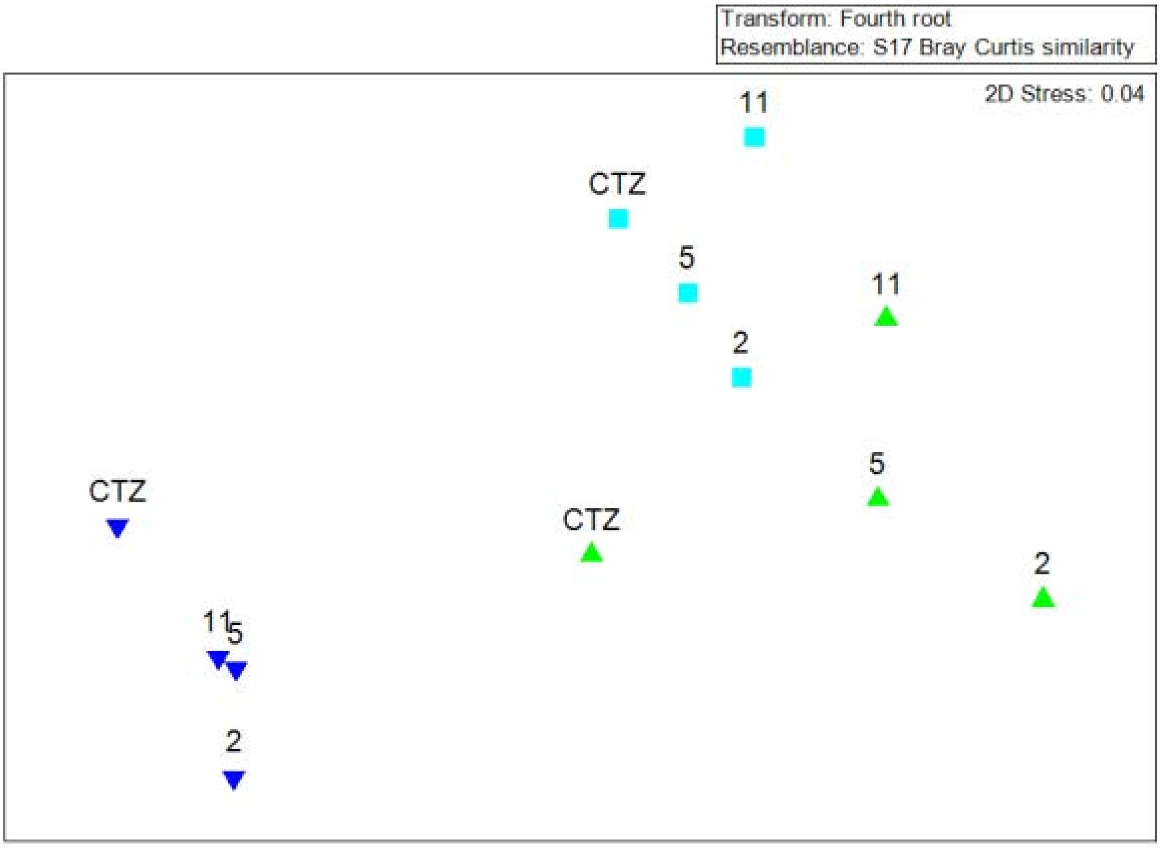

Figure 12 MDS plot of infaunal community composition data averaged to distance within location (light blue squares = Falmouth, green triangles = Mylor, dark blue triangles = St. Mawes). Within locations, the 11 metre and 5 metre samples are consistently closer to the control zone (CTZ) samples, with the 2 metre samples at the far extent. This indicates that within each location the communities of the 11 metre and 5 metre samples are closer to those of the relevant un-impacted control.

The infaunal abundance data was averaged and analysed using an analysis of covariance (ANCOVA) with the inclusion of the particle size data as a covariate, to allow consideration of the influence of all recorded factors. The ANCOVA output supported the significance of particle size in determining community composition (P=0.0011). The factors of distance, site within location and location were all identified as significant sources of difference in the infaunal community composition (P=0.0006, P=0.0001 and P=0.0254 respectively) indicating that the distance from the mooring infrastructure, small- and large-scale variation are all important in determining the community composition found within the samples (Table 8). In this analysis, to better represent the spatial variability within the samples, two non-significant terms – the interaction of location and distance and site within location and distance – were pooled.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Particle Size (Mean Meth. Mom. Log. ϕ)	1	12210	12210	3.1628	0.0011	9919
Location	2	30933	15466	2.4108	0.0254	720
Distance	3	7065.3	2355.1	2.0219	0.0006	9893
Site (Location)	3	19893	6631	5.9685	0.0001	9896
Pooled terms	61	67771	1111			
Total	70	1.38E+05				

Table 8 Table of results for the analysis of covariance (ANCOVA) on the infaunal community data. The analysis identified particle size, location, distance and site within location all as factors influencing the community composition (significance identified by grey rows). The pooled terms are the interactions of location and distance and site within location and distance, both of which were independently non-significant.

5.6 Summary of Results

The following table (Table 9) gives a summary of the results outlined throughout the results section, highlighting analyses which indicated a significant influence of distance on the measured variables.

Analysis		Significance	Distance
Epifaunal Analysis	Epifaunal Video	Insufficient resolution to detect impact.	n/a
Sediment Analysis	Organic Carbon Analysis	No significant influence of distance on the sediment carbon content.	n/a
	Particle Size Analysis	Significant influence of distance on sediment particle size.	2m and 5m samples are significantly different to the 11m samples. Control samples are significantly different to the 2m and 11m samples.
Infaunal Analysis	Overall Abundance	Significant influence of distance on organism abundance.	2m samples significantly different from 5 and 11m samples. 5 and 11m samples significantly different to Control samples.
	Species Richness	Significant influence of distance on species richness.	2m samples significantly different to 5m, 11m and Control samples.
	Grouped Abundance (Annelida)	No significant influence of distance on the grouped abundance of Annelid worms.	n/a
	Grouped Abundance (Crustacea)	Significant influence of distance on the grouped abundance of crustaceans.	2m samples significantly different to 5m samples. 2m, 5m and 11m samples significantly different to Control samples.
	Grouped Abundance (Mollusca)	No significant influence of distance on the grouped abundance of molluscs.	n/a
	Community Composition	Significant influence of distance on the infaunal community composition.	Falmouth: 2m and 5m samples significantly different to 11m and Control samples. St. Mawes and Mylor: significant difference between mooring distances (2m, 5m, 11m) and Control samples.

Table 9 Summary table of results. Analyses are grouped into the three areas of analysis (epifaunal, sediment, infaunal) and significant results are highlighted in grey.

6 Discussion

6.1 Impact on Sediment Characteristics

Previous studies have identified sediment characteristics including organic content and granulometry to be influenced by the presence of moorings (Collins et al., 2010; Herbert et al., 2009). Disturbance of the seabed has been indicated to decrease the organic carbon content of sediment (Lee et al., 2011) or to provide conditions that may result in an increased organic carbon content (Thistle, 1981). However, the results of this study indicated no significant influence of the distance from the mooring on the organic content of the samples, suggesting that the organic content of the sediments is not different as a result of the presence of the mooring infrastructure. Initial graphical representation of the results across the three locations indicated some potential influence of locational differences on the carbon content; however the presence of highly significant small scale, within location variability may mask the significance of other factors. This significance influence of sites within locations does identify localised spatial variation as an important factor in determining the organic carbon content recorded. The organic carbon content within the sediments is also likely to fluctuate over seasonal scales and following storm events.

A significant influence of the distance from the mooring on the sediment particle size was identified by this study and this is supported by previous work identifying sediment particle size distributions as strongly influenced by the presence of mooring infrastructure and the resulting disturbance (Collins et al., 2010; Herbert et al., 2009). The movement of the mooring chains on the seabed physically disturbs the sediment (pers. obs.) which, in combination with water currents within the area, is suggested to result in the re-suspension and removal of smaller silt particles. This is in line with the findings of Herbert et al., 2009 who identified a greater proportion of coarser sediments in the vicinity of the moorings. The differences in particle size distributions were most prominent in the Falmouth sediments, with a distinct visible difference in the seabed (pers. obs. Angie Gall). It is possible this is due to the more mixed sediment composition within this area, with muddy sediment containing a large coarse gravel and dead maerl fraction, whereas Mylor and St. Mawes locations consisted of more homogenous sediments.

While the results of the sediment analyses give an indication of potential effects on the sediment particle size distribution, this was not the primary focus of this study and replication of samples was limited. As a result, care should be taken in the interpretation of the results but it is positive that the particle size distribution trends identified here appear to be supported by previous studies. The presence of a lasting physical feature of disturbance within the sediment itself has also been previously been identified (Dernie, Kaiser, Richardson, & Warwick, 2003). Within the area of study for this project, physical disturbance of the sediment was detected at a scale visible within bathymetric data as circular depressions in the region of 20-40cm deeper than the surrounding sediment (pers. obs.)[n]. An additional sediment consideration, which could not be recorded as part of this work but which could be of interest in future work, was the potential for contaminant accumulation in estuarine sediments which disturbance events may subsequently release increasing contaminant bioavailability (Eggleton & Thomas, 2004).

6.2 Ecological Impact

The results of this study do suggest that there is a detectable physical impact of the mooring infrastructure on the infaunal communities within the Fal estuary, which is concurrent with the findings of recent studies of mooring infrastructure on sediment habitats (Herbert et al., 2009; Smith, 2000). The physical extent to which this is significant varies across the different analyses, with different biological measures impacted to different extents. Measures of total organism abundance and overall biodiversity considered across all locations showed significant reductions in the 2 metre samples, when compared to the 5 metre and 11 metre samples, indicating that the samples closest to the mooring block are significantly impacted by direct physical disturbance from the mooring infrastructure. The

[n] See also Figure 3.

overall pattern apparent in the biodiversity measures against the distance from the mooring matches that previously identified in commercial mooring infrastructure (Smith, 2000). Community level analysis supported the importance of distance in influencing the infaunal community, indicating dis-similarity between the 2 metre and 11 metre samples but also indicating some significant influence at 5 metres.

When considered across all biodiversity measures and all survey locations, a significant impact can be identified with confidence in the 2 metre samples, giving a radius impacted as between 2 and 5 metres. This gives a total area of seabed significantly physically impacted per mooring of between 12.6 and 78.5 metres^2. The community analysis also indicated a significant impact at 5 metres, which would give an impact extending from 5 metres out to 11 metres and an area of impact per mooring of between 78.5 and 380.1 metres^2. Of these two areas calculated there is greater support for an impact between 2 metres and 5 metres, but the presence of an impact in the 5 metre samples should not be overlooked. A clarification of the level of confidence is given in Section 7.1 (Table 12). The area figures are given as a range, rather than a single number, to reflect the uncertainty in the distance breakpoint for the presence of significance, i.e that a biodiversity measure identified as significant at 2 metres but not at 5 metres may be significant to anywhere between 2.1 and 4.9 metres, but without any samples from between these two points this cannot be ascertained. From the per mooring impact areas calculated above it is possible to estimate the total impacted area impacted by moorings within the Fal and Helford estuaries. These calculations are included in Section 7 and suggest that moorings represent a substantial area of potential impact within the estuaries. The areas of impact are also mapped onto mooring locations to visualise the impacted areas within the surveyed mooring areas (Section 7 Figure 13 and Figure 14).

The indication of an ecological impact extending out to 11 metres also suggests extent of impact similar to that identified previously in seagrass beds, where average scour radius' of 10 metres were recorded and greater impact was again apparent closest to the centre of the mooring (Egerton, 2011). The measures of total abundance, species richness and the community level analyses also detected an overall difference between the mooring samples (2m, 5m, and 11m) and the control samples. While this may reflect spatial differences between the areas, it may also be indicative of a wider influence of impacts within the mooring areas. The greater homogeneity of control samples compared to all of the mooring distance samples is indicative of lower stress on the system in these areas (Warwick & Clarke, 1993) and supports the expected lower level of impacts in these Control areas.

Following a disturbance, 'recovery' of an area follows successional patterns, which eventually revert back to the community that was present prior to the disturbance via a series of intermediate communities. Species do not recolonize simultaneously and following disturbance within an area, differential re-colonisation by different taxa has been indicated for different species (Dernie et al., 2003). The re-colonisation of some species has also been indicated to be negatively affected by chemical stimuli released from disturbed sediments, from chemicals in the sediments or secretions from injured/decaying fauna, resulting in longer than anticipated community recovery times (Ferns et al., 2000). In light of this it may be considered that if certain taxa actively avoid colonisation of newly disturbed sediments that in areas of more frequent disturbance, such as close to the mooring infrastructure where communities may not have chance to recover or 'recovery' may only be partial prior to the next disturbance, certain taxa may not colonise at all or only rarely. Frequent disturbance may select for organisms that can reproduce between disturbance recurrances (Probert, 1984) or for organisms that can tolerate sub-lethal effects of a frequent disturbance (Lee et al., 2011).

Within this study individual analyses of several large taxonomic groups, the Annelida (segmented worms), Crustacea (crabs, lobsters and shrimp) and Mollusca (gastropods and bivalves), did result in differences in the significance of distance as a factor in determining abundance, indicating a differential impact on different taxa. Both Annelida and Mollusca indicated no significant influence of distance on the total abundance of representatives within that group. Crustacea however, did indicate a highly significant influence of distance on the total abundance of organisms within this group. This suggests that organisms within the phylum Crustacea are particularly highly impacted by the presence of moorings. Herbert et al., (2009) found significant reductions in *Corophium volutator* (a burrowing amphipod) within areas of mooring scour and suggested that the motion of the chain may damage burrows or modify sediment in a way that may influence burrow construction. These analyses only looked at the total abundance of organisms within the group, not the composition of the group, therefore in Annelida and Mollusca while a difference was not detected at the level of the group differential effects may be present on the taxa within the group.

The three different mooring locations (Falmouth, Mylor, St. Mawes) were identified as significantly different at the community level analyses and within the analysis of the sub-phylum Crustacea. This was anticipated based on the different biotopes indicated by the MNCR biotope maps (Moore et al., 1999) and the habitats identified during the epifaunal surveys. The multivariate community analysis identified significantly different community compositions at the different locations and identified differences of infaunal communities within different locations. The fine sand sediments in the relatively more exposed location of St. Mawes indicated the least influence of disturbance from the mooring infrastructure on community composition, while the muddier sediments of Falmouth and Mylor indicated significant differences at 2 and 5 metres and 2 metres respectively. The greater influence of disturbance on mud sediments is concurrent with the findings of Ferns, Rostron, & Siman, 2000, who indicated quicker post-disturbance recovery in sandy sediments when compared to more structured muddy sediments and relatively low impacts of physical disturbance have been demonstrated on well-sorted sediments with only small amounts of fine sediment (Moore, 1991). It is likely that this reduced impact on sandy sediments is due to the greater wave exposure in this area; hence the infaunal community is already accustomed to an elevated intensity and frequency of disturbance within this habitat. This indication of lower impact on sandy sediment habitats does not include areas of seagrass beds which have been previously demonstrated to be significantly impacted by mooring infrastructure, see (Egerton, 2011; Hastings, 1995; Walker et al., 1989). The potential for differential impact on different biotopes is also outlined in the mapping of biotope sensitivities (Section 7.3 Figure 18 and Figure 19). These are theoretical based on biotope data from the MNCR report and in some case conclude a different level of sensitivity to that suggested by the results of the study.

In assessing the potential impact of the recreational boating infrastructure on the estuaries, the contributions of additional impacts and the scale and frequency of the disturbance caused by the infrastructure must also be considered. While the actual physical effect of disturbance caused by mooring infrastructure may be similar to natural disturbances, such as crabs digging and rays feeding, the scale and frequency at which an area is impacted may well be elevated and the moorings are present within large areas of the estuaries. This longevity of impact has been previously discussed within seagrass beds where the impact of mooring infrastructure has been compared to that of natural blowouts (bare sand patches) within the bed. Natural blowouts migrate through the bed and are recolonized as the bed grows back over them, whilst in areas of moorings bare patches are created which remain open through constant disturbance (Hastings, 1995). There will also be additional natural and anthropogenic disturbances within mooring areas and the importance of considering additional impacts when managing areas to ensure favourable ecological status is considered further in the management recommendations made in Section 8.

The effect of disturbance is usually perceived as constant, i.e. and area is disturbed or not, or that there is a gradual consistent increase in disturbance close to the source of disturbance. Within the case of the moorings it is possible that the area within the influence of the mooring is not the disturbed patch, but instead contains numerous smaller patches as the disturbance from the chain is unlikely to act in a uniform manner around the mooring. The distances selected for this study reflected the different potential for impact – 2 metre samples are within the reach of the heavy thrash chain, 5 metre samples are within the radius of the lighter, more mobile riser chain and samples collected at 11 metres are outside of the scoured area and are unlikely to be impacted by the chain except on exceptionally large tides. It was considered that the thrash chain would move infrequently but would cause considerable disturbance, while the riser chain moves much more frequently but each movement causes a smaller physical disturbance. In reality the mooring chain doesn’t move in a constant crescent (pers. obs.) and some areas are likely to be disturbed to a greater degree and more frequently than others resulting in a patchwork of disturbance within the area of mooring scour. It is still likely, however, that this will result in an overall gradient of decreasing intensity and frequency of disturbance with distance away from the mooring.

The areas of moorings investigated as part of this study were identified as located on muddy gravels and fine sand sediments, identified within the MNCR report as sub-littoral muddy gravel (MarMu; FaMx; VsenMtru) with algae (LsacX), sub-littoral estuarine mud (AphTub) with kelp on available hard substrata (LsacX) and sub-littoral sediment with *Zostera marina* beds (Zmar) (Moore et al., 1999). These biotopes were indicated to be widely distributed throughout the lower Fal estuary and concurrent with wider areas of similar moorings around the estuary (Section 7 Figure 22 and Figure 23). The results of this study do however suggest that the biotopes encountered in the study areas differ to those predicted by the available biotope maps of the Fal and Helford estuaries. This could be due to the broadscale nature of the biotopes and spatial variation across the area. This variation does limit the confidence of the extrapolation of results across these areas (Section 7) in the absence of further biotope data in these areas.

Some of the habitats encountered as part of this study are protected as part of the SAC under the habitat and interest features of shallow inlets and bays and sub-tidal sandbanks and as such the impact of moorings infrastructure should be managed to prevent detrimental effects of these features. Although the calculated area of impact per mooring is relatively small, when multiplied across the number of moorings within the SAC this figure does represent a substantial area of seabed (Section 7) and this must be considered in line with other influences on the estuary to manage for the future sustainability of the marine environment and of recreational maritime activities within the area. The results of the granulometry and video analysis also suggest that some of the moorings locations which are not currently identified under the features of interest within the SAC should be included in these features, namely inclusion of areas into the sub-tidal sandbanks feature. An example of this would be the moorings areas in St. Mawes, where the main biotope is identified as the same as the Falmouth area (sub-littoral estuarine mud (AphTub) with kelp on available hard substrata (LsacX)), but both the sediment and video analysis show a consistently high proportion of sand to be present in this area and the infaunal analysis identified species with habitat preferences for sandy sediments.

6.3 Further Study

Due to limitations of time and resources it was necessary to constrain this study to investigating the ecological footprint of the impact of a specific type of mooring infrastructure. While this has increased knowledge of the impact of this type of infrastructure and allows estimations of the overall influence of this infrastructure within the estuary, it also raises additional questions that compliment or continue this work.

A number of obvious additional areas for future study were identified early on. A key area of investigation would be the comparison of the size of the significant area of disturbance of single block moorings with that of trot moorings, as these represent the main alternative type of mooring present within the estuaries. Establishment of the relative extent of disturbance for each type of mooring would potentially allow for a gradual phasing out of the type with the highest impact. Another aspect is that all mooring infrastructure is not of the same size, larger vessels are generally situated in deeper water, require larger blocks, longer thrash chains and longer risers and the chains are generally of a greater thickness. In this respect larger moorings could offer the potential for a greater impact. This study was conducted on moorings for vessels within the 30-40ft size range within the different locations as within the estuaries these moorings offered the most comparable options across all the study locations. A further study in this area would establish if the area of impact of the mooring impact is relative to the size of the mooring and would allow a more accurate estimation of the total ecological impact of mooring infrastructure.

The presence of differences between the 11m mooring samples and the control samples suggests a potential wider influence of the mooring infrastructure within the mooring areas. As identified in the scoping study and literature reviews (Mather, 2009; Neilly, 2011), there are a number of potential factors which may influence the wider mooring area including pollution and hydrography changes. To accurately estimate the ecological impact of recreational boating infrastructure within an area, further work into the additional potential impacts would be necessary as the influence of these impacts could potentially impact the area to a greater or lesser extent than the impact of any direct physical disturbance.

As part of this study an influence of location on the infaunal community was detected, indicating that the mud sediments of Mylor and Falmouth were influenced by physical disturbance from the moorings to a greater extent than the sand sediments of St. Mawes. Further study to conclusively establish the type of sediments least impacted by the presence of moorings would enable future management to situate moorings, where feasible, on sediments less likely to be impacted by the presence of such structures. Linked to this would also be the influence of exposure on the impact of the moorings; however moorings are generally located in sheltered areas for obvious reasons.

An important piece of further work which would be valuable for the Fal and Helford estuaries would be a comprehensive compilation of biological records and survey information for the SAC area. A wide variety of data is available but this has not been compiled into an easily accessible, up to date habitat map of the area. The available habitat data within the Fal and Helford was generally old and was found to be not representative of the habitats present during the surveys conducted here. In all situations, a strong, accurate baseline knowledge of the area will provide a better basis for future study and an accurate representation of the area for management purposes.

7 Wider Application

7.1 Estimation of the Ecological Impact of Recreational Mooring Infrastructure within the Fal and Helford Estuaries

An important output of the Fal and Helford project was the use of the scientific results to make an estimate of the ecological impact of recreational mooring infrastructure within the Fal and Helford estuaries. The following details the calculation of this estimate, based on the varying extents of impact identified in the discussion. As the following is an estimate, care should be taken to acknowledge the source and extent of inaccuracies present and several caveats are identified throughout this section to highlight the limits of this work. All estimates are based solely on the ecological impact resulting from direct physical disturbance of the seabed by the type of mooring surveyed. No estimations of impact for alternate mooring types can be made without further study and estimations do not account for any wider additional impacts within the estuaries.

The mooring numbers around the estuary were collated through direct liaison with moorings operators and the Fal and Helford recreational boating infrastructure audit (Natural England, 2011). Lloyd Pond at Falmouth Harbour Commissioners provided the moorings estimates for Falmouth Inner Harbour; Paul Ferris at Port of Truro and Penryn provided numbers for Port of Truro and Penryn waters and Restronguet creek; Hugh Jones at Percuil River Moorings provided numbers for the Percuil River and Simon Walker at Helford River Moorings provided numbers for the Helford River, a figure corroborated by Chris Matthews at Duchy of Cornwall. All parties also indicated areas where information may be lacking or numbers are inaccurate, this information is included in the footnote to Table 10. Table 11 then narrows down these figures to identify the number of moorings present in the areas surveyed as part of the Fal and Helford Study.

The initial estimation, Table 13, calculates the ecological impact from permanent, single block, sub-tidal moorings across the three locations surveyed as part of this study. It was not possible to further split the figure for permanent, single block, sub-tidal moorings into size classes; therefore the area of impact within this type will still vary and care must be taken to emphasize the limitations associated with this value. While efforts have been made to use the most accurate figures possible, the numbers given are not exact and some moorings may have been missed. Where such inaccuracies are known these are indicated alongside the relevant table. A visual representation of ecological impact is given in Figure 13, Figure 14 and Figure 15. Secondly, an estimate was made for the wider estuaries, based on permanent, single block, sub-tidal mooring infrastructure across mud and sand sediment habitats. Less confidence can be placed in the accuracy of this estimate as the sediment habitats encountered in other areas of the estuaries may differ considerably in comparison with those surveyed and extreme care must be taken in the use of this value. It is included here only to give a wider estimate of the potential ecological impact of moorings within the estuaries.

The number of permanent, single block, sub-tidal moorings within the Fal estuary is calculated to be at least 903; which gives a total impacted area in the Fal to range from at least 7.1ha (5 metre radius) to 34.3 ha (11 metre radius). This estimate can be extended to the whole SAC area, although the level of confidence in this figure is lower. This gives a potential total area of seabed impacted by permanent, single block, sub-tidal moorings within the SAC of up to 48 ha (1263 moorings). These figures do not account for at least 2615 additional moorings of different types, drying state or only seasonally deployed within the estuaries. The results also detected a differential impact on different groupings of organisms and a potential wider influence of the moorings on the seabed within the mooring areas.

	Falmouth Estuary						Helford Estuary[d]				Additional moorings[e]	Total
	Falmouth[a▲]	Port of Truro[b▲]	Penryn	Restron-guet[c]	St. Mawes[▲]	Percuil[▲]	Durgan[▲]	Main river[▲]	Calaman-sac[▲]	Port Navas[▲]		
Permanent, single block, sub-tidal	437	316[f]	0	0	150	0	80	260	20	0	?	1263
Permanent, trot, sub-tidal	183	236	0	0	0	0	0	35	0	0	?	454
Permanent, single block, intertidal	0	291	243	277	0	0	0	130	30	150	?	1121
Permanent, trot, intertidal	0	0	7	0	0	0	0	45	0	0	?	52
Permanent, single block*	0	0	0	0	0	550	0	0	0	0	?	550
Seasonal, single block, sub-tidal	0	438	0	0	0	0	0	0	0	0	?	438
Seasonal, trot, sub-tidal	0	0	0	0	0	0	0	0	0	0	?	0
Seasonal, intertidal	0	0	0	0	0	0	0	0	0	0	?	0
Total	620	1281	250	277	150	550	80	470	50	150	?	**3878**

Table 10 Table showing the main locations, types and numbers of moorings around the Fal and Helford estuaries. [a]Falmouth moorings include the moorings operated by Falmouth Harbour Commissioners (FHC). Further moorings are present between Flushing New Quay and the FHC border at Penryn, these are operated through Trefusis Estate and the Greenbank Hotel and no numbers are known. [b]Truro moorings include the main body of the estuary upwards of the FHC limit at Penarrow Point and Messack Point but not including all of the creeks. Some areas are not included in this figure, notably the moorings at Malpas. [c]Restronguet Creek moorings numbers were given by Paul Ferris at Port of Truro, although Restronguet Creek is outside Port of Truro harbour limits. [d]The figures given for the Helford identify the main areas of moorings. Notable exceptions from this figure include the Gillian Creek and an unknown number of private moorings around the smaller creeks. [e]This column is present to unknown numbers of moorings additional moorings which may be missing from this figure. [f]The majority of moorings within this category are located at Mylor. *No information on the drying state (intertidal or sub-tidal) was available for these moorings. [▲]The values for these areas include moorings infrastructure within the SAC.

	Falmouth Estuary			
	Falmouth[a]	Port of Truro[b]	St. Mawes	**Total**
Permanent, single block, sub-tidal	437	316	150	903

Table 11 Table identifying the sub-set of moorings identified in **Table 10** that were surveyed as part of the Fal and Helford Study. No further division of these moorings into size classes was possible given the information available. [a]The numbers given for Falmouth do not include moorings operated through Trefusis Estate and the Greenbank Hotel. [b]The numbers for Truro include the all Port of Truro waters, but the majority of this figure are at Mylor.

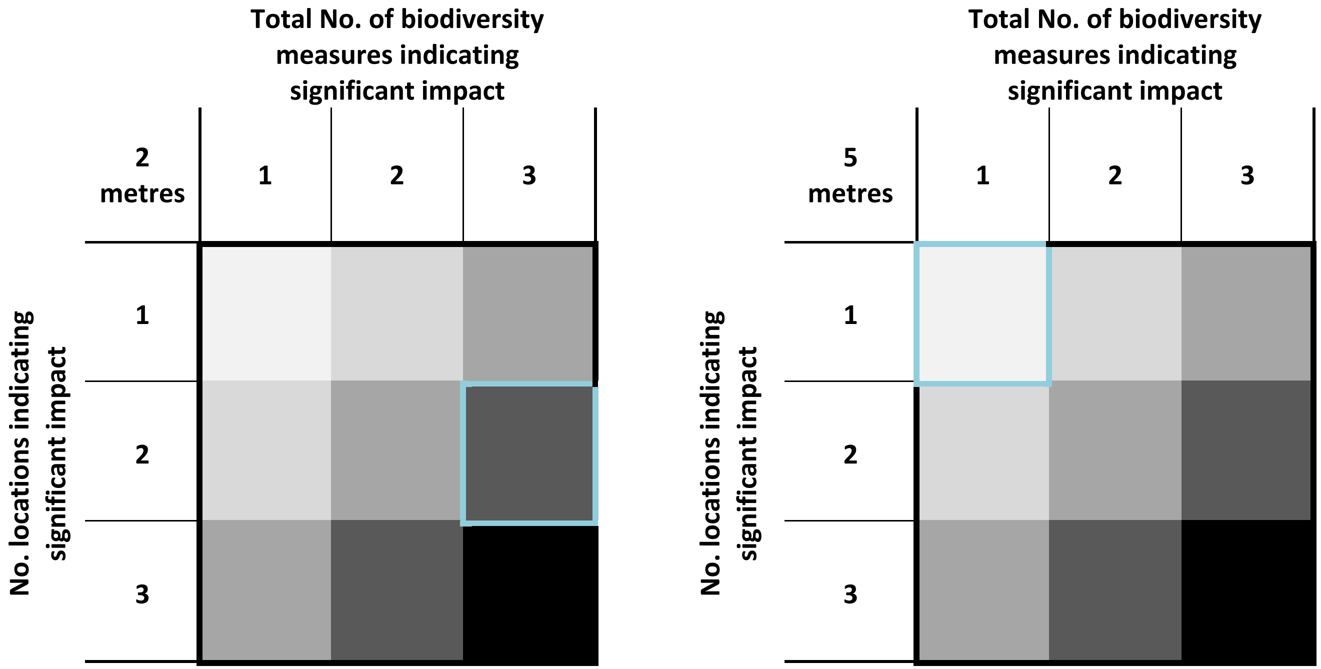

Table 12 Impact matrix to summarise the indicators of significance of impact as both number of locations and number of biodiversity measures (overall abundance, species richness and community composition) indicating significance of distances in determining the infaunal community.

This impact matrix is to clarify the rationale behind the allocation of significance shown on the Fal and Helford Study GIS visualisation. The 2 metre and 5 metre results were compared against the 11 metre 'internal controls' to identify with greater confidence differences in the infaunal community due to the direct physical impact of the moorings. The 11 metre mooring samples were different to the control samples with relative consistency, indicating that an additional impact may also be influencing the community within the moorings areas. The 11 metre radius is identified by a white circle surrounding the mooring location.

At 2 metres a significant impact was present in all three of the main biodiversity measures (overall abundance, biodiversity and infaunal community composition) across 2 of the locations sampled; this is highlighted above by a light blue border. At 5 metres a significant impact was present in one of the three main biodiversity measures and in only one location. This matrix is used to determine the colourations used for the estimation of ecological impact (Table 13 and Table 14) and the visual representation of ecological impact (Figure 13 and Figure 14).

	Estimate of impacted area - 2m radius	Estimate of impacted area - 5m radius	Estimate of impacted area - 11m radius
N°. of permanent, single block, sub-tidal moorings in the areas surveyed	903	903	903
Ecological impact per permanent, single block, sub-tidal moorings (m^2)	12.6	78.5	380.1
Ecological impact of permanent, single block, sub-tidal moorings within the areas surveyed (ha)	**1.1**	**7.1**	**34.3**
Total area of the Fal and Helford SAC (ha)	6387.8 *includes marine and terrestrial areas		

Table 13 Table of calculations giving the estimated ecological impact of permanent, single block, sub-tidal moorings within the areas surveyed as part of the Fal and Helford. This calculation extrapolates to wider areas of habitat in the areas surveyed and relative confidence can be place upon the figures calculated. A level of inaccuracy is present within these figures as no further division of these moorings into size classes was possible given the information available.

	Estimate of impacted area - 2m radius	Estimate of impacted area - 5m radius	Estimate of impacted area - 11m radius
N^{o}. of permanent, single block, sub-tidal moorings in estuaries*[a]	1263	1263	1263
Ecological impact per permanent, single block, sub-tidal mooring (m^2)	12.6	78.5	380.1
Ecological impact of permanent, single block, sub-tidal moorings within the Fal and Helford Estuaries (ha)	**1.6**	**9.9**	**48.0**
Total area of the Fal and Helford SAC (ha)	6387.8 *includes marine and terrestrial areas		

Table 14 Table of calculations giving the estimated impact of permanent, single block, sub-tidal moorings within the Fal and Helford Estuaries. This calculation extrapolates to other sediment habitats within the estuaries and less accurate than the estimation for the areas surveyed, given this care must be taken when using this figure. A level of inaccuracy is present within these figures as no further division of these moorings into size classes was possible given the information available. The calculation above does not include any moorings outside of the permanent, single block, sub-tidal moorings category. This gives a total of 2088 moorings of different types or drying states that are not comparable to the moorings surveyed and therefore are not included in any calculations.

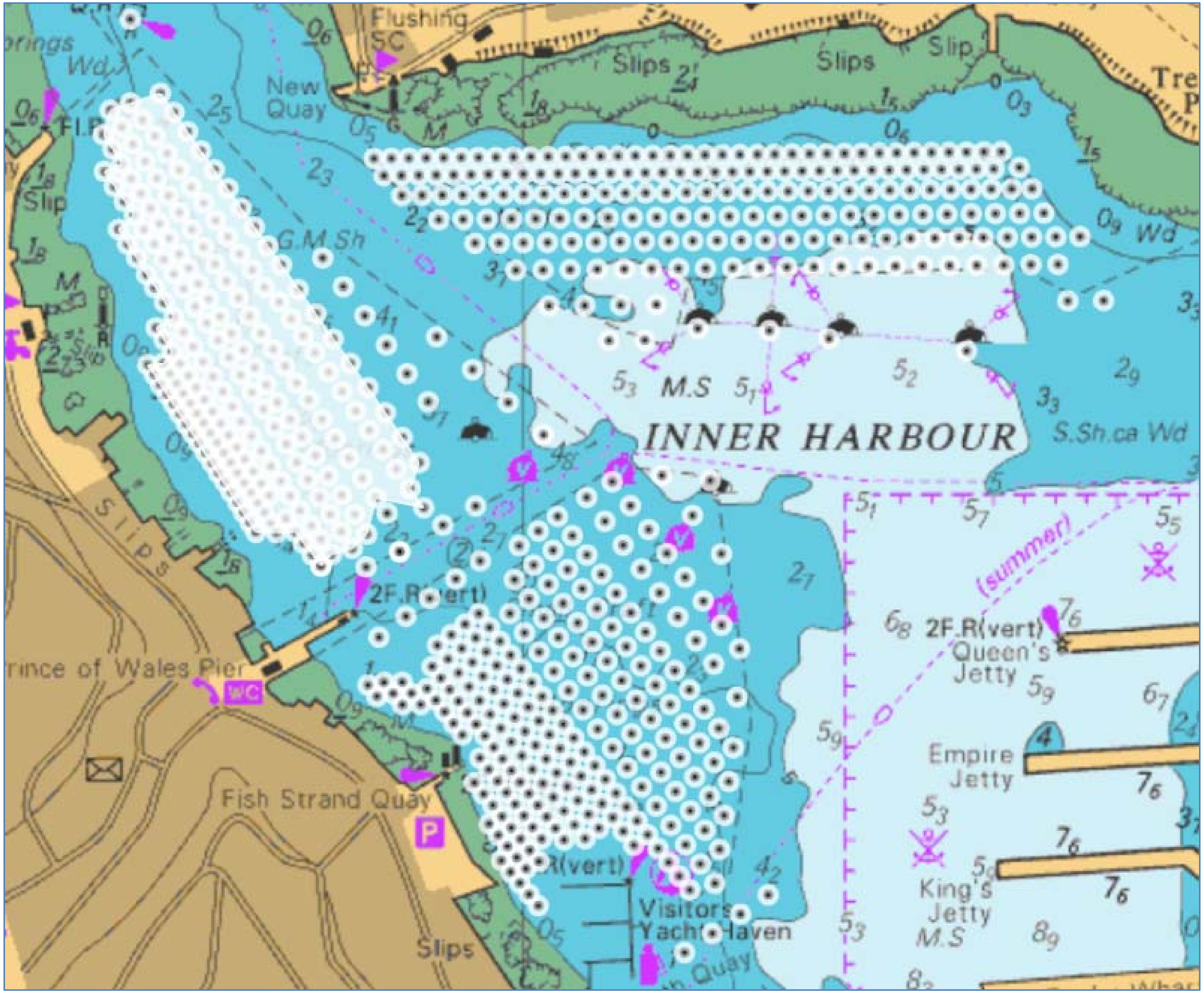

Figure 13 Visual representation of the ecological impact of mooring infrastructure within Falmouth Inner Harbour.

Graduated circular symbols represent differing areas of impact and coordinate with the levels of ecological impact identified in Table 11.

	2 metre radius.
	5 metre radius
	11 metre radius

Black and grey represent areas with a significant influence clearly identified. White represents the radius out to the outer samples, indicating the more conservative estimate of ecological impact.

The white polygon represents an area of trot moorings which are **not included** in this study. The area of ecological impact identified is only representative of direct physical disturbance.

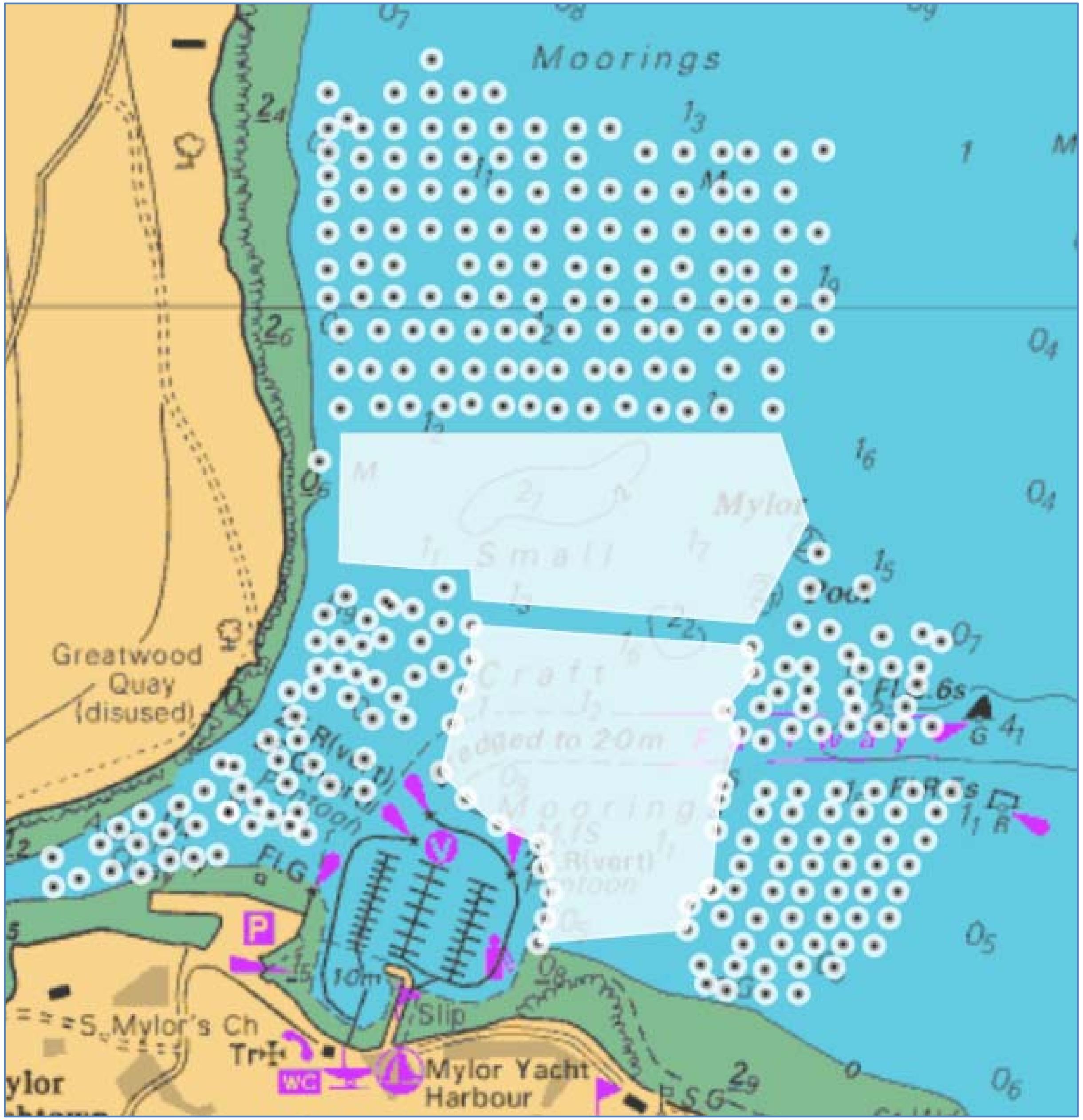

Figure 14 Visual representation of the ecological impact of mooring infrastructure within Mylor.

Graduated circular symbols represent differing areas of impact and coordinate with the levels of ecological impact identified in Table 11.

	2 metre radius.
	5 metre radius
	11m metre radius

Black and grey represent the area with a significant influence clearly identified. White indicates the radius out to the outer samples, indicating the more conservative estimate of ecological impact.

White polygons represent areas of trot moorings which were **not included** in this study and for which individual locations were not given. Some gaps are present within the data; these are apparent in the mooring rows as missing symbols. The area of ecological impact identified is only representative of direct physical disturbance.

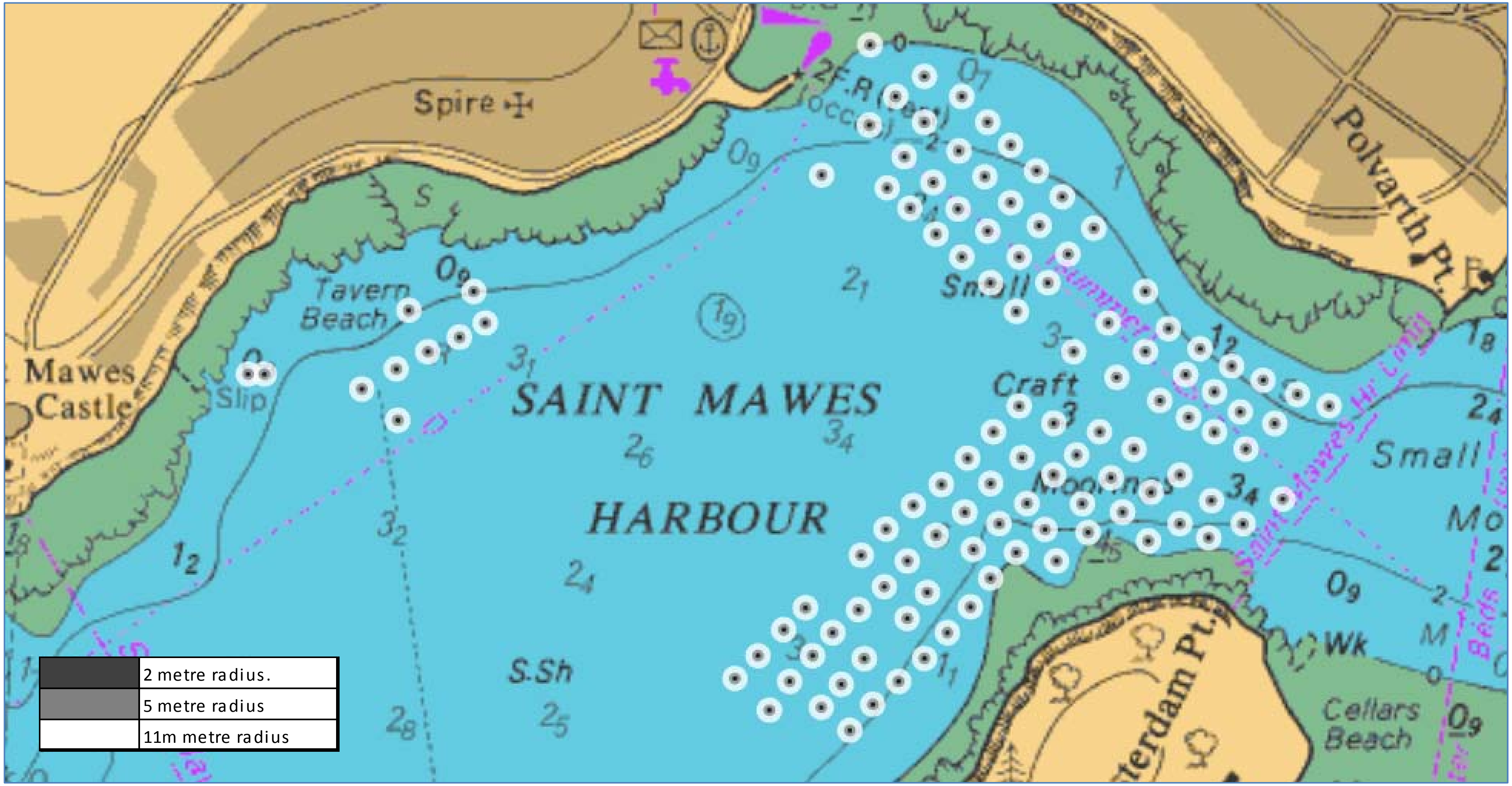

Figure 15 Visual representation of the ecological impact of mooring infrastructure within St. Mawes Harbour.

Graduated circular symbols represent differing areas of impact and coordinate with the levels of ecological impact identified in the discussion. Black and grey represent the 2 and 5 metre radius' respectively, with a significant influence clearly present. The white, outer circle represents the radius out to 11 metres, indicating the more conservative estimate of ecological impact (5-11 metres). Some gaps are present within the data; these are apparent in the mooring rows as missing symbols. The moorings data for Tavern Beach was incomplete and only a limited number of 22 moorings present are displayed. The area of ecological impact identified is only representative of direct physical disturbance.

7.2 Clarification of Mooring Areas

The following two figures clarify the main broad areas of recreational mooring infrastructure identified in the Fal and Helford estuaries.

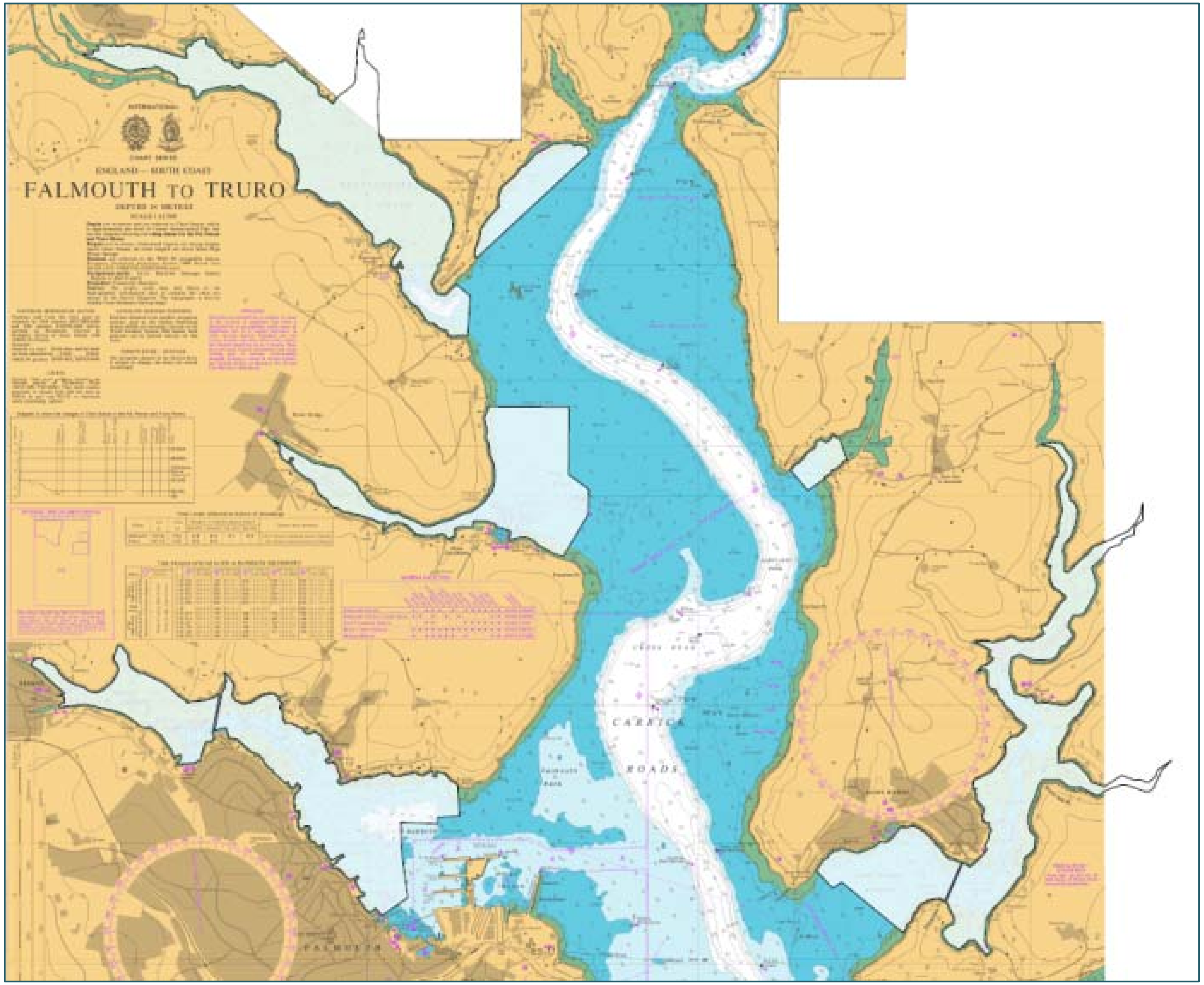

Figure 16 The Fal estuary and the main areas of mooring infrastructure. Mooring infrastructure areas are shown as white polygons with black boundaries. Mooring areas in some locations lacked detail therefore polygons indicate broad areas containing moorings rather than dense areas of moorings.

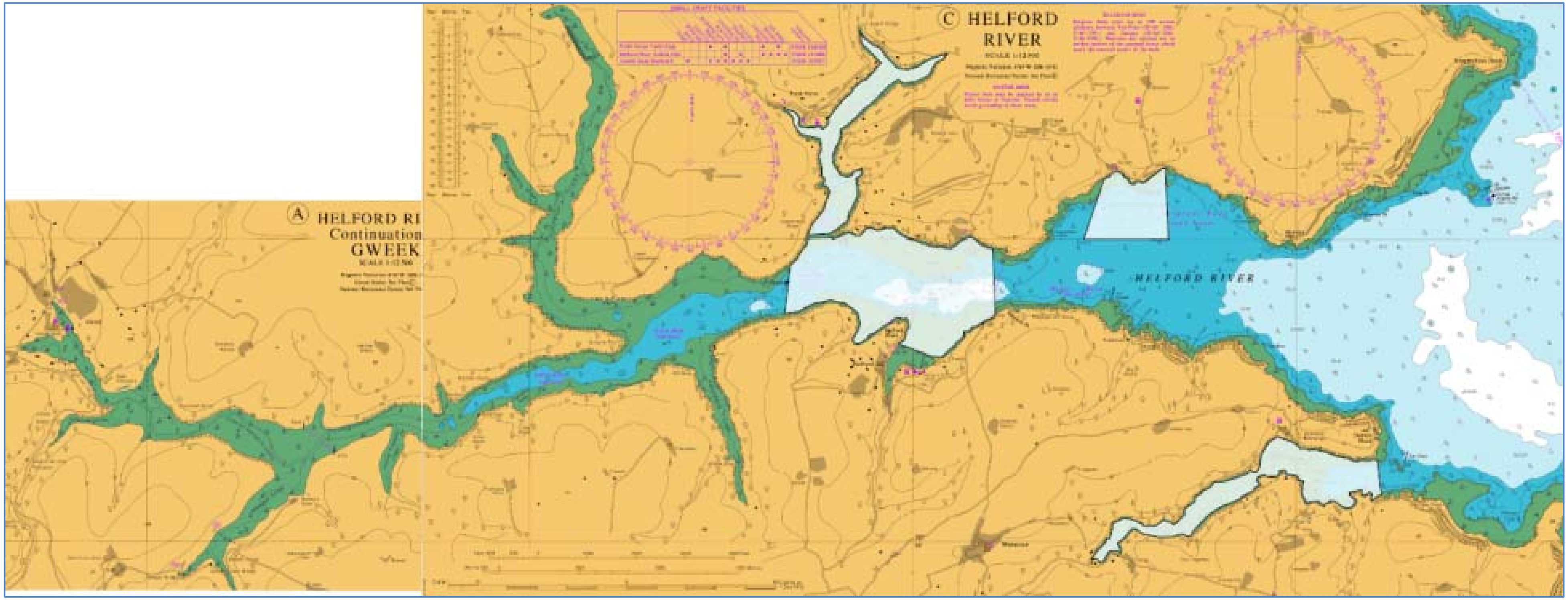

Figure 17 The Fal estuary and the main areas of mooring infrastructure. Mooring infrastructure areas are shown as white polygons with black boundaries. Mooring areas for the Helford were given as the main areas of mooring infrastructure within the estuary and these incorporate most of the permanent, single block, sub-tidal moorings. Some less dense and intertidal moorings areas are not shown here.

7.3 Biotope Sensitivities and Mooring Areas

The following two figures (Figure 18,Figure 19) detail the sensitivity of biotopes within the Fal and Helford estuaries to abrasion and physical disturbance. The main areas of mooring infrastructure are identified to indicate overlap between sensitive biotopes and the presence of impact from mooring infrastructure. Sensitivities identified as 'very high' and 'high' overlapping with mooring infrastructure represent areas in which mooring impacts could be addressed as priority to minimise ecological impact within the estuaries. A number of the biotope sensitivities identified in Figure 18 and Figure 19 differ from the findings of this study; therefore a continual program of survey and renew would be highly beneficial in accurately determining areas of greatest concern.

Habitat sensitivity maps were not readily available for the Fal and Helford estuaries. As a result, habitat sensitivity maps were drawn up based on the existing biotope maps for the estuaries and sensitivities were assigned using the following method. The MNCR biotopes identified by the existing biotope maps were separated out and searched in the MarLIN online biotope database http://www.marlin.ac.uk/habitats.php. The level of sensitivity to abrasion and physical disturbance was identified for each constituent biotope and a sensitivity level of 0 to 5 was assigned along with a colour. Where multiple different sensitivities levels were identified for the constituent biotopes the precautionary principle was applied and the highest sensitivity level was used. The existing biotope maps were then colour-coded appropriately within GIS to produce the following two figures. All information used to determine sensitivities is available in Appendix 15 and Appendix 16.

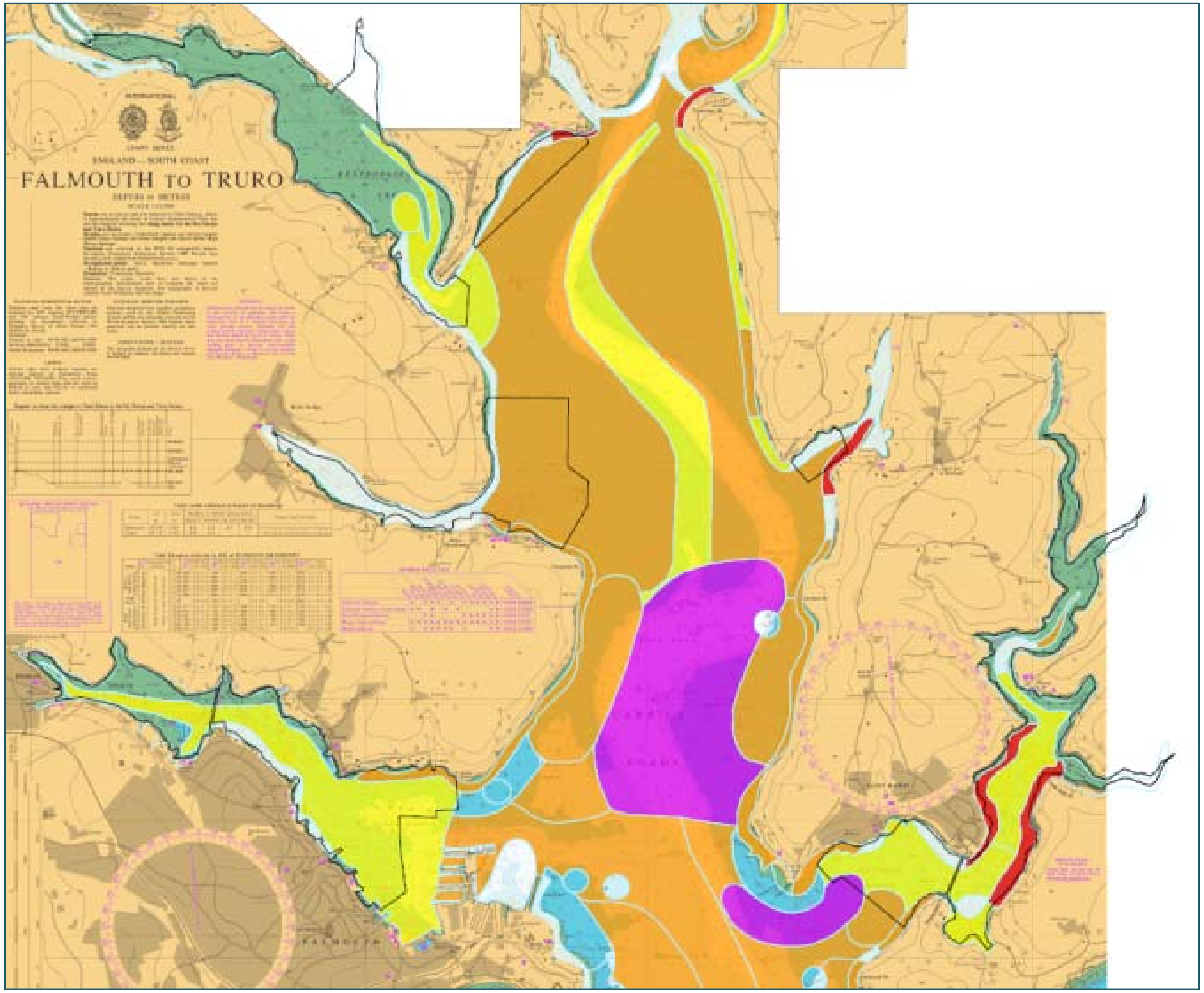

Figure 18 The Fal Estuary showing biotope polygons indicating sensitivity to abrasion and physical disturbance.

Sensitivity	Colour
Very Low	
Low	
Moderate	
High	
Very High	

Appendix 15 gives the rationale behind the assignment of biotope sensitivities. White polygons (with no external border) indicate areas where no biotope data was available and hollow polygons (no fill) indicate areas where no sensitivity assessment was available. Areas of moorings are shown as polygons with black outlines. These areas represent the main locations of recreational mooring infrastructure within the estuary; however the accuracy of these areas and the density of the moorings within are variable.

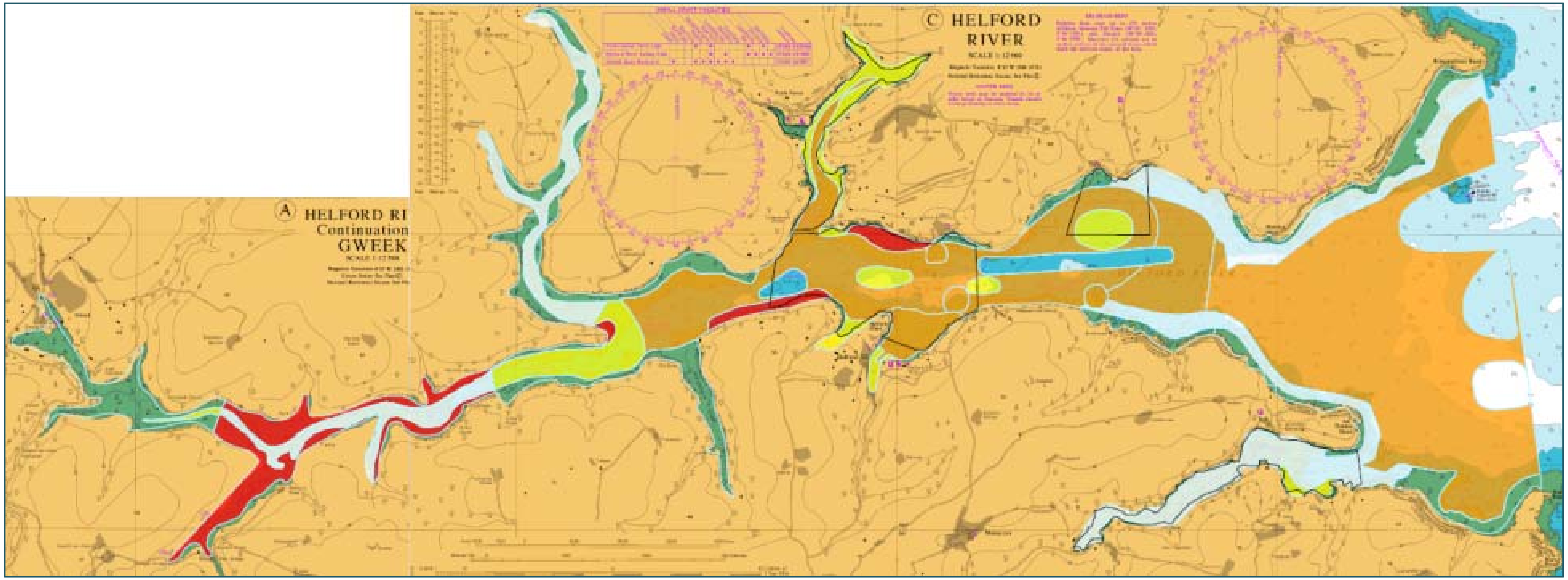

Figure 19 The Helford Estuary showing biotope polygons indicating sensitivity to abrasion and physical disturbance.

Sensitivities	Colour
Very Low	
Low	
Moderate	
High	
Very High	

Appendix 16 gives the rationale behind the assignment of biotope sensitivities. White polygons (with no external border) indicate areas with no biotope data was available and hollow polygons (no fill) indicate areas where no sensitivity assessment was available. Areas of moorings are shown as polygons with black outlines. These areas represent the main locations of recreational mooring infrastructure within the estuary; however the accuracy of these areas and the density of the moorings within are variable.

7.4 Biotope Distributions and Mooring Areas

The following two figures detail the distribution of biotopes within the Fal and Helford estuaries based on Moore et al., 1999. The main areas of moorings within the estuaries are identified to indicate the overlap between biotopes and impact from mooring infrastructure.

Sub-littoral muddy gravel (MarMu; FaMx; VsenMtru) with algae (LsacX) (e.g. Mylor)
Sub-littoral estuarine mud (AphTub) with kelp on available hard substrata (e.g. Falmouth Inner Harbour)
Sub-littoral marine mixed sediments with sponges and ascidians (MarMu; FaMs; AlcMas; Aasp; SubSoAS)
Sub-littoral sediment with *Zostera marina* beds (Zmar) (e.g. St. Mawes)
Sub-littoral maerl beds (Phy; MrlMx; Lcor) (e.g. St. Mawes bank)
Littoral soft mud with *Hediste* (HedScr; HedStr; HedOl) (e.g. Penryn and Restronguet creeks)

Figure 21 Key to the main biotopes within the Fal estuary. A full list of biotopes is available in Moore et al. (1999).

Sub-littoral muddy sand (FaMS; EcorEns; LsacX) (e.g. main river)
Sub-littoral gravel and sand (FaG; Sell; FaS; Lcon; FabMag)
Sub-littoral rock with *Laminaria hyperborea* (Lhyp.Ft; XKScrR) and sub-littoral gravel and sand (FaG; Sell; FaS; Lcon; FabMag) (e.g. estuary mouth)
Sub-littoral gravel/ sand with maerl beds (Phr.R; Lcor)
Lower shore or sub-littoral sediment with *Zostera marina* beds (Zmar) and *Lanice* (Lan) (e.g. Helford)
Littoral sandy mud (HedMac; HedMac.Are) (e.g. Porth Navas creek)

Figure 20 Key to the main biotopes within the Helford estuary. A full list of biotopes is available in Moore et al. (1999).

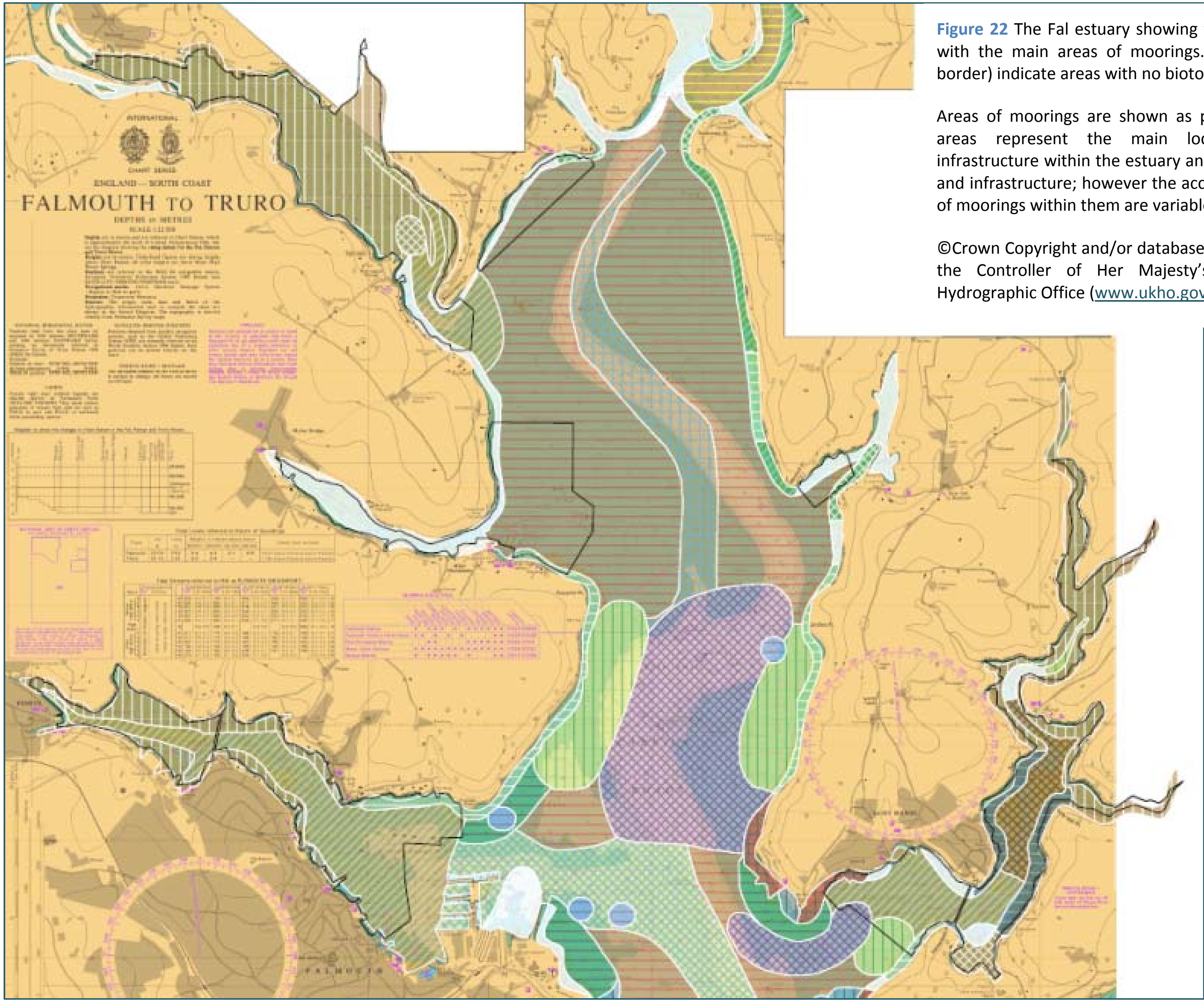

Figure 22 The Fal estuary showing the distribution of biotopes overlaid with the main areas of moorings. White polygons (with no external border) indicate areas with no biotope data was available.

Areas of moorings are shown as polygons with **black** outlines. These areas represent the main locations of recreational mooring infrastructure within the estuary and indicate overlap between biotopes and infrastructure; however the accuracy of these areas and the density of moorings within them are variable.

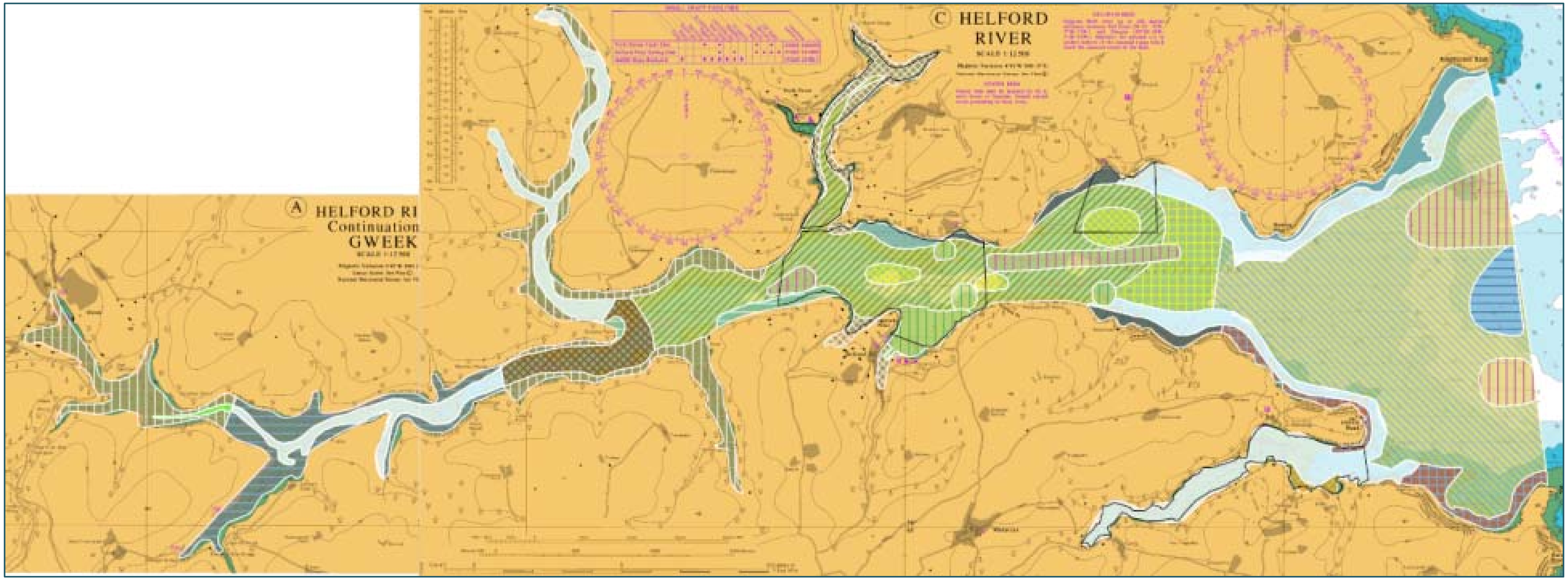

Figure 23 The Helford estuary showing the distribution of biotopes overlaid with the main areas of mooring infrastructure. White polygons (with no external border) indicate areas with no biotope data was available.

Areas of moorings are shown as polygons with **black** outlines. These areas represent the main locations of recreational mooring infrastructure within the estuary and indicate overlap between biotopes and infrastructure; however the accuracy of these areas and the density of moorings within them are variable.

8 Draft Management Recommendations

The Fal and Helford Study identified an ecological impact of permanent, single block, sub-tidal moorings within the Fal and Helford SAC extending to a potential 48 hectares of seabed. Given that permanent, single block, sub-tidal moorings account for less than a third of the moorings within the SAC the total impacted area could well be considerably larger. In light of the results of the Fal and Helford Study and existing information in scientific literature, it is possible to develop management recommendations to reduce and/or mitigate for this impact and to maintain the diversity and productivity of the estuaries and attain favourable condition of the features of interest within the SAC.

The following management recommendations are based purely on ecological considerations in response to the evidence of impacts resulting from direct physical disturbance from mooring infrastructure. It is recognised that implementation of these recommendations would require careful consideration of economic, social, practical and logistical factors beyond the scope of this report. A combination of measures may be employed and through pragmatic decision-making the implementation of these measures would not need to result in a reduction in the overall number of moorings or berths.

8.1 Establishing Baseline Data

Accurate baseline ecological data is absolutely essential for any monitoring or management, as without an understanding of the habitats present large-scale changes can easily go undetected. The lack of available ecological data around the mooring areas was identified as a major drawback in the Fal and Helford Study. Revision of the outdated biotope map for the Fal and Helford currently available would prove invaluable for future study and management of the area.

There are obvious practical and budgetary limitations to detailed surveying at the scale of the whole estuary; however detailed survey effort can be prioritised for areas of greatest ecological risk, where current mooring infrastructure and higher sensitivity habitats overlap. The information arising from these surveys would help further refine the habitat sensitivity indices.

8.2 Identification of Priority Areas

Best available habitat data for the estuaries can be used to identify high priority areas, identified as a combination of higher sensitivity habitats and/or features of interest and overlap with mooring infrastructure, in which rapid implementation of mitigation measures, uptake of management recommendations or further studies should be directed.

8.3 Priority Habitat Types

Previous literature and the results of this study suggest that habitats are not equally affected by physical disturbance from mooring infrastructure. Research suggests that homogenous, high energy habitats (e.g. mobile clean sand without seagrass) appear less impacted by the physical disturbance from the mooring infrastructure than highly stable, low energy habitats (e.g. stable muds); therefore, where practical moorings could be concentrated on areas of habitat less affected by physical disturbance.

Some habitats, for example seagrass beds, have substantial scientific literature identifying the presence of negative impacts in response to physical disturbance from mooring infrastructure. Seagrass has been identified as spreading through the moorings in some areas; however the quality of this habitat is likely to be reduced as the habitat is fragmented. Where possible, a combination of measures including schemes to minimise overlap (re-organisation of mooring layouts), minimise impact (alternative mooring types) or compensate for reduced quality habitat by increasing protection of other areas of habitat (no anchor zones) would ensure areas of good quality habitat remain.

Live maerl habitat has also been identified as highly sensitive to physical disturbance and abrasion; therefore it is suggested that any moorings which overlap with this habitat could be strategically re-aligned and situated on habitats with lower sensitivities or, where necessary, replaced with a lower impacting alternative mooring systems.

8.4 Zoning and Inclusion of Un-impacted Areas

Strategic planning of harbour areas could incorporate areas of minimal impact within the harbour to protect areas of habitat free of moorings impacts and/or provide areas for habitat restoration. These should be areas of similar habitat, but with no or minimal direct physical impact. Within some harbours there may be non-dredged navigation channels or similar open areas around moorings, within which minimal additional impacts are present, which may fulfil this role. Areas of un-impacted habitat are invaluable for providing ecological recruitment input and buffering against impacts in ecosystems; as well as providing un-impacted 'control areas' in support of robust scientific studies.

Careful harbour design can incorporate ecological recommendations into harbour layouts, particularly where harbours include a multitude of commercial and recreational activities. Zoning schemes, the clear identification of areas for specific uses (e.g. navigation channels (non-dredged) and defined anchorage areas) can identify areas of minimal physical impact on habitats. A wider marine spatial planning exercise within the Fal and Helford estuaries would allow ecological planning to fit alongside other diverse uses of the area.

As the positioning of moorings becomes increasingly more precise through the use of increasingly accurate GPS positions and Computer-Aided Design (CAD) systems, it may be possible to condense existing moorings within the harbour into a smaller space, creating areas of minimal impact within the estuaries. Such practices are already in progress in some areas. Monitoring, reporting and removal of rogue (unofficial) moorings will also contribute to an overall reduction in the ecological impact of moorings.

8.5 Habitat Restoration

Where impact extends over a large proportion of a harbour area, habitat restoration schemes could be used to compensate for areas of detrimentally impacted seabed. Non-mooring/ un-impacted areas, identified above, could be created to ensure areas of good quality habitat are present within the harbour.

8.6 Evaluation of Alternative Mooring Systems or Configurations

Harbour Authorities and mooring operators could continue to evaluate the potential for alternative mooring configurations or systems, both traditional and 'eco' developments, to reduce ecological impacts. Relevant authorities and organisations could keep track of new studies, follow developments and trial alternatives to assess the suitability, ecological impact and practicalities of alternative options.

8.7 Additional Impacts

Impacts do not act in isolation on ecological systems. Multiple impacts affecting an ecological system increase the stress that that the community is under; by minimising additional impacts within a harbour, the number of stressors acting on an ecosystem can also be reduced. Both voluntary (e.g. RYA's The Green Blue) and statutory (e.g. Water Framework Directive) schemes are currently in place which are working to minimise anthropogenic impacts, particularly water quality issues, resulting from recreational boating activities. Encouraging maximum participation and compliance with such schemes will go a long way to minimising the wider impact of recreational boating activities.

8.8 Sharing Best Practise and Partnership Working

All study and survey results should be widely distributed amongst local organisations, allowing the value of research to be maximised and ensuring subsequent decision-making at strategic and local level by relevant authorities is driven by best available knowledge. An estuary-wide approach to spatial planning would ensure transparency, allow sharing of resources and prevent duplication of effort. Based on the findings of this study relevant organisations may wish to collectively agree an estuary-wide mooring stratergy, a maximum acceptable impacted area and an associated cap on mooring numbers to reflect this.

Relevant organisations may wish to consider partnership working as an effective approach to conducting future studies. Partnership studies ensure a coherent approach, maximise opportunities for future study, minimise financial commitment, include diverse perspectives and approaches and maximise available resources.

8.9 Continual Cycles of Study and Review

Review available literature on relevant impacts regularly to ensure best practise reflects the best available, current evidence. Future work may identify a type of mooring which has a smaller area of ecological footprint. Keeping documents, such as the audit of recreational boating infrastructure, updated regularly will aid in tracking changes in infrastructure around the estuary.

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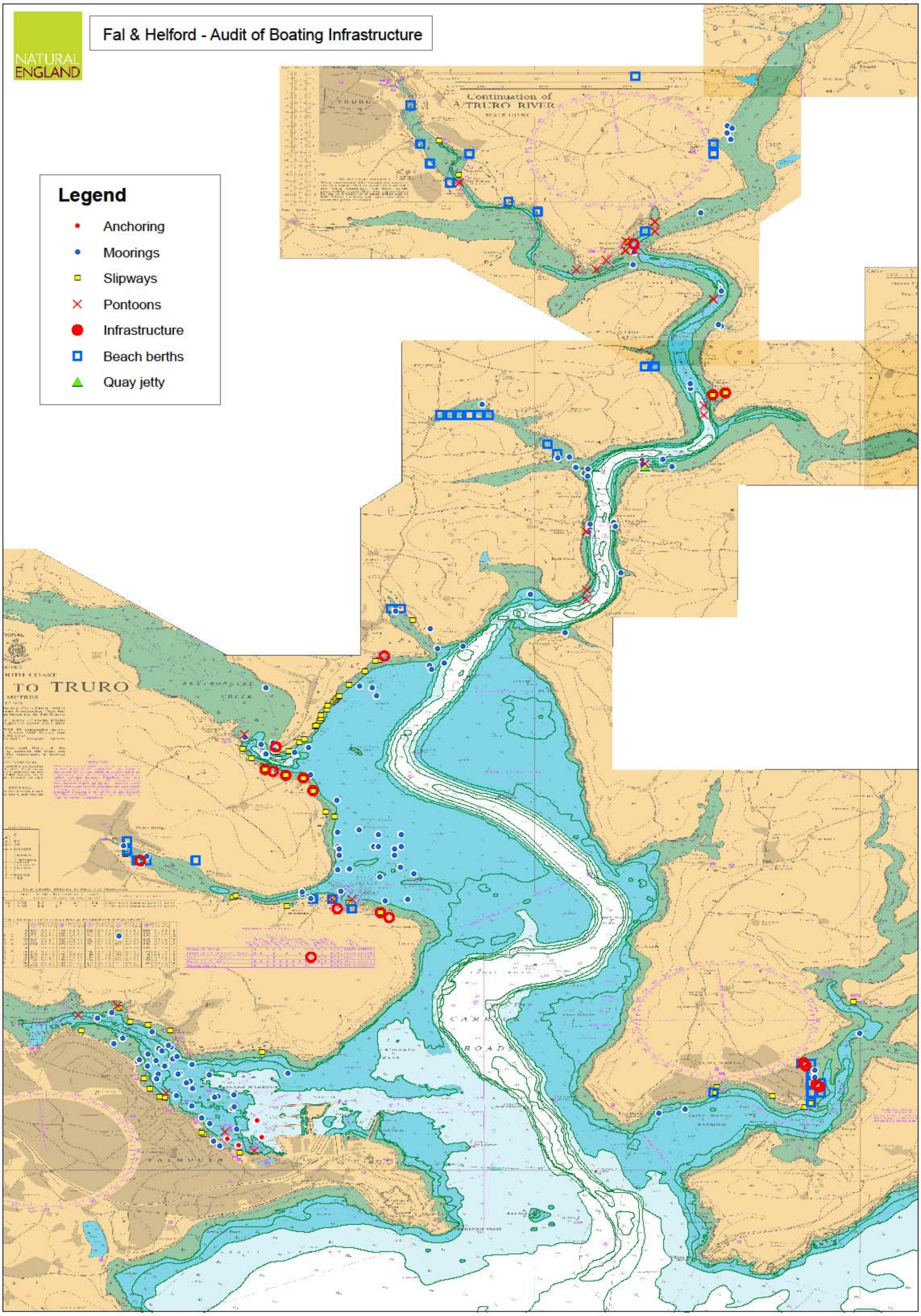
Appendix 1: Fal and Helford Audit of Recreational Boating Infrastructure



Appendix 2: Fal and Helford Recreational Boating Audit Form

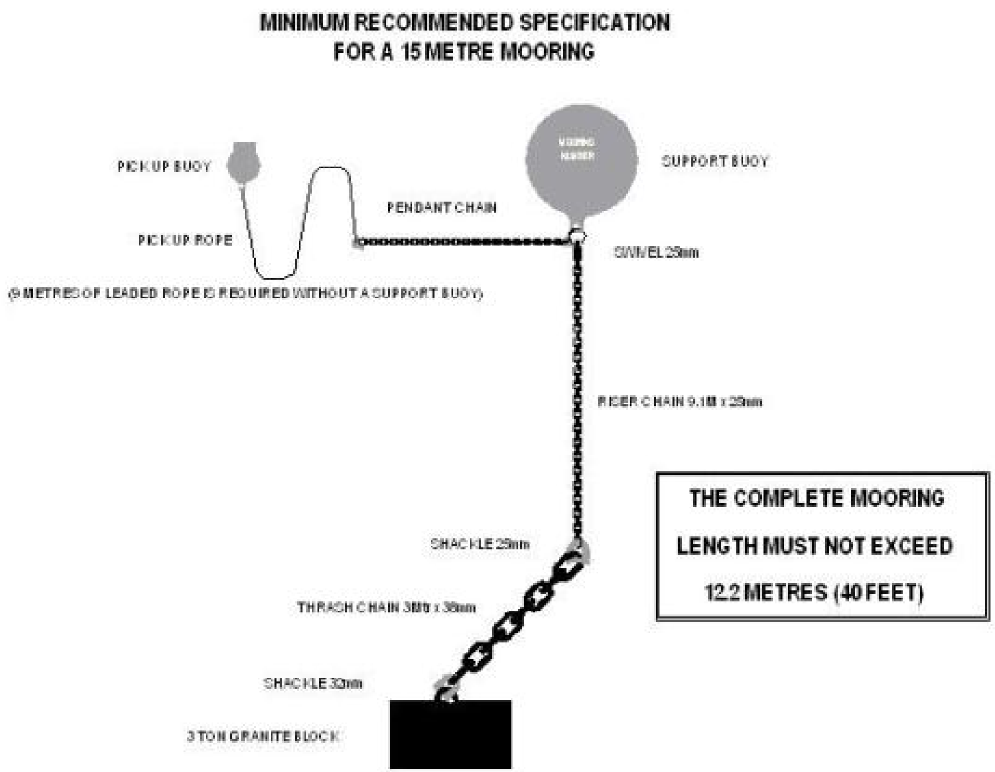
Fal and Helford Recreational Boating Study- Audit of recreational boating infrastructure

Please return to ……………………………………………….. once completed. Use one form per item.

Ref No.			
Recorders name and organisation		**Date**	**Time**
Time of low water		**State of tide (Low or High)**	
Method of survey (please circle one of the following)	Boat	On foot	From aerial photo (give date)
Name of structure if known FHC Visitors moorings	**Location/address**	**Lat./Long. of centre point of structure**	
Photo reference number(s)	i.	ii.	iii.

Description of item (please circle as many of the following as necessary)						
1	**Slipway:**	Public slipway	Private slipway	Construction (please circle) - stone/stone with mortar/concrete/wood/sheet piling/ Other(please state) ……………		
2	**Moorings:**	Private moorings	Harbour Authority (HA) moorings managed by HA	Harbour Authority moorings leased to moorings management organisation	Visitor moorings	Commercial moorings
		Seaflex moorings	Chain and block moorings	Trot moorings	Grid moorings	Shore tethered dingy
3	**quay/jetty/landing stage:**	Private quay/jetty/landing stage	Public quay/jetty/landing stage	Perpendicular to shore	Parallel to shore	
		Stilted	solid	Construction (please circle) - stone/stone with mortar/concrete/wood/sheet piling/ Other(please state) ……………		
4	**Beach haul out:**	Boat scrub down area	Boat winter lay up	Houseboat lay up (all yr)	Boatyard	
5	**Pontoons:**	Marina	Visitor pontoon	Commercial pontoon		
		Seaflex pontoon	Chain and block	Light columns	Piles (please circle) - wood/metal/other (please state)……..	
6	**Anchoring:**	Formal anchor zone	Informal anchor zone			
	Other (please specify) …………….					
	Estimated age of structure…………					
	Approximate size of item (m^2) to be calculated from aerial photo…………					

Appendix 3: Minimum Recommended Specification for a 15m Mooring



The figure above details the minimum technical specifications for a 15m mooring as used by Falmouth Harbour Commissioners within their waters. This diagram is representative of the specification of the moorings infrastructure surveyed as part of the Fal and Helford Study.

Appendix 4: ROV List of Taxa

Full table of taxonomic groupings identified in the video footage. Common names are given where available.

PHYLUM	CLASS	FAMILY	GENUS	TAXONOMIC GROUP	COMMON NAMES
Porifera	Demospongiae	Suberitidae		Suberitidae	Sponges
Annelida	Polychaeta	Arenicolidae		Arenicolidae	Lug worms
Annelida	Polychaeta	Sabellidae	Megalomma	Sabellidae; *Megalomma*	Fan worms
Annelida	Polychaeta	Sabellidae	Myxicola	Sabellidae; *Myxicola*	
Annelida	Polychaeta	Sabellidae	Sabella	Sabellidae; *Sabella*	
Mollusca	Bivalvia	Pectinidae		Pectinidae	Bivalves
Mollusca	Bivalvia			BIVALVE Indet.	
Mollusca	Cephalopoda	Sepiidae		Sepiidae	Cuttlefish
Mollusca	Gastropoda	Trochidae		Trochidae	Gastropods
Mollusca	Gastropoda	Calyptraeidae		Calyptraeidae	
Cnidaria	Anthozoa	Actiniidae	Anemonia	Actiniidae; *Anemonia*	Anemones
Cnidaria	Anthozoa	Metriidae		Metriidae	
Cnidaria	Anthozoa			ACTINARIA Indet.	
Echinodermata	Asteroidea	Asteriidae		Asteriidae	Starfish
Echinodermata	Asteroidea	Astropectinidae		Astropectinidae	
Echinodermata	Ophiuroidea			OPHURIOIDEA Indet.	Brittlestars
Arthropoda	Malacostraca	Inachidae		Inachidae	Crabs
Arthropoda	Malacostraca	Paguridae		Paguridae	
Arthropoda	Malacostraca	Portunidae		Portunidae	
Chordata	Ascidiacea	Ascidiidae		Ascidiidae	Sea squirts
Chordata	Actinopterygii			TELEOSTEI Indet.	Ray-finned fishes
Chordata	Actinopterygii	Labridae		Labridae	
Chordata	Actinopterygii	Gobiidae		Gobiidae	
Chordata	Actinopterygii	Callionymidae		Callionymidae	
Chordata	Actinopterygii	Pleuronectidae		Pleuronectidae	
Chordata	Actinopterygii	Moronidae		Moronidae	
Chordata	Eslamobranchii	Rajidae		Rajidae	Sharks, skates, rays
Chlorophyta				CHOLORPHYTA Indet.	Green algae
Chlorophyta	Ulvophyceae	Ulvaceae		Ulvaceae	
Rhodophyta				RHODOPHYTA Indet.	Red algae
Rhodophyta	Florideophyceae	Bonnemaisoniaceae		Bonnemaisoniaceae	
Ochrophyta	Phaeophyceae			PHAEOPHYCEAE Dichotomous *Dictyota*	Brown algae
Ochrophyta	Phaeophyceae			PHAEOPHYCEAE Bulbous *Colpomenia*	
Ochrophyta	Phaeophyceae	Fucaceae		Fucaceae	
Ochrophyta	Phaeophyceae	Laminariaceae		Laminariaceae	
Ochrophyta	Phaeophyceae	Chordaceae		Chordaceae	
				MACROALGAE Indet.	Algae
Tracheophyta	Magnoliidae	Zosteraceae		Zosteraceae	Seagrass

Appendix 5: Particle Size Distribution Pairwise Comparisons (Distances)

Pairwise comparisons of particle sizes for the sampled distances and control zones across all locations. Within the moorings areas, the 2 metre and 5 metre samples are significantly different to the 11 metre samples. The external control zones (CTZ) are significantly different to 2 metre and 11 metre but not the 5 metre samples. Significant interactions are highlighted by grey rows.

(I) DISTANCE	(J) DISTANCE	Mean Difference (I-J)	Std. Error	Sig.c	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
11	2	.760	.276	.008	.205	1.315
	5	1.041	.270	.000	.497	1.585
	CTZ	.353	.270	.198	-.191	.897
2	11	-.760	.276	.008	-1.315	-.205
	5	.281	.270	.305	-.263	.825
	CTZ	-.407	.270	.139	-.951	.137
5	11	-1.041	.270	.000	-1.585	-.497
	2	-.281	.270	.305	-.825	.263
	CTZ	-.688	.265	.013	-1.221	-.155
CTZ	11	-.353	.270	.198	-.897	.191
	2	.407	.270	.139	-.137	.951
	5	.688	.265	.013	.155	1.221

Appendix 6: Particle Size Distribution Pairwise Comparisons (Distances within Locations)

Mean method of moments pairwise comparisons of distances and control zones (CTZ) within study locations. Significant differences in the particle size distributions with distance from the mooring are primarily driven by Falmouth sediments (highlighted by grey rows).

LOCATION	(I) DISTANCE	(J) DISTANCE	Mean Difference (I-J)	Std. Error	Sig.[c]	95% Confidence Interval for Difference[c]	
						Lower Bound	Upper Bound
Falmouth	11	2	1.876[*,a,b]	.486	.000	.897	2.855
		5	2.149[*,a,b]	.459	.000	1.226	3.072
		CTZ	.340[a,b]	.459	.463	-.583	1.263
	2	11	-1.876[*,a,b]	.486	.000	-2.855	-.897
		5	.273[a,b]	.486	.577	-.706	1.252
		CTZ	-1.536[*,a,b]	.486	.003	-2.515	-.557
	5	11	-2.149[*,a,b]	.459	.000	-3.072	-1.226
		2	-.273[a,b]	.486	.577	-1.252	.706
		CTZ	-1.809[*,a,b]	.459	.000	-2.732	-.886
	CTZ	11	-.340[a,b]	.459	.463	-1.263	.583
		2	1.536[*,a,b]	.486	.003	.557	2.515
		5	1.809[*,a,b]	.459	.000	.886	2.732
Mylor	11	2	.375[a,b]	.486	.445	-.604	1.354
		5	.460[a,b]	.486	.349	-.519	1.440
		CTZ	.626[a,b]	.486	.205	-.353	1.605
	2	11	-.375[a,b]	.486	.445	-1.354	.604
		5	.085[a,b]	.459	.853	-.838	1.009
		CTZ	.251[a,b]	.459	.587	-.672	1.174
	5	11	-.460[a,b]	.486	.349	-1.440	.519
		2	-.085[a,b]	.459	.853	-1.009	.838
		CTZ	.165[a,b]	.459	.720	-.758	1.089
	CTZ	11	-.626[a,b]	.486	.205	-1.605	.353
		2	-.251[a,b]	.459	.587	-1.174	.672
		5	-.165[a,b]	.459	.720	-1.089	.758
St. Mawes	11	2	.029[a,b]	.459	.949	-.894	.953
		5	.513[a,b]	.459	.269	-.410	1.436
		CTZ	.093[a,b]	.459	.840	-.830	1.016
	2	11	-.029[a,b]	.459	.949	-.953	.894
		5	.483[a,b]	.459	.297	-.440	1.407
		CTZ	.064[a,b]	.459	.890	-.860	.987
	5	11	-.513[a,b]	.459	.269	-1.436	.410
		2	-.483[a,b]	.459	.297	-1.407	.440
		CTZ	-.420[a,b]	.459	.365	-1.343	.503
	CTZ	11	-.093[a,b]	.459	.840	-1.016	.830
		2	-.064[a,b]	.459	.890	-.987	.860
		5	.420[a,b]	.459	.365	-.503	1.343

Based on estimated marginal means

Appendix 7: List of Infaunal Taxonomic Groupings

Full table of taxonomic groupings identified from the infaunal samples. Common group names are given where available.

PHYLUM	CLASS	ORDER	FAMILY	TAXONOMIC GROUP	COMMON GROUP NAMES
NEMATODA				NEMATODA	Nematode worms
NEMERTEA				NEMERTEA	Nemertean worms
PLATYHELMINTHES	Turbellaria			TURBELLARIA	Flat worms
ANNELIDA				OLIGOCHETA	Oligochaete worms
CHAETOGNATHA				CHAETOGNATHA	Arrow worms
ANNELIDA	Polychaeta	Terebellida	Ampharetidae	Ampharetidae	Polychaete worms
ANNELIDA	Polychaeta	Phyllodocida	Aphroditidae	Aphroditidae	
ANNELIDA	Polychaeta		Capitellidae	Capitellidae	
ANNELIDA	Polychaeta	Terebellida	Cirratulidae	Cirratulidae	
ANNELIDA	Polychaeta		Cossuridae	Cossuridae	
ANNELIDA	Polychaeta	Eunicida	Eunicidae	Eunicidae	
ANNELIDA	Polychaeta	Phyllodocida	Glyceridae	Glyceridae	
ANNELIDA	Polychaeta	Phyllodocida	Hesionidae	Hesionidae	
ANNELIDA	Polychaeta	Eunicida	Lumbrineridae	Lumbrineridae	
ANNELIDA	Polychaeta		Opheliidae	Opheliidae	
ANNELIDA	Polychaeta		Orbiniidae	Orbiniidae	
ANNELIDA	Polychaeta	Sabellida	Oweniidae	Oweniidae	
ANNELIDA	Polychaeta		Maldanidae	Maldanidae	
ANNELIDA	Polychaeta	Spionida	Magelonidae	Magelonidae	
ANNELIDA	Polychaeta	Phyllodocida	Nephtyidae	Nephtyidae	
ANNELIDA	Polychaeta	Phyllodocida	Nereididae	Nereididae	
ANNELIDA	Polychaeta		Paraonidae	Paraonidae	
ANNELIDA	Polychaeta	Terebellida	Pectinariidae	Pectinariidae	
ANNELIDA	Polychaeta	Phyllodocida	Phyllodocidae	Phyllodocidae	
ANNELIDA	Polychaeta	Spionida	Poecilochaetidae	Poecilochaetidae	
ANNELIDA	Polychaeta	Sabellida	Sabellidae	Sabellidae	
ANNELIDA	Polychaeta	Spionida	Spionidae	Spionidae	
ANNELIDA	Polychaeta	Phyllodocida	Syllidae	Syllidae	
ANNELIDA	Polychaeta	Terebellida	Terebellidae	Terebellidae	
ANNELIDA	Polychaeta			POLYCHAETA Indet.	
PHORONIDA				PHORONIDA	Phoronids
ARTHROPODA	Copepoda[a]			COPEPODA	Copepods
ARTHROPODA	Ostracoda			OSTRACODA	Ostracods
ARTHROPODA	Malacostraca	Mysida		MYSIDA	Mysid shrimp
ARTHROPODA	Malacostraca	Decapoda	Crangonidae	Crangonidae	Decapods (crabs, hermit crabs, squat lobsters and shrimps)
ARTHROPODA	Malacostraca	Decapoda	Caridea[c]	CARIDEA Indet.	
ARTHROPODA	Malacostraca	Decapoda	Galatheidae	Galatheidae	
ARTHROPODA	Malacostraca	Decapoda	Hippolytidae	Hippolytidae	
ARTHROPODA	Malacostraca	Decapoda	Paguridae	Paguridae	
ARTHROPODA	Malacostraca	Decapoda	Pasiphaeidae	Pasiphaeidae	
ARTHROPODA	Malacostraca	Decapoda	Portunidae	Portunidae	
ARTHROPODA	Malacostraca	Decapoda		DECAPODA Indet.	
ARTHROPODA	Malacostraca	CRAB ZOAE		DECAPODA Zoae	Larval crabs
ARTHROPODA	Malacostraca	Amphipoda	Aoridae	Aoridae	Amphipods
ARTHROPODA	Malacostraca	Amphipoda	Ampeliscidae	Ampeliscidae	
ARTHROPODA	Malacostraca	Amphipoda	Ampithoidae	Ampithoidae	
ARTHROPODA	Malacostraca	Amphipoda	Calliopiidae	Calliopiidae	
ARTHROPODA	Malacostraca	Amphipoda	Caprelloidea[d]	CAPRELLOIDEA	*Caprellids
ARTHROPODA	Malacostraca	Amphipoda	Corophiidae	Corophiidae	
ARTHROPODA	Malacostraca	Amphipoda	Dexaminidae	Dexaminidae	
ARTHROPODA	Malacostraca	Amphipoda	Gammaridae	Gammaridae	
ARTHROPODA	Malacostraca	Amphipoda	Ischyroceridae	Ischyroceridae	
ARTHROPODA	Malacostraca	Amphipoda	Leucothoidae	Leucothoidae	
ARTHROPODA	Malacostraca	Amphipoda	Lysianassidae	Lysianassidae	
ARTHROPODA	Malacostraca	Amphipoda	Oedicerotidae	Oedicerotidae	

ARTHROPODA	Malacostraca	Amphipoda	Melitidae	Melitidae	
ARTHROPODA	Malacostraca	Amphipoda	Pontoporeiidae	Pontoporeiidae	
ARTHROPODA	Malacostraca	Amphipoda	Stenothoidae	Stenothoidae	
ARTHROPODA	Malacostraca	Amphipoda	Urothoidae	Urothoidae	
ARTHROPODA	Malacostraca	Amphipoda		AMPHIPODA Indet.	
ARTHROPODA	Malacostraca	Isopoda	Arcturidae	Arcturidae	Isopods
ARTHROPODA	Malacostraca	Isopoda	Gnathiidae	Gnathiidae	
ARTHROPODA	Malacostraca		Nebaliidae	Nebaliidae	
ARTHROPODA	Malacostraca	Cumacea	Bodotriidae	Bodotriidae	Hooded shrimps
ARTHROPODA	Malacostraca	Cumacea	Diastylidae	Diastylidae	
ARTHROPODA	Malacostraca	Tanaidacea	Apseudidae	Apseudidae	Tanaids
ARTHROPODA	Malacostraca	Tanaidacea		TANAIDACEA Indet.	
ARTHROPODA	Pycnogonida	Pantopoda	Ammotheidae	Ammotheidae	Sea spiders
ARTHROPODA	Arachnida	Acarina		ACARINA	Mites
ARTHROPODA	Insecta	Collembola	Neanuridae	Neanuridae	Insects
ARTHROPODA	Insecta			INSECTA	
ARTHROPODA	LARVAE			LARVAE Indet.	Larvae
ECHINODERMATA	Echinoidea	Spatangoida	Loveniidae	Loveniidae	Heart urchins
ECHINODERMATA	Ophiuroidea	Ophiurida	Amphiuridae	Amphiuridae	Brittlestars
ECHINODERMATA	Ophiuroidea			OPHIUROIDEA Indet.	
ECHINODERMATA	Holothuroidea			HOLOTHUROIDAE Indet.	Sea cucumbers
CNIDARIA	Anthozoa	Actiniaria	Edwardsiidae	Edwardsiidae	Anemones
CNIDARIA	Anthozoa	Actiniaria		ACTINIARIA Indet.	
MOLLUSCA	Bivalvia	Cartitoida	Astartidae	Astartidae	
MOLLUSCA	Bivalvia	Euheterodonta[b]	Hiatellidae	Hiatellidae	
MOLLUSCA	Bivalvia	Euheterodonta[b]	Solenidae	Solenidae	*Razor shells
MOLLUSCA	Bivalvia	Euheterodonta[b]	Thraciidae	Thraciidae	
MOLLUSCA	Bivalvia	Lucinoida	Lucinidae	Lucinidae	*Hatchet shells
MOLLUSCA	Bivalvia	Lucinoida	Thyasiridae	Thyasiridae	
MOLLUSCA	Bivalvia	Pectinoida	Pectinidae	Pectinidae	Scallops
MOLLUSCA	Bivalvia	Mytiloida	Mytilidae	Mytilidae	Mussels
MOLLUSCA	Bivalvia	Veneroida	Cardiidae	Cardiidae	*Cockles
MOLLUSCA	Bivalvia	Veneroida	Montacutidae	Montacutidae	
MOLLUSCA	Bivalvia	Veneroida	Psammobiidae	Psammobiidae	*Sunset clams
MOLLUSCA	Bivalvia	Veneroida	Semelidae	Semelidae	
MOLLUSCA	Bivalvia	Veneroida	Tellinidae	Tellinidae	*Tellins
MOLLUSCA	Bivalvia	Veneroida	Veneridae	Veneridae	*Venus clams
MOLLUSCA	Bivalvia			BIVALVIA Indet.	
MOLLUSCA	Gastropoda	Cephaloaspidea	Retusidae	Retusidae	
MOLLUSCA	Gastropoda	Littorinimorpha	Calyptraeidae	Calyptraeidae	*Slipper limpets
MOLLUSCA	Gastropoda	Littorinimorpha	Rissoidae	Rissoidae	
MOLLUSCA	Gastropoda		Pyramidellidae	Pyramidellidae	*Pyramid shells
MOLLUSCA	Gastropoda		Trochidae	Trochidae	*Topshells
MOLLUSCA	Gastropoda		Turbinidae	Turbinidae	*Turban snails
MOLLUSCA	Opisthobranchia[b]			OPISTHOBRANCHIA Indet.	Opisthobranchs
MOLLUSCA	Polyplacophora	Chitonida	Ischnochitonidae	Ischnochitonidae	Chitons
CHORDATA	Ascidiacea	Phlebobranchia	Ascidiidae	Ascidiidae	Sea squirts

[a]sub-class
[b]infra-class
[c]infra-order
[d]super-family
*common names specific to a family group

Appendix 8: Abundance (N) Pairwise Comparisons (Distances within Locations)

Pairwise comparisons of the abundance (N) of organism between distances and control zones (CTZ) within the study locations. Significant differences in the overall abundance of organisms are present in pairwise comparisons at all locations.

LOCATION	(I) DISTANCE	(J) DISTANCE	Mean Difference (I-J)	Std. Error	Sig.[c]	95% Confidence Interval for Difference[c]	
						Lower Bound	Upper Bound
FALMOUTH	11	2	28.000[a,b]	31.529	.376	-34.188	90.188
		5	-11.333[a,b]	31.529	.720	-73.521	50.855
		CTZ	-92.056[a,b,*]	31.529	.004	-154.244	-29.867
	2	11	-28.000[a,b]	31.529	.376	-90.188	34.188
		5	-39.333[a,b]	31.529	.214	-101.521	22.855
		CTZ	-120.056[a,b,*]	31.529	.000	-182.244	-57.867
	5	11	11.333[a,b]	31.529	.720	-50.855	73.521
		2	39.333[a,b]	31.529	.214	-22.855	101.521
		CTZ	-80.722[a,b,*]	31.529	.011	-142.910	-18.534
	CTZ	11	92.056[a,b,*]	31.529	.004	29.867	154.244
		2	120.056[a,b,*]	31.529	.000	57.867	182.244
		5	80.722[a,b,*]	31.529	.011	18.534	142.910
MYLOR	11	2	65.889[a,b,*]	31.529	.038	3.701	128.077
		5	-2.556[a,b]	31.529	.935	-64.744	59.633
		CTZ	-102.000[a,b,*]	31.529	.001	-164.188	-39.812
	2	11	-65.889[a,b,*]	31.529	.038	-128.077	-3.701
		5	-68.444[a,b,*]	31.529	.031	-130.633	-6.256
		CTZ	-167.889[a,b,*]	31.529	.000	-230.077	-105.701
	5	11	2.556[a,b]	31.529	.935	-59.633	64.744
		2	68.444[a,b,*]	31.529	.031	6.256	130.633
		CTZ	-99.444[a,b,*]	31.529	.002	-161.633	-37.256
	CTZ	11	102.000[a,b,*]	31.529	.001	39.812	164.188
		2	167.889[a,b,*]	31.529	.000	105.701	230.077
		5	99.444[a,b,*]	31.529	.002	37.256	161.633
ST. MAWES	11	2	56.833[a,b]	31.529	.073	-5.355	119.021
		5	-52.056[a,b]	31.529	.100	-114.244	10.133
		CTZ	-114.944[a,b,*]	31.529	.000	-177.133	-52.756
	2	11	-56.833[a,b]	31.529	.073	-119.021	5.355
		5	-108.889[a,b,*]	31.529	.001	-171.077	-46.701
		CTZ	-171.778[a,b,*]	31.529	.000	-233.966	-109.590
	5	11	52.056[a,b]	31.529	.100	-10.133	114.244
		2	108.889[a,b,*]	31.529	.001	46.701	171.077
		CTZ	-62.889[a,b,*]	31.529	.047	-125.077	-.701
	CTZ	11	114.944[a,b,*]	31.529	.000	52.756	177.133
		2	171.778[a,b,*]	31.529	.000	109.590	233.966
		5	62.889[a,b,*]	31.529	.047	.701	125.077

Based on estimated marginal means

Appendix 9: Species Richness (S) Pairwise Comparisons (Distances within Locations)

Table showing the pairwise comparisons of distance within individual locations for the species richness (S) of infaunal samples. The significance is driven primarily by the St. Mawes and Mylor samples (significance highlighted by grey rows).

LOCATION	(I) DISTANCE	(J) DISTANCE	Mean Difference (I-J)	Std. Error	Sig.[c]	95% Confidence Interval for Difference[c]	
						Lower Bound	Upper Bound
FALMOUTH	11	2	2.444[a,b]	1.948	.211	-1.397	6.286
		5	-.111[a,b]	1.948	.955	-3.952	3.730
		CTZ	.667[a,b]	1.948	.732	-3.175	4.508
	2	11	-2.444[a,b]	1.948	.211	-6.286	1.397
		5	-2.556[a,b]	1.948	.191	-6.397	1.286
		CTZ	-1.778[a,b]	1.948	.362	-5.619	2.064
	5	11	.111[a,b]	1.948	.955	-3.730	3.952
		2	2.556[a,b]	1.948	.191	-1.286	6.397
		CTZ	.778[a,b]	1.948	.690	-3.064	4.619
	CTZ	11	-.667[a,b]	1.948	.732	-4.508	3.175
		2	1.778[a,b]	1.948	.362	-2.064	5.619
		5	-.778[a,b]	1.948	.690	-4.619	3.064
MYLOR	11	2	4.167[a,b,*]	1.948	.034	.325	8.008
		5	1.333[a,b]	1.948	.494	-2.508	5.175
		CTZ	-1.889[a,b]	1.948	.333	-5.730	1.952
	2	11	-4.167[a,b,*]	1.948	.034	-8.008	-.325
		5	-2.833[a,b]	1.948	.147	-6.675	1.008
		CTZ	-6.056[a,b,*]	1.948	.002	-9.897	-2.214
	5	11	-1.333[a,b]	1.948	.494	-5.175	2.508
		2	2.833[a,b]	1.948	.147	-1.008	6.675
		CTZ	-3.222[a,b]	1.948	.100	-7.064	.619
	CTZ	11	1.889[a,b]	1.948	.333	-1.952	5.730
		2	6.056[a,b,*]	1.948	.002	2.214	9.897
		5	3.222[a,b]	1.948	.100	-.619	7.064
ST. MAWES	11	2	2.444[a,b]	1.948	.211	-1.397	6.286
		5	-1.000[a,b]	1.948	.608	-4.841	2.841
		CTZ	-4.278[a,b,*]	1.948	.029	-8.119	-.436
	2	11	-2.444[a,b]	1.948	.211	-6.286	1.397
		5	-3.444[a,b]	1.948	.079	-7.286	.397
		CTZ	-6.722[a,b,*]	1.948	.001	-10.564	-2.881
	5	11	1.000[a,b]	1.948	.608	-2.841	4.841
		2	3.444[a,b]	1.948	.079	-.397	7.286
		CTZ	-3.278[a,b]	1.948	.094	-7.119	.564
	CTZ	11	4.278[a,b,*]	1.948	.029	.436	8.119
		2	6.722[a,b,*]	1.948	.001	2.881	10.564
		5	3.278[a,b]	1.948	.094	-.564	7.119

Based on estimated marginal means

Appendix 10: Polychaeta ANOVA Results Table

Results from the analysis of variance (ANOVA) of Polychaeta. This analysis contained all families identified in Annelida, but excluded the sub-class Oligochaeta. The results reflected those identified in the analysis of the whole phylum analysis, with no significance effect of distance identified (significant factors highlighted by grey rows).

Tests of Between-Subjects Effects

Dependent Variable: POLYCHAETA

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
DISTANCE	Hypothesis	105329.352	3	35109.784	3.400	.067
	Error	92946.806	9	10327.423[b]		
LOCATION	Hypothesis	426835.861	2	213417.931	2.436	.235
	Error	262854.194	3	87618.065[a]		
SITE(LOCATION)	Hypothesis	262854.194	3	87618.065	8.484	.005
	Error	92946.806	9	10327.423[b]		
LOCATION * DISTANCE	Hypothesis	60790.065	6	10131.677	.981	.490
	Error	92946.806	9	10327.423[b]		
DISTANCE * SITE(LOCATION)	Hypothesis	92946.806	9	10327.423	3.613	.000
	Error	548849.556	192	2858.591[c]		

a. MS(SITE(LOCATION))

b. MS(DISTANCE * SITE(LOCATION))

c. MS(Error)

Appendix 11: Crustacea Abundance Pairwise Comparisons (Distances within Locations)

Pairwise comparisons of distance at the study locations for the abundance of Crustacea. The significance of the distance effect is primarily driven by the samples from St. Mawes (significance highlighted by grey rows).

LOCATION	(I) DISTANCE	(J) DISTANCE	Mean Difference (I-J)	Std. Error	Sig.[c]	95% Confidence Interval for Difference[c]	
						Lower Bound	Upper Bound
FALMOUTH	11	2	7.056[a,b]	18.002	.696	-28.451	42.562
		5	-3.722[a,b]	18.002	.836	-39.229	31.784
		CTZ	-2.889[a,b]	18.002	.873	-38.395	32.617
	2	11	-7.056[a,b]	18.002	.696	-42.562	28.451
		5	-10.778[a,b]	18.002	.550	-46.284	24.729
		CTZ	-9.944[a,b]	18.002	.581	-45.451	25.562
	5	11	3.722[a,b]	18.002	.836	-31.784	39.229
		2	10.778[a,b]	18.002	.550	-24.729	46.284
		CTZ	.833[a,b]	18.002	.963	-34.673	36.340
	CTZ	11	2.889[a,b]	18.002	.873	-32.617	38.395
		2	9.944[a,b]	18.002	.581	-25.562	45.451
		5	-.833[a,b]	18.002	.963	-36.340	34.673
MYLOR	11	2	3.611[a,b]	18.002	.841	-31.895	39.117
		5	-1.167[a,b]	18.002	.948	-36.673	34.340
		CTZ	-4.222[a,b]	18.002	.815	-39.729	31.284
	2	11	-3.611[a,b]	18.002	.841	-39.117	31.895
		5	-4.778[a,b]	18.002	.791	-40.284	30.729
		CTZ	-7.833[a,b]	18.002	.664	-43.340	27.673
	5	11	1.167[a,b]	18.002	.948	-34.340	36.673
		2	4.778[a,b]	18.002	.791	-30.729	40.284
		CTZ	-3.056[a,b]	18.002	.865	-38.562	32.451
	CTZ	11	4.222[a,b]	18.002	.815	-31.284	39.729
		2	7.833[a,b]	18.002	.664	-27.673	43.340
		5	3.056[a,b]	18.002	.865	-32.451	38.562
ST. MAWES	11	2	40.944[a,b,*]	18.002	.024	5.438	76.451
		5	-14.167[a,b]	18.002	.432	-49.673	21.340
		CTZ	-95.833[a,b,*]	18.002	.000	-131.340	-60.327
	2	11	-40.944[a,b,*]	18.002	.024	-76.451	-5.438
		5	-55.111[a,b,*]	18.002	.003	-90.617	-19.605
		CTZ	-136.778[a,b,*]	18.002	.000	-172.284	-101.271
	5	11	14.167[a,b]	18.002	.432	-21.340	49.673
		2	55.111[a,b,*]	18.002	.003	19.605	90.617
		CTZ	-81.667[a,b,*]	18.002	.000	-117.173	-46.160
	CTZ	11	95.833[a,b,*]	18.002	.000	60.327	131.340
		2	136.778[a,b,*]	18.002	.000	101.271	172.284
		5	81.667[a,b,*]	18.002	.000	46.160	117.173

Based on estimated marginal means

a. An estimate of the modified population marginal mean (I).

b. An estimate of the modified population marginal mean (J).

c. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

*. The mean difference is significant at the .05 level.

Appendix 12: Amphipoda ANOVA Table of Results

Table of results for the analysis of variance (ANOVA) of Amphipoda. This analysis contained only amphipod families and excluded the influence of large numbers of tanaids present in the samples and the rare occurrence of Pycnogonida and Isopoda. The output closely mirrors that of the whole phylum analysis, with the exception that location becomes a non-significant influence (significance identified by grey rows).

Tests of Between-Subjects Effects

Dependent Variable: AMPHIPODA

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
DISTANCE	Hypothesis	12200.273	3	4066.758	6.042	.015
	Error	6057.875	9	673.097[b]		
LOCATION	Hypothesis	22265.009	2	11132.505	3.040	.190
	Error	10987.514	3	3662.505[a]		
SITE(LOCATION)	Hypothesis	10987.514	3	3662.505	5.441	.021
	Error	6057.875	9	673.097[b]		
LOCATION * DISTANCE	Hypothesis	15516.324	6	2586.054	3.842	.035
	Error	6057.875	9	673.097[b]		
DISTANCE * SITE(LOCATION)	Hypothesis	6057.875	9	673.097	1.639	.107
	Error	78838.222	192	410.616[c]		

a. MS(SITE(LOCATION))

b. MS(DISTANCE * SITE(LOCATION))

c. MS(Error)

Appendix 13: Bivalvia ANOVA Table of Results

The table of results for the analysis of variance (ANOVA) for the abundance of bivalves within the infaunal samples. No significant effect of distance from mooring infrastructure on the abundance of bivalves is visible in the results. The significance of sites within locations however indicates small-scale spatial variation is an important factor influencing abundance (significance is identified by highlighted grey rows).

Tests of Between-Subjects Effects

Dependent Variable: BIVALVIA

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
DISTANCE	Hypothesis	73.537	3	24.512	1.542	.270
	Error	143.028	9	15.892[b]		
LOCATION	Hypothesis	662.731	2	331.366	.956	.477
	Error	1040.194	3	346.731[a]		
SITE(LOCATION)	Hypothesis	1040.194	3	346.731	21.818	.000
	Error	143.028	9	15.892[b]		
LOCATION * DISTANCE	Hypothesis	251.824	6	41.971	2.641	.092
	Error	143.028	9	15.892[b]		
DISTANCE * SITE(LOCATION)	Hypothesis	143.028	9	15.892	.926	.504
	Error	3294.667	192	17.160[c]		

Appendix 14: MDS Plots of Individual Survey Locations and ANOSIM Results

Multi-dimensional scaling (MDS) plots of the similarities between the infaunal community compositions across distances from mooring, separated out to the individual study locations. Result of the pairwise tests of distance, performed as part of the analysis of similarity (ANOSIM), are also shown.

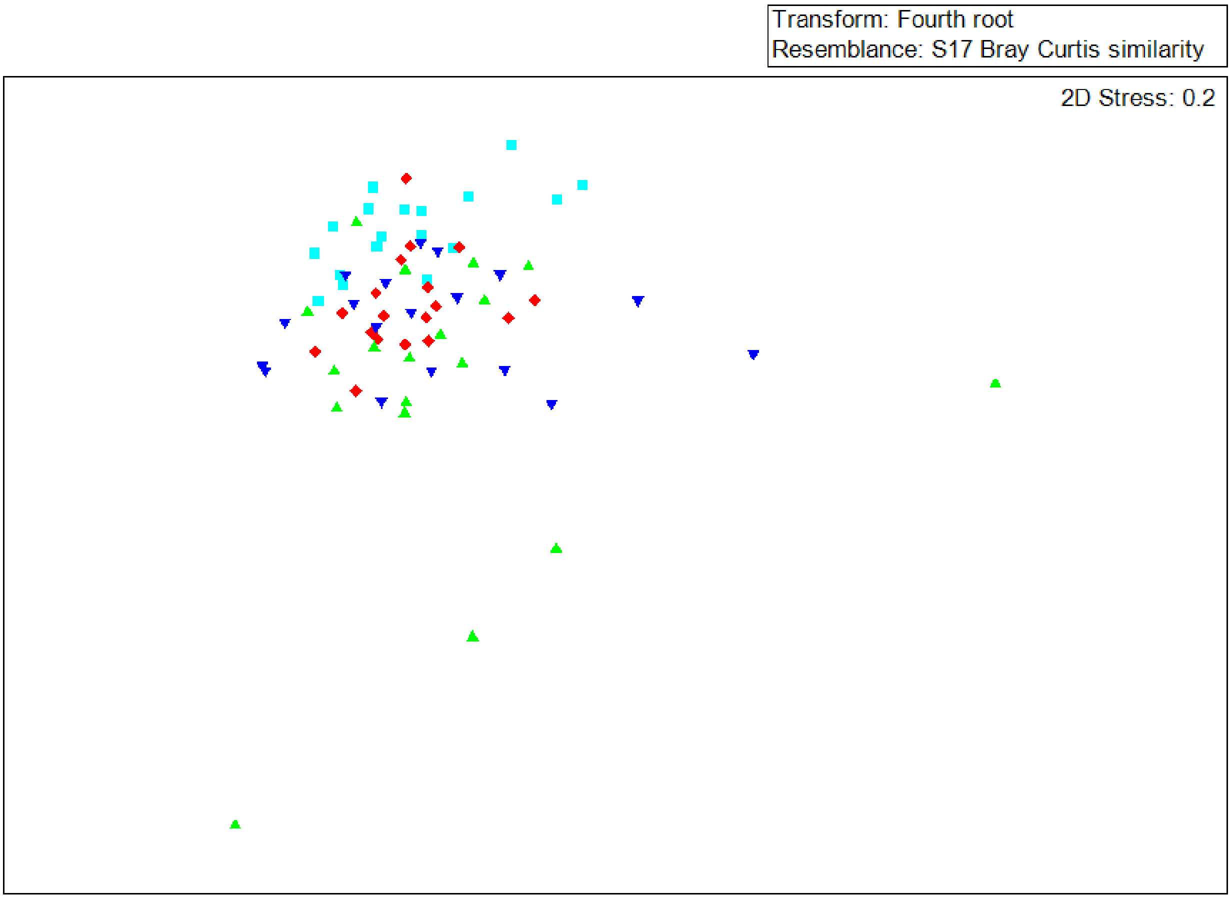


Figure 24 MDS plot illustrating similarity of infaunal community compositions within the Falmouth study location. Distance from mooring is identified by colour (2 metres = green triangles, 5 metres = dark blue triangles, 11 metres = light blue squares, control zone (CTZ) = red diamonds). The control zone samples are clumped tightly, indicative of lower levels of disturbance.

Pairwise Tests - Falmouth

Groups	R Statistic	Significance level %	Possible permutations	Actual permutations	Number >= Observed
2, 5	0.002	43.1	590976100	999	430
2, 11	0.340	0.1	590976100	999	0
2, CTZ	0.238	0.1	590976100	999	0
5, 11	0.203	0.1	590976100	999	0
5, CTZ	0.220	0.1	590976100	999	0
11, CTZ	0.445	0.1	590976100	999	0

Table 15 Pairwise tests of distance from the analysis of similarity (ANOSIM) within the Falmouth data indicate significant differences at all comparisons except 2 metre, 5 metre (significance indicated by grey rows).

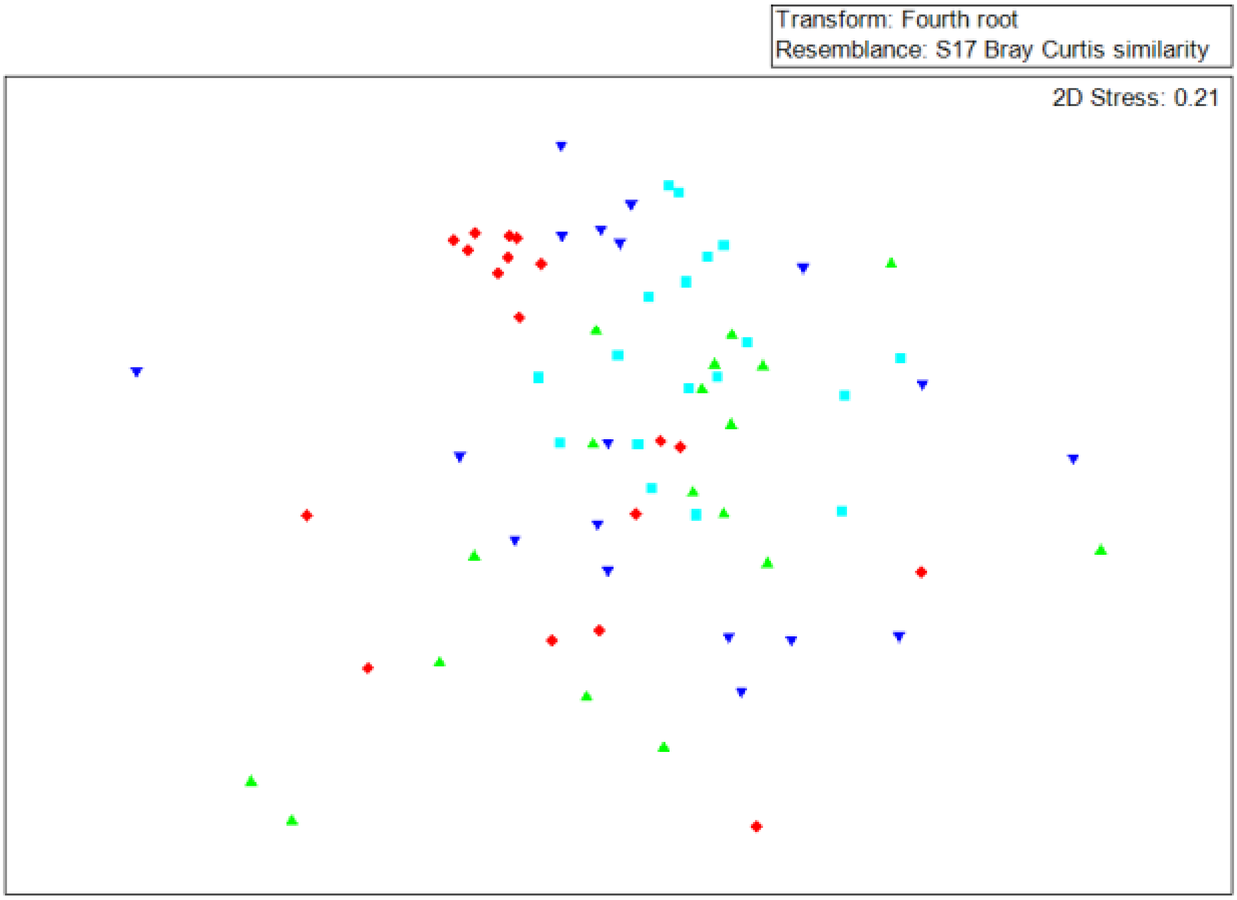


Figure 25 MDS plot illustrating similarity of infaunal community compositions within the Mylor study location. Distance from mooring is identified by colour (2 metres = green triangles, 5 metres = dark blue triangles, 11 metres = light blue squares, control zone (CTZ) = red diamonds). Although some spread is visible within the control zone (CTZ) samples, there is still clumping visible.

Pairwise Tests – Mylor

Groups	R Statistic	Significance level %	Possible permutations	Actual permutations	Number >= Observed
2, 5	0.059	14.3	590976100	999	142
2, 11	0.243	0.1	590976100	999	0
2, CTZ	0.411	0.1	590976100	999	0
5, 11	0.129	3	590976100	999	29
5, CTZ	0.22	0.1	590976100	999	0
11, CTZ	0.496	0.1	590976100	999	0

Table 16 Pairwise tests of distance from the analysis of similarity (ANOSIM) within the Mylor data indicate significant differences between all distances and the control zone (CTZ) and between the 2 metre and 11 metre samples (significance is indicated by grey rows).

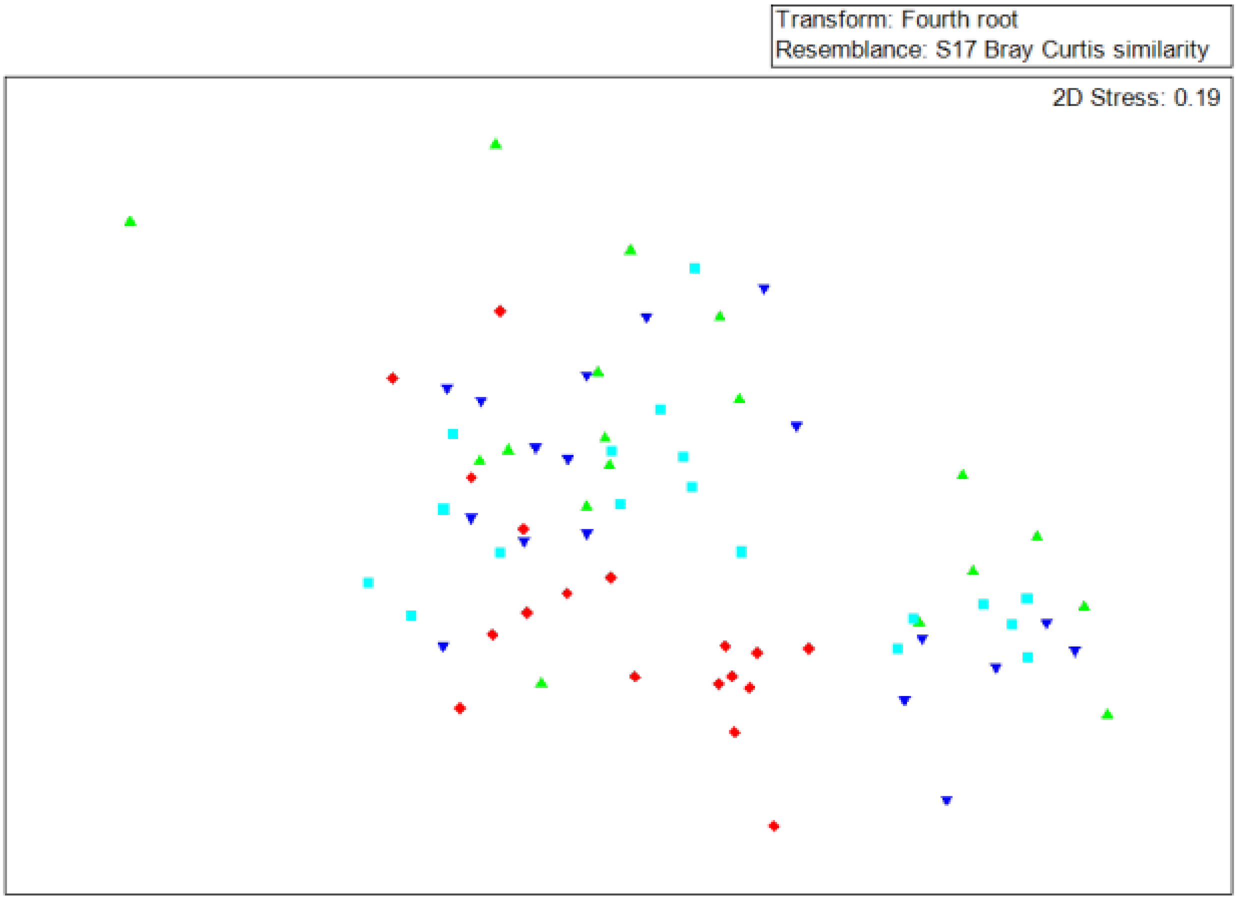


Figure 26 MDS plot illustrating similarity of infaunal community compositions within the St. Mawes study location. Distance from mooring is identified by colour (2 metres = green triangles, 5 metres = dark blue triangles, 11 metres = light blue squares, control zone (CTZ) = red diamonds). The control zone (CTZ) samples are less dispersed than the distance samples (2, 5, 11 metres) indicative of lower levels of disturbance.

Pairwise Tests – St. Mawes

Groups	R Statistic	Significance level %	Possible permutations	Actual permutations	Number >= Observed
2, 5	-0.02	60.4	590976100	999	603
2, 11	0.018	26.9	590976100	999	268
2, CTZ	0.418	0.1	590976100	999	0
5, 11	-0.005	45.4	590976100	999	453
5, CTZ	0.364	0.1	590976100	999	0
11, CTZ	0.395	0.1	590976100	999	0

Table 17 Pairwise tests of distance from the analysis of similarity (ANOSIM) within the St. Mawes data indicate significant differences between the control zone (CTZ) and distance samples (2, 5 and 11 metre) only (significance is indicated by grey rows).

Appendix 15: Falmouth Biotope Sensitivity Assessments

Moore et al., 1999. Marine Nature Conservation Review. Sector 8. Inlets of the western English Channel: Area summaries. JNCC

Sensitivities	**Sensitivity Level Assigned**	**Colour**
Not sensitive	0	
Very Low	1	
Low	2	
Moderate	3	
High	4	
Very High	5	

				All Assessments for Biotopes				**Final Assigned**		
MNCR Biotopes	**MNCR Biotope**	**MarLIN Biotope**	**MarLIN Biotope description**	**Abrasion and Physical disturbance**	**Sensitivity Level Assigned**	**Colour**	**MarLIN link**	**Comments**	**Sensitivity Level Assigned**	**Colour**
Exposed/ moderately exposed bedrock shore with fucoids and barnacles (Bpat; XR; Him; FvesB)	LR.ELR.MB.BPat	LR.ELR.MB.BPat.Fvesl	Barnacles and Patella spp. on exposed or moderately exposed, or vertical sheltered, eulittoral rock	Moderate	3		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=199&code=1997	Two sensitivity assessments available relevant to the LR.ELR.MB.Bpat biotope (one incomplete). Therefore precautionary principle adopted and most sensitive biotope assigned.	3	
	XR	XR	n/a	n/a	n/a	n/a	n/a	Biotope code not found.		
	LR.ELR.FR.Him	LR.ELR.FR.Him	Himanthalia elongata and red seaweeds on exposed lower eulittoral rock	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=360&code=1997			
	LR.MLR.BF.FvesB	LR.MLR.BF.FvesB	Fucus vesiculosus and barnacle mosaics on moderately exposed mid eulittoral rock	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=198&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\MarLIN_Web\marlin_final_design\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.		
Sheltered littoral rock with fucoids (Bpat; Pel; Fspi; Asc.VS; Fser.VS; FserX)	LR.ELR.MB.BPat	LR.ELR.MB.BPat.Fvesl	Barnacles and Patella spp. on exposed or moderately exposed, or vertical sheltered, eulittoral rock	Moderate	3		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=199&code=1997	Two sensitivity assessments available relevant to the LR.ELR.MB.Bpat biotope (one incomplete). Therefore precautionary principle adopted and most sensitive biotope assigned.	3	
	LR.SLR.F.Pel	LR.SLR.F.Pel	Pelvetia canaliculata on sheltered littoral fringe rock	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=322&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\MarLIN_Web\marlin_final_design\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.		
	LR.SLR.F.Fspi	LR.SLR.F.Fspi	Fucus spiralis on moderately exposed to very sheltered upper eulittoral rock	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=307&code=1997	No assessment available.		
	LR.SLR.F.Asc.VS	LR.SLR.F.Asc.VS	Ascophyllum nodosum and Fucus vesiculo sus on variable salinity mid eulittoral rock	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=78&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\\MarLIN_Web\\marlin_final_design\\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.		
	LR.SLR.F.Fserr.VS	LR.SLR.F.Fserr.VS	Fucus serratus and large Mytilus edulis on variable salinity lower eulittoral rock	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=110&code=1997	No assessment available.		
	LR.SLR.FX.FserX	LR.SLR.FX.FserX.T	Fucus serratus with sponges, ascidians and red seaweeds on tide-swept lower eulittoral mixed substrata	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=221&code=	No assessment available for LR.SLR.FX.FserX. Sensitivity assessment for LR.SLR.FX.FserX.T available within biotope.		
Sheltered littoral rock and mixed substrata shores (Pel; Fspi; Asc; Fser; FvesX; FserX.T)	LR.SLR.F.Pel	LR.SLR.F.Pel	Pelvetia canaliculata on sheltered littoral fringe rock	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=322&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\MarLIN_Web\marlin_final_design\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.	4	

	LR.SLR.F.Fspi	LR.SLR.F.Fspi	Fucus spiralis on moderately exposed to very sheltered upper eulittoral rock	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=307&code=1997	No assessment available.	
	LR.SLR.F.Asc	LR.SLR.F.Asc	Ascophyllum nodosum on very sheltered mid eulittoral rock	High	4		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=4&code=1997		
	LR.SLR.FX.Fser	LR.SLR.FX.FserX.T	Fucus serratus with sponges, ascidians and red seaweeds on tide-swept lower eulittoral mixed substrata	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=221&code=	No assessment available for LR.SLR.FX.Fser. Sensitivity assessment for LR.SLR.FX.FserX.T available within biotope.	
	LR.SLR.FX.FvesX	LR.SLR.FX.FvesX	Fucus vesiculosus on mid eulittoral mixed substrata	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=329&code=1997		
	LR.SLR.FX.FserX	LR.SLR.FX.FserX.T	Fucus serratus with sponges, ascidians and red seaweeds on tide-swept lower eulittoral mixed substrata	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=221&code=	No assessment available for LR.SLR.FX.FserX. Sensitivity assessment for LR.SLR.FX.FserX.T available within biotope.	
Mixed substrata shores (FvesX; FserX; HedStr)	LR.SLR.FX.FvesX	LR.SLR.FX.FvesX	Fucus vesiculosus on mid eulittoral mixed substrata	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=329&code=1997		2
	LR.SLR.FX.FserX	LR.SLR.FX.FserX.T	Fucus serratus with sponges, ascidians and red seaweeds on tide-swept lower eulittoral mixed substrata	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=221&code=	No assessment available for LR.SLR.FX.FserX. Sensitivity assessment for LR.SLR.FX.FserX.T available within biotope.	
	LS.LMU.Mu.HedStr	LS.LMU.Mu.HedStr	Hediste diversicolor and Streblospio shrubsolii in sandy mud or soft mud shores	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=132&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\MarLIN_Web\marlin_final_design\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.	
Steep upper shre bedrock and sheltered lower shore mixed substrata with fucoids (Pel; Fspi; Asc.Asc; Asc.X; FvesX; FserX) and littoral soft mud (HedStr)	LR.SLR.F.Pel	LR.SLR.F.Pel	Pelvetia canaliculata on sheltered littoral fringe rock	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=322&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\MarLIN_Web\marlin_final_design\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.	4
	LR.SLR.F.Fspi	LR.SLR.F.Fspi	Fucus spiralis on moderately exposed to very sheltered upper eulittoral rock	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=307&code=1997	No assessment available.	
	LR.SLR.F.Asc.Asc	LR.SLR.F.Asc	Ascophyllum nodosum on very sheltered mid eulittoral rock	High	4		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=4&code=1997	No assessment available for LR.SLR.F.Asc.Asc. Sensitivity for wider LR.SLR.F.Asc biotope code.	
	LR.SLR.F.Asc.X	LR.SLR.F.Asc	Ascophyllum nodosum on very sheltered mid eulittoral rock	High	4		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=4&code=1997	No assessment available for LR.SLR.F.Asc.X. Sensitivity for wider LR.SLR.F.Asc biotope code.	
	LR.SLR.FX.FvesX	LR.SLR.FX.FvesX	Fucus vesiculosus on mid eulittoral mixed substrata	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=329&code=1997		
	LR.SLR.FX.FserX	LR.SLR.FX.FserX.T	Fucus serratus with sponges, ascidians and red seaweeds on tide-swept lower eulittoral mixed substrata	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=221&code=	No assessment available for LR.SLR.FX.FserX. Sensitivity assessment for LR.SLR.FX.FserX.T available within biotope.	
	LS.LMU.Mu.HedStr	LS.LMU.Mu.HedStr	Hediste diversicolor and Streblospio shrubsolii in sandy mud or soft mud shores	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=132&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\MarLIN_Web\marlin_final_design\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.	
Sandy mud shores with *Hediste* and *Macoma* (MacAre; HedMac)	LS.LMS.MS.MacAre	LS.LMS.MS.MacAre	Macoma balthica, Arenicola marina and Mya arenaria in muddy sand shores	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=83&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\MarLIN_Web\marlin_final_design\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.	2
	LS.LMU.SMu.HedMac	LS.LMU.SMu.HedMac	Hediste diversicolor and Macoma balthica in sandy mud shores	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=209&code=1997		
Littoral soft mud with *Hediste* (HedScr; HedStr; HedOl)	LS.LMU.Mu.HedScr	LS.LMU.Mu.HedScr	Hediste diversicolor and Scrobicularia plana in reduced salinity mud shores	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=331&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\MarLIN_Web\marlin_final_design\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%	No assessment available.	n/a

							3E			
	LS.LMU.Mu.HedStr	LS.LMU.Mu.HedStr	Hediste diversicolor and Streblospio shrubsolii in sandy mud or soft mud shores	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=132&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\MarLIN_Web\marlin_final_design\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.		
	LS.LMU.Mu.HedOl	LS.LMU.Mu.HedOl	Hediste diversicolor and oligochaetes in low salinity mud shores	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=268&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\MarLIN_Web\marlin_final_design\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.		
Sublittoral moderately exposed rock with *Laminaria hyperborea* (Lhyp.Ft; SCAs.ByH)	IR.MIR.KR.Lhyp.Ft	IR.MIR.KR.Lhyp.Ft	Laminaria hyperborea forest and foliose red seaweeds on moderately exposed upper infralittoral rock	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=159&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\MarLIN_Web\marlin_final_design\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.	n/a	
	EIR.SCAs.ByH	EIR.SCAs.ByH	Sponge crust, polyclinid ascidian and bryozoan / hydroid on exposed infralittoral rock	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsbasicinfo.php?habitatid=251&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:%5CMarLIN_Web%5Cmarlin_final_design%5Chabitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No information available on the SCAs.ByH biotope - linked to alternative biotope (see web link)		
Sand-scoured rock outcrops with mixed kelps (XKScrR)/ ephemeral res algae on cobbles (EphR)	IR.MIR.SedK.XKScrR	IR.MIR.SedK.XKScrR	Mixed kelps with scour-tolerant and opportunistic foliose red seaweeds on scoured or sand-covered infralittoral rock	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=183&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\\\\MarLIN_Web\\\\marlin_final_design\\\\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.	n/a	
	EphR	EphR	n/a	n/a	n/a	n/a	n/a	Biotope code not found.		
Sublittoral mud (MarMu) with bedrock outcrops (XKScrR; AlcMaS; LsacX)	IR.MIR.SedK.XKScrR	IR.MIR.SedK.XKScrR	Mixed kelps with scour-tolerant and opportunistic foliose red seaweeds on scoured or sand-covered infralittoral rock	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=183&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\\\\MarLIN_Web\\\\marlin_final_design\\\\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.	2	
	CR.ECR.AlcMaS	CR.ECR.AlcMaS	Alcyonium-dominated communities (tide-swept/vertical)	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=149&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\MarLIN_Web\marlin_final_design\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.		
	SS.IMX.KSwMx.LsacX	SS.IMX.KSwMx.LsacX	Laminaria saccharina, Chorda filum and filamentous red seaweeds on sheltered infralittoral sediment	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=58&code=1997			
Sheltered sublittoral rock with *Laminaria saccharina* (Lsac.Ldig; Lsac.Ft)	IR.SIR.K.Lsac.Ldig	IR.SIR.K.Lsac.Ldig	Laminaria saccharina and Laminaria digitata on sheltered sublittoral fringe rock	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=346&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\MarLIN_Web\marlin_final_design\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.	n/a	
	IR.SIR.K.Lsac.Ft	IR.SIR.K.Lsac.Ft	Laminaria saccharina forest on very sheltered upper infralittoral rock	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=295&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\MarLIN_Web\marlin_final_design\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.		
Shallow sublittoral rock with kelp and sponges (LsacRS.FiR; CuSH; Flu.Hocu) and muddy gravek with sabelllid worms, anthozoans, ascidians and polychaetes (Aasp; LsacX; Ost; VsenMtru; EstMx; PolMtru)	IR.SIR.K.LsacRS.FiR	IR.SIR.K.LsacRS	Laminaria saccharina on reduced or low salinity infralittoral rock	Moderate	3		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=345&code=1997	No assessment available for IR.SIR.K.LsacRS.FiR. Assessment for wider biotope IR.SIR.K.LsacRS used.	3	
	CR.ECR.BS.CuSH	CR.ECR.BS.CuSH	Cushion sponges, hydroids and ascidians on tide-swept sheltered circalittoral rock	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=243&code=1997	No assessment available.		
	CR.MCR.ByH.Flu.Hocu	CR.MCR.ByH.Flu.Hocu	Haliclona oculata and Flustra foliacea with a rich faunal turf on tide-swept sheltered circalittoral mixed substrata	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=248&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\MarLIN_Web\marlin_final_design\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.		
	SS.IMS.SCR.Aasp	SS.IMS.SCR.Aasp	n/a	n/a	n/a	n/a	n/a	No biotope information available.		
	SS.IMX.KSwMx.LsacX	SS.IMX.KSwMx.LsacX	Laminaria saccharina, Chorda filum and filamentous red seaweeds on sheltered infralittoral sediment	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=58&code=1997			

	SS.IMX.Oy.Ost	SS.IMX.Oy.Ost	Ostrea edulis beds on shallow sublittoral muddy sediment	Moderate	3		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=69&code=1997		
	SS.IMX.FaMx.VsenMtru	SS.IMX.FaMx.VsenMtru	Venerupis senegalensis and Mya truncata in lower shore or infralittoral muddy gravel	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=354&code=1997		
	SS.IMX.EstMx	SS.IMX.EstMx	Estuarine sublittoral mixed sediments	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=52&code=1997 ; http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=114&code=1997 ; http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=36&code=1997	No assessment available for SS.IMX.EstMx. Sensitivity assigned using assessments for SS.IMX.EstMx.CreAph; SS.IMX.EstMx.PolMtru; SS.IMX.EstMx.MytV (all Low) within EstMx biotope.	
	SS.IMX.EstMx.PolMtru	SS.IMX.EstMx.PolMtru	Polydora ciliata, Mya truncata and solitary ascidians in variable salinity infralittoral mixed sediment	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=114&code=1997		
Sublittoral marine mixed sediments with sponges and ascidians (MarMu; FaMS; AlcMaS; Aasp; SubSoAs)	SS.IMU.MarMu	SS.IMU.MarMu.PhiVir	Philine aperta and Virgularia mirabilis in soft stable infralittoral mud	Moderate	3		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=202&code=1997	Four sensitivity assessments available relevant to the SS.IMU.MarMu biotope. Therefore precautionary principle adopted and most sensitive biotope assigned SS.IMU.MarMu.PhiVir	3
	SS.IMS.FaMS	SS.IMS.FaMS.EcorEns	Echinocardium cordatum and Ensis spp. in lower shore or shallow sublittoral muddy fine sand	Moderate	3		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=124&code=1997	Three sensitivity assessments available relevant to the SS.IMS.FaMS biotope. Therefore precautionary principle adopted and most senitive biotope assigned SS.IMS.FaMS.EcorEns	
	CR.ECR.AlcMaS	CR.ECR.AlcMaS	Alcyonium-dominated communities (tide-swept/vertical)	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=149&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\MarLIN_Web\marlin_final_design\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.	
	SS.IMS.SCR.Aasp	SS.IMS.SCR.Aasp	n/a	n/a	n/a	n/a	n/a	No biotope information available.	
	SCR.BrAs.SubSoAs	SCR.BrAs.SubSoAs	Suberites spp. and other sponges with solitary ascidians on very sheltered circalittoral rock	Moderate	3		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=94&code=1997		
Sublittoral sediment with Zostera marina beds (Zmar)	SS.IMS.Sgr.Zmar	SS.IMS.Sgr.Zmar	Zostera marina/angustifolia beds in lower shore or infralittoral clean or muddy sand	Moderate	3		http://www.marlin.ac.uk/speciessensitivity.php?speciesID=4600		3
Sublittoral muddy gravel (MarMu; FaMx; VsenMtru) with algae (LsacX)	SS.IMU.MarMu	SS.IMU.MarMu.PhiVir	Philine aperta and Virgularia mirabilis in soft stable infralittoral mud	Moderate	3		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=202&code=1997	Four sensitivity assessments available relevant to the SS.IMU.MarMu biotope. Therefore precautionary principle adopted and most sensitive biotope assigned.	3
	SS.IMX.FaMx	SS.IMX.FaMx.VsenMtru	Venerupis senegalensis and Mya truncata in lower shore or infralittoral muddy gravel	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=354&code=1997	Two sensitivity assessments relevant to SS.IMX.FaMx biotope. SS.IMX.FaMx.VsenMtru used as SS.IMX.FaMx.Lim although higher sensitivity represents a habitat not recorded in the Helford.	
	SS.IMX.FaMx.VsenMtru	SS.IMX.FaMx.VsenMtru	Venerupis senegalensis and Mya truncata in lower shore or infralittoral muddy gravel	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=354&code=1997		
	SS.IMX.KSwMx.LsacX	SS.IMX.KSwMx.LsacX		Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=58&code=1997		
Sublittoral estuarine mud (AphTub) with kelp on available hard substrata	SS.IMU.EstMu.AphTub	SS.IMU.EstMu.AphTub	Aphelochaeta marioni and Tubificoides sp p. in variable salinity infralittoral mud	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=201&code=1997		2

(LsacX)	SS.IMX.KSwMx.LsacX	SS.IMX.KSwMx.LsacX	Laminaria saccharina, Chorda filum and filamentous red seaweeds on sheltered infralittoral sediment	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=58&code=1997			
Sublittoral estuarine mud (EstMu; AphTub)	SS.IMU.EstMu	SS.IMU.EstMu	Sublittoral estuarine mud	Low	2		-	Two sensitivity assessments available relevant to the SS.IMS.EstMu biotope. Sensitivity assigned using assessments for SS.IMX.EstMu.PolVS; SS.IMX.EstMu.AphTun (both Low) within EstMx biotope.	2	
	SS.IMU.EstMu.AphTub	SS.IMU.EstMu.AphTub	Aphelochaeta marioni and Tubificoides sp p. in variable salinity infralittoral mud	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=201&code=1997			
Sublittoral marerl beds (Phy; MrlMx; Lcor)	SS.IGS.Mrl.Phy	SS.IGS.Mrl.Phy.HEc	Phymatolithon calcareum maerl beds with hydroids and echinoderms in deeper infralittoral clean gravel or coarse sand	Very High	5		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=64&code=1997	No sensitivity assessment available relevant to SS.IGS.Mrl.Phy. Assessment for SS.IGS.Mrl.Phy.HEc within biotope used.	5	
	SS.IMX.MrlMx	SS.IMX.MrlMx	Maerl beds (open coast/clean sediments)	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=255&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\MarLIN_Web\marlin_final_design\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.		
	SS.IMX.MrlMx.Lcor	SS.IMX.MrlMx.Lcor	Lithothamnion corallioides maerl beds on infralittoral muddy gravel	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=219&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\\MarLIN_Web\\marlin_final_design\\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.		

Appendix 16: Helford Biotope Sensitivity Assessments

Moore et al., 1999. Marine Nature Conservation Review. Sector 8. Inlets of the western English Channel: Area summaries. JNCC

Sensitivities	**Sensitivity Level Assigned**	**Colour**
Not sensitive	0	
Very Low	1	
Low	2	
Moderate	3	
High	4	
Very High	5	

				All Assessments for Biotopes				**Final Assigned**		
MNCR Biotopes	**MNCR Biotope**	**MarLIN Biotope**	**MarLIN Biotope description**	**Abrasion and Physical disturbance**	**Sensitivity Level Assigned**	**Colour**	**MarLIN link**	**Comments**	**Sensitivity Level Assigned**	**Colour**
Moderately exposed littoral rock (MLR) (no data)	LR.MLR	LR.MLR	Moderately exposed littoral rock	n/a	n/a		n/a	No single assessment available. Code contains many biotopes.	n/a	
Moderately exposed littoral rock with barnacles, fucoids and red algal turfs (Ver.B; Bpat.Cht; Fspi; XR; Fser.R)	LR.MLR.L.Ver.B	LR.MLR.L.Ver.B	Verrucaria maura and sparse barnacles on exposed littoral fringe rock	n/a	n/a		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=38&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\MarLIN_Web\marlin_final_design\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.	n/a	
	LR.ELR.MB.BPat.Cht	LR.ELR.MB.BPat.Cht	Chthamalus sp. barnacles on exposed or moderately exposed, or vertical sheltered, eulittoral rock	n/a	n/a			No information available for this biotope.	n/a	
	LR.SLR.F.Fspi	LR.SLR.F.Fspi	Fucus spiralis on moderately exposed to very sheltered upper eulittoral rock	n/a	n/a		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=307&code=1997	No assessment available.	n/a	
	XR	XR	n/a	n/a	n/a		n/a	Biotope code not found.		
	LR.MLR.BF.Fser.R	LR.MLR.BF.Fser.R	Fucus serratus and red seaweeds on moderately exposed lower eulittoral rock	n/a	n/a		n/a	No assessment available.	n/a	
Sheltered littoral rock (SLR) (no data)	LR.SLR	LR.SLR	Sheltered littoral rock	n/a	n/a		n/a	No single assessment available. Code contains many biotopes.	n/a	
Littoral rock with dense fucoids (Fser.Fser; Pel; Fspi; Asc.Asc)	LR.MLR.BF.Fser.Fser	LR.MLR.BF.Fser.Fser		n/a	n/a		n/a	No information available for this biotope.	4	
	LR.SLR.F.Pel	LR.SLR.F.Pel	Pelvetia canaliculata on sheltered littoral fringe rock	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=322&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\MarLIN_Web\marlin_final_design\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.		
	LR.SLR.F.Fspi	LR.SLR.F.Fspi	Fucus spiralis on moderately exposed to very sheltered upper eulittoral rock	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=307&code=1997	No assessment available.		
	LR.SLR.F.Asc.Asc	LR.SLR.F.Asc	Ascophyllum nodosum on very sheltered mid eulittoral rock	High	4		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=4&code=1997	No assessment available for LR.SLR.F.Asc.Asc. Sensitivity for wider LR.SLR.F.Asc biotope code.		
Littoral muddy sand (Lan; Zmar) with fucoids on mixed substrata (FserX)	LS.LGS.S.Lan	LS.LGS.S.Lan	Dense Lanice conchilega in tide-swept lower shore sand	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=195&code=1997		3	
	SS.IMS.Sgr.Zmar	SS.IMS.Sgr.Zmar	Zostera marina/angustifolia beds in lower shore or infralittoral clean or muddy sand	Moderate	3		http://www.marlin.ac.uk/speciessensitivity.php?speciesID=4600			
	LR.SLR.FX.FserX	LR.SLR.FX.FserX.T	Fucus serratus with sponges, ascidians and red seaweeds on tide-swept lower eulittoral mixed substrata	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=221&code=	No assessment available for LR.SLR.FX.FserX. Sensitivity assessment for LR.SLR.FX.FserX.T available within biotope.		

Littoral sand and gravel (LGS; Lan)	LS.LGS	LS.LGS	Littoral sand and gravel	n/a	n/a		n/a	No single assessment available. Code contains many biotopes.	2	
	LS.LGS.S.Lan	LS.LGS.S.Lan	Dense Lanice conchilega in tide-swept lower shore sand	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=195&code=1997			
Littoral sandy mud (HedMac; HedMac.Are)	LS.LMU.SMu.HedMac	LS.LMU.SMu.HedMac	Hediste diversicolor and Macoma balthica in sandy mud shores	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=209&code=1997		2	
	LS.LMU.SMu.HedMac.Are	LS.LMU.SMu.HedMac.Are	Hediste diversicolor, Macoma balthica and Arenicola marina in muddy sand or sandy mud shores	n/a	n/a		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=196&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\MarLIN_Web\marlin_final_design\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.		
Sheltered littoral bedrock, mixed substrata and lower shore mud (Pel; AscX; HedScr)	LR.SLR.F.Pel	LR.SLR.F.Pel	Pelvetia canaliculata on sheltered littoral fringe rock	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=322&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\MarLIN_Web\marlin_final_design\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.	4	
	LR.SLR.F.Asc.X	LR.SLR.F.Asc	Ascophyllum nodosum on very sheltered mid eulittoral rock	High	4		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=4&code=1997	No assessment available for LR.SLR.F.Asc.X. Sensitivity for wider LR.SLR.F.Asc biotope code.		
	LS.LMU.Mu.HedScr	LS.LMU.Mu.HedScr	Hediste diversicolor and Scrobicularia plana in reduced salinity mud shores	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=331&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\MarLIN_Web\marlin_final_design\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.		
Soft mud shores (Mu; HedScr)	LS.LMU.Mu	LS.LMU.Mu	Soft mud shores	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=67&code=	No assessment available.		
	LS.LMU.Mu.HedScr	LS.LMU.Mu.HedScr	Hediste diversicolor and Scrobicularia plana in reduced salinity mud shores	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=331&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\MarLIN_Web\marlin_final_design\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.		
Sublittoral rock with *Laminaria hyperborea* (Lhyp.Ft; XKScrR)	IR.MIR.KR.Lhyp.Ft	IR.MIR.KR.Lhyp.Ft	Laminaria hyperborea forest and foliose red seaweeds on moderately exposed upper infralittoral rock	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=159&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\MarLIN_Web\marlin_final_design\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.		
	IR.MIR.SedK.XKScrR	IR.MIR.SedK.XKScrR	Mixed kelps with scour-tolerant and opportunistic foliose red seaweeds on scoured or sand-covered infralittoral rock	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=183&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\\\\MarLIN_Web\\\\marlin_final_design\\\\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.		
Sublittoral rock with Laminaria hyperborea (Lhyp.Ft; XKScrR) and sublittoral gravel and sand (FaG; Sell; FaS; Lcon; FabMag)	IR.MIR.KR.Lhyp.Ft	IR.MIR.KR.Lhyp.Ft	Laminaria hyperborea forest and foliose red seaweeds on moderately exposed upper infralittoral rock	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=159&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\MarLIN_Web\marlin_final_design\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.	3	
	IR.MIR.SedK.XKScrR	IR.MIR.SedK.XKScrR	Mixed kelps with scour-tolerant and opportunistic foliose red seaweeds on scoured or sand-covered infralittoral rock	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=183&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\\\\MarLIN_Web\\\\marlin_final_design\\\\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.		
	SS.IGS.FaG	SS.IGS.FaG.HalEdw	Halcampa chrysanthellum and Edwardsia timida on sublittoral clean stone gravel	Moderate	3		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=80&code=1997	No assessment availble for SS.IGS.FaG. Relevant assessment used for SS.IGS.FaG.HalEdw biotope nested within SS.IGS.FaG		
	SS.IGS.Sell	SS.IGS.Sell	Spisula elliptica in infralittoral fine sand	n/a	n/a			No information available for this biotope.		
	SS.IGS.FaS	SS.IGS.FaS.Lcon	Dense Lanice conchilega and other polychaetes in tide-swept infralittoral sand	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=116&code=1997#	Three sensitivity assessments available relevant to the SS.IGS.FaS biotope. Therefore precautionary principle adopted and most sensitive biotope assigned SS.IGS.FaS.Lcon. (SS.IGS.FaS.FabMag also Low; SS.IGS.FaS.NcirBat Very Low)		

	SS.IGS.FaS.Lcon	SS.IGS.FaS.Lcon	Dense Lanice conchilega and other polychaetes in tide-swept infralittoral sand	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=116&code=1997#			
	SS.IGS.FaS.FabMag	SS.IGS.FaS.FabMag	Fabulina fabula and Magelona mirabilis with venerid bivalves in infralittoral compacted fine sand	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=142&code=1997			
Sublittoral gravel/ sand with maerl beds (Phy.R; Lcor)	SS.IGS.Mrl.Phy.R	SS.IGS.Mrl.Phy.R	Phymatolithon calcareum maerl beds with red seaweeds in shallow infralittoral clean gravel or coarse sand	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=172&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\\MarLIN_Web\\marlin_final_design\\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.		
	SS.IMX.MrlMx.Lcor	SS.IMX.MrlMx.Lcor	Lithothamnion corallioides maerl beds on infralittoral muddy gravel	n/a	n/a	n/a	http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=219&code=%3Cbr%20/%3E%3Cb%3ENotice%3C/b%3E:%20%20Undefined%20index:%20%20code%20in%20%3Cb%3EC:\\MarLIN_Web\\marlin_final_design\\habitatsbasicinfo.php%3C/b%3E%20on%20line%20%3Cb%3E140%3C/b%3E%3Cbr%20/%3E	No assessment available.		
Sublittoral gravel and sand (FaG; Sell; FaS; Lcon; FabMag)	SS.IGS.FaG	SS.IGS.FaG.HalEdw	Halcampa chrysanthellum and Edwardsia timida on sublittoral clean stone gravel	Moderate	3		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=80&code=1997	No assessment availble for SS.IGS.FaG. Relevant assessment used for SS.IGS.FaG.HalEdw biotope nested within SS.IGS.FaG	3	
	SS.IGS.Sell	SS.IGS.Sell	Spisula elliptica in infralittoral fine sand	n/a	n/a			No information available for this biotope.		
	SS.IGS.FaS	SS.IGS.FaS.Lcon	Dense Lanice conchilega and other polychaetes in tide-swept infralittoral sand	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=116&code=1997#	Three sensitivity assessments available relevant to the SS.IGS.FaS biotope. Therefore precautionary principle adopted and most sensitive biotope assigned SS.IGS.FaS.Lcon. (SS.IGS.FaS.FabMag also Low; SS.IGS.FaS.NcirBat Very Low)		
	SS.IGS.FaS.Lcon	SS.IGS.FaS.Lcon	Dense Lanice conchilega and other polychaetes in tide-swept infralittoral sand	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=116&code=1997#			
	SS.IGS.FaS.FabMag	SS.IGS.FaS.FabMag	Fabulina fabula and Magelona mirabilis with venerid bivalves in infralittoral compacted fine sand	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=142&code=1997			
Lower shore or sublittoral sediment with *Zostera marina* beds (Zmar) and *Lanice* (Lan)	SS.IMS.Sgr.Zmar	SS.IMS.Sgr.Zmar	Zostera marina/angustifolia beds in lower shore or infralittoral clean or muddy sand	Moderate	3		http://www.marlin.ac.uk/speciessensitivity.php?speciesID=4600		3	
	LS.LGS.S.Lan	LS.LGS.S.Lan	Dense Lanice conchilega in tide-swept lower shore sand	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=195&code=1997			
Sublittoral muddy sand (FaMS; EcorEns; LSacX)	SS.IMS.FaMS	SS.IMS.FaMS.EcorEns	Echinocardium cordatum and Ensis spp. in lower shore or shallow sublittoral muddy fine sand	Moderate	3		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=124&code=1997	Three sensitivity assessments available relevant to the SS.IMS.FaMS biotope. Therefore precautionary principle adopted and most senitive biotope assigned SS.IMS.FaMS.EcorEns	3	
	SS.SSa.IMuSa.EcorEns	SS.SSa.IMuSa.EcorEns	Echinocardium cordatum and Ensis spp. in lower shore or shallow sublittoral muddy fine sand	Moderate	3		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=124&code=2004			
Estuarine sublittoral mud (AphTub)	SS.IMU.EstMu.AphTub	SS.IMU.EstMu.AphTub	Aphelochaeta marioni and Tubificoides sp p. in variable salinity infralittoral mud	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=201&code=1997		2	
Sublittoral mixed sediment (FaMx; VsenMtru; EstMx)	SS.IMX.FaMx	SS.IMX.FaMx.VsenMtru	Venerupis senegalensis and Mya truncata in lower shore or infralittoral muddy gravel	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=354&code=1997	Two sensitivity assessments relevant to SS.IMX.FaMx biotope. SS.IMX.FaMx.VsenMtru used as SS.IMX.FaMx.Lim although higher sensitivity represents a habitat not recorded in the Helford.	2	

SS.IMX.FaMx.VsenMtru	SS.IMX.FaMx.VsenMtru	Venerupis senegalensis and Mya truncata in lower shore or infralittoral muddy gravel	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=354&code=1997	Two sensitivity assessments relevant to SS.IMX.FaMx biotope. SS.IMX.FaMx.VsenMtru used as SS.IMX.FaMx.Lim although higher sensitivity represents a habitat not recorded in the Helford.	
SS.IMX.EstMx	SS.IMX.EstMx	Estuarine sublittoral mixed sediments	Low	2		http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=52&code=1997 ; http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=114&code=1997 ; http://www.marlin.ac.uk/habitatsensitivity.php?habitatid=36&code=1997	No assessment available for SS.IMX.EstMx. Sensitivity assigned using assessments for SS.IMX.EstMx.CreAph; SS.IMX.EstMx.PolMtru; SS.IMX.EstMx.MytV (all Low) within EstMx biotope.	

Appendix 17: Glossary

Abiotic – an abiotic factor is a non-living chemical or physical factor (e.g. light or temperature).

Analysis of variance (ANOVA) – a statistical method for comparing two or more means and assessing the contribution of each variable to the variation in the samples.

Analysis of covariance (ANCOVA) – a statistical method that aims to increase the precision of comparisons by accounting for variation due to known variables.

Benthos – the seabed.

Benthic – relating to the bottom of a body of water, in marine studies this is associated with the seabed.

Biodiversity measures – a series of measures which describe the biodiversity of the samples. These may include the total abundance of organisms, the species diversity and a range of scientifically calculated measures e.g. Shannon-Weiner Diversity Index.

Biotic – a biotic factor is a living component of an ecosystem which exerts an influence on another organism.

Covariate – a covariate is a variable within a study which may correlate with the primary studied variable.

Elutriate – a method for separating organisms from sediment prior to sieving. Water is added to the sample and the sample is stirred to separate the infauna (which floats) and the sediment (which sinks). When using this method the sediment must be checked for large, heavy organisms (e.g. bivalves) which may be missed.

Epifauna/ Epifaunal – the organisms that live on the surface of the sediment/ seabed.

Granulometry – the computation of the size distribution of the particles within sediment.

Ground chain – see thrash chain.

Infauna/ Infaunal – the organisms that live within the sediment of the seabed.

Multi-dimensional scaling (MDS) – statistical techniques used to visualise and explore similarities in data.

Multivariate statistics – statistical techniques that analyse multiple variables of interest (e.g. abundances of multiple taxa within a community).

PRIMER 6 – a widely used standard statistical analysis package for marine biological scientific studies.

PERMANOVA – an add-on to the PRIMER 6 package. It extends PRIMER to allow analysis of data from more complex sampling structures and experimental designs.

Riser – the lighter chain that rises from the thrash chain to the mooring buoy. This chain rises and falls with the movement of the vessel above.

Taxonomic/ Taxonomy – the scientific classification of organisms.

Taxa – a taxonomic group at any rank of the taxonomic hierarchy (e.g. phyla, family, genus, species).

Thrash chain – the large heavy chain that forms part of the mooring infrastructure between the mooring block and the riser chain.

Univariate statistics – statistical techniques that analyse a single variable of interest (e.g. organism abundance).

Fal and Helford Recreational Boating Study

Chapter 2:

Marinas

Ecological impact on infaunal communities due to direct, physical disturbance from marina infrastructure

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The Fal and Helford Recreational Boating Study Project Partners are:

Falmouth Harbour Commissioners

Cornwall Council

Natural England

University of Plymouth

Environment Agency

A&P Ports

St. Mawes Pier and Harbour Company

Truro and Penryn Harbour Authority

Duchy of Cornwall

Port Pendennis Marina

Version	*Distribution*
Version 1.0	Distributed to project representatives and scientific advisors for comment.
Version 1.1	Distributed to all Project Partners.

Executive Summary

Introduction

The Fal marina study forms part of the wider Fal and Helford Recreational Boating Environmental Assessment and complements information already compiled in the Fal and Helford mooring study (Chapter 1: Ecological impact on infaunal communities due to direct, physical disturbance from mooring infrastructure). This marina study compared infaunal communities in areas subject to physical disturbance from the marina anchorage system (pilings or anchor chains) with internal control areas located within the marina dredged footprint and external control areas of comparable habitat outside the marina footprint. It addresses several objectives of the wider Environmental Assessment, including describing the environmental impact associated with marina anchorage systems, identifying infrastructure within the study area and proposing management recommendations and avenues of future study. The study was not designed in a manner that would allow calculation of the overall extent of impacts associated with marinas.

The Fal and Helford estuaries are highly biologically diverse, of socio-economic importance and of conservation interest. Both estuaries are extremely popular for water-based recreation; with at least 23 marinas and pontoon systems within the Fal and Helford estuaries (Natural England, 2011). A wide range of anthropogenic impacts on marine ecosystems are associated with marinas, including physical disturbances, chemical inputs and biological invasions. Previous studies have focussed on chemical inputs, for example antifoul chemicals, and more recently the effects of shading and the introduction of non-native species. Less work has focussed on physical disturbance from the marina infrastructure on the adjacent sediments. Anchor chains create disturbance as they move relative to the tide and the movement of the pontoons above. Pilings do not physically scour the seabed directly; however previous studies have identified impacted areas around them and the surrounding sediment may be scoured as a result of modified water flow. The two marinas studied, Falmouth Yacht Haven and Port Pendennis, are situated within the Falmouth Inner Harbour area of the Fal estuary, Cornwall. Both are comparable in depth and habitat and both marinas were dredged when built.

Methods

Infaunal samples were taken using a hand-operable Van Veen grab. Within each marina samples were collected across four treatments; two sites alongside marina infrastructure (site 1 and site 2), an internal control site, within the dredged footprint, and an external control site, located close to the marinas in areas of minimal disturbance. Replicate samples were collected within blocks of three around the marina infrastructure or in separate blocks of three within the control sites. All samples were elutriated, preserved with 75% IMS and stained with Rose Bengal. Sub-sampling was employed to ensure all samples could be processed in the time available. Specimens were identified to intermediate taxonomic level (usually family) and the abundances recorded. Sediment cores were collected alongside the infaunal samples to determine the sediment particle (grain) size and organic content.

A series of biodiversity measures were calculated (overall abundance, species richness, Simpson's Index and the abundance of individual taxonomic groups) from the infaunal data and these were analysed to determine the significance of treatment (site 1, site 2, internal control, external control) on each measure. Similarities were investigated at infaunal community level and this data was again analysed to determine the significance of any impact on the benthos. Sediment data was analysed to determine the influence of infrastructure and the wider marina on sediment characteristics and the influence of these characteristics on the infaunal community.

Results

No differences in sediment characteristics were observed between treatments and biodiversity measures of abundance and species richness did not detect any significant influence. Simpson's Index did indicate a significant influence of treatment but only Falmouth Yacht Haven indicated any influence of treatment attributable specifically to the marina infrastructure. Abundances of individual taxonomic groups indicated a significant influence of treatment on the abundance of Crustacea (crabs, shrimp, amphipods, isopods), with crustacean abundances in the marina treatments (1, 2, internal control) significantly reduced in comparison with the external controls. No other taxonomic groups analysed indicated significant influences on abundance. A consistent, statistically significant difference was present across several biodiversity measures between marina samples (1, 2, internal control) and the external controls.

Multivariate analysis of the infaunal community data indicated a significant influence of treatment in determining the composition present. Of the four treatments, the external controls showed greatest homogeneity (similarity) between samples and planned contrasts confirmed a significant difference between the external control site and the marina sites. Contrasts of sites 1 and 2 and the internal control site did not identify any significant difference.

Conclusions

Sediment analysis did not indicate a significant influence of physical disturbance from the marina infrastructure or the wider influence of the marina on the sediment characteristics. Whilst these results indicate marina infrastructure does not significantly influence sediment characteristics, this work was not the primary focus of this study and care should be taken in this interpretation. Wider chemical characteristics of the sediment (e.g. antifoul chemicals) were not measured as part of this study but previous studies have identified elevated levels within marinas.

Although a physical disturbance of the marina infrastructure was visible *in situ*, statistical analysis of the infaunal data suggests if present this is only of small magnitude and extent. The results do indicate a wider impact of the marina on infaunal biodiversity; significant differences are present between marina treatments (1, 2, internal control) and the external controls. Samples within the marina treatments also exhibited greater variability, a trait indicative of an impacted ecosystem. The reduction in crustacean abundance does not have an immediately apparent explanation; this could potentially be a response to physical changes, chemical factors, biological interactions or a combination of several different influences.

The design of this study did not allow an area of impact to be calculated; however a rough comparison of the marina dredged footprints and moorings areas indicates a marina may moor at least twice the number of vessels in the same physical area, this would concentrate any impact into a smaller area. Recommendations to minimise the impacts of marinas include siting marinas, where practical, in ecosystems that have been previously depleted (such as commercial sites), maximising compliance with current environmental initiatives and minimising pressure on local ecosystems by reducing additional impacts.

Contents

1 Introduction

1.1 Project Background and Study Objectives

This marina study was conducted as part of a wider Fal and Helford Recreational Boating Environmental Assessment. It forms part of the Environmental Assessment and complements information already compiled in the Fal and Helford Recreational Boating Study: Chapter 1. Chapter 1 consisted of a scientific study to quantify, describe and map the environmental impact of direct physical disturbance associated with single block, sub-tidal, permanent moorings. A detailed introduction to the background of the Fal and Helford Recreational Boating Environmental Assessment, its remit and origins are included in the Fal and Helford Recreational Boating Study: Chapter 1 (Section 1.1). This section also includes details of the wider objectives of the Recreational Boating Environmental Assessment; these are referred to in *blue* below.

The remit of the marina study was condensed to ensure a viable study despite operational and time limitations. The study compared infaunal communities in areas in, around and outside marinas to identify influence of the direct, physical impact of infrastructure and additional wider marina impacts. The primary aim was to identify and describe the environmental impact associated with marina anchorage systems (*Objective 2*). The study also identified marina types, layouts and footprints within the study area (*Objective 1*) and, where possible, identified potential management recommendations (*Objective 3*) and identified areas for future study (*Objective 5*). As graduated distances were not incorporated into the study design, this research was not capable of calculating the overall extent of ecological impact for marinas, as was completed in Chapter 1.

1.2 Established Marina Impacts

A wide range of anthropogenic impacts on marine ecosystems are associated with marinas. Direct impacts include physical disturbance from anchorage systems, modification of habitats and the introduction of novel substrate, modification of water currents, reduced wave energy, light reduction, sediment disturbance and leachate from boats and infrastructure (Albanis, Lambropoulou, Sakkas, & Konstantinou, 2002; Brooks, 1996; S. Connell, 2000; S. D. Connell, 2001; Holloway & Connell, 2006). All of these may occur during the lifespan of the marina and some impacts may be elevated during the construction phases (summarised in Neilly, 2011). Neilly (2011) also identifies the tendency for studies of environmental quality within marinas to focus on inputs into the environment, including impacts from fuelling operations, engine maintenance, zinc from sacrificial anodes, antifouling chemicals, bilge water and sewage; all of which are likely to be present in higher concentrations where there are high concentrations of vessels (Claisse & Alzieu, 1993; Jones & Bolam, 2007; Langston, Burt, & Mingjiang, 1987; Young, Alexander, & Mcdermott-ehrlich, 1979). Work was established early on to investigate many of the depositional sources of pollution within harbours (Young et al., 1979) and many of these inputs are currently being addressed through voluntary schemes and preventative guidelines, including the Green Blue's Self-assessment Environmental Toolkit[1], the British Marine Federation's Environmental Code of Practice[2] and the Port Waste Management Planning Guide (Royal Yachting Association & British Marine Federation, 2003).

More recently the potential impact of shading from marine structures has received greater attention; this may be primarily as the source of this impact is reasonably easily addressed in marina design or refit (Fresh, Wyllie-Eecheverria, Wyllie-Eecheverria, & Williams, 2006; T M Glasby, 1999; Ono et al., 2010). Marinas have also been recognised as important hotspots in the transfer and spread of non-native species (Arenas et al., 2006; Boudouresque & Verlaque, 2005; Brock-morgan, 2010; Eno, Clark, & Sanderson, 1997; Tim M. Glasby, Connell,

[1] Details available at www.marinetoolkit.co.uk
[2] Details available at www.britishmarine.co.uk/other/environmental_code_of_practice.aspx

Holloway, & Hewitt, 2006). Previous studies have investigated marina impacts on nearby habitats (Di Franco et al., 2011) and epifaunal assemblages (T. Glasby, 1999; Turner et al., 1997); however relatively few studies have looked at differences in infaunal assemblages around marinas. Of the limited work on infaunal assemblages identified, previous studies have detected reduced abundances of crustaceans, a decreased number of taxa, greater dis-similarity and greater variability in the number of taxa present in areas with pontoons present (Lindegarth, 2001).

1.3 Physical Impacts of Marinas

Marinas are not generally considered to disturb soft sediment in the same manner as moorings, by creating a 'scour' or depression in the sediment as they move relative to wind and tide; however, dependent upon the type of anchorage system used, the potential for a similar direct physical impact is present. Two types of anchorage system are present within the Fal estuary; pontoons attached to large pilings (posts) driven into the seabed or pontoons held in place by a series of anchor points, mostly traditional chain risers. Falmouth Yacht Haven marina has a chain anchor system and Port Pendennis marina uses metal pilings.

An anchor system utilising chain risers may have a similar effect to large-scale moorings as the chains connecting the pontoons to the anchors move on the seabed with tidal changes and the influence of the wind and currents (Appendix 1: ROV screen grab). A section of anchor chain, several metres long, rises and falls with the movement of the pontoons on the tide creating a visible physical disturbance in the sediment (pers. obs. Holly Latham). The remainder of the anchor chains remain stationary on the seabed under normal operating conditions (pers. comm. Captain Mark Sansom). An exception to these circumstances is during periods of very strong winds which push the pontoons and result in drag along a larger section of chain.

A marina piling system consists of stationary upright pilings and exerts no direct physical disturbance on the seabed; however they may cause substantial indirect scour through altering the hydrography around the piling (Neilly, 2011). Previous studies have also indicated reduced regrowth of seagrass around dock pilings leaving bare areas of seabed, between 89-198cm diameter, around piling bases and indicating that re-growth is potentially affected by the presence of pilings or associated leachate (Shafer and Robinson 2001 in Neilly, 2011).

1.4 Natural and Background Disturbance

Disturbance is a natural factor within ecosystems, modifying the environment and influencing the communities that inhabit them. An introduction into natural variation, the role of disturbance within marine ecosystems and the importance of the frequency, type and extent of disturbance have been addressed previously in the Fal and Helford Recreational Boating Study: Chapter 1 (Sections 1.5 and 1.6). An intermediate level of disturbance within an ecosystem is generally considered to result in the highest diversity through creating a mosaic of communities; however large, frequent or cumulative disturbances can change communities, reduce biodiversity or change ecological functioning. As discussed in Chapter 1, physical impacts such as those investigated as part of this study, may be indistinguishable in terms of their actual effect on the seabed to those experienced naturally in marine ecosystems.

2 Study Location

A full introduction to the wider environs and character of the Fal estuary is included in the Fal and Helford Recreational Boating Study: Chapter 1 (Section 1.3) and is not repeated here. The two marinas used in this study, Falmouth Yacht Haven and Port Pendennis marina, are both situated within the Falmouth Inner Harbour area of the Fal estuary, Cornwall. Both marinas are of comparable depth (1-3m CD), located on similar muddy gravel sediments and both have both been previously dredged to increase the draft available within the berths. Falmouth Yacht Haven was capital dredged in 1997 (pers. comm. Captain Mark Sansom); Port Pendennis in 1999, with some maintenance dredging in 2007 (pers. Comm. Mike Webb). The areas dredged are clearly visible within bathymetric data of Falmouth Inner Harbour (Figure 1). Falmouth Yacht Haven marina is held in position by 39 anchor chains, made of 2" diameter chain links, which run in opposing directions for up to 95 metres and are anchored at the end (Appendix 2: Falmouth Yacht Haven). Port Pendennis marina is piled; the pontoons rise and fall alongside metal pilings driven into the seabed. Port Pendennis has an approximate dredged footprint of 25,000m^2, accommodating around 80 vessels. Falmouth Yacht Haven is smaller, approximately 13,000m^2, but is capable of accommodating a similar number of vessels which are generally more transient (pers. comm. Barry Buist).

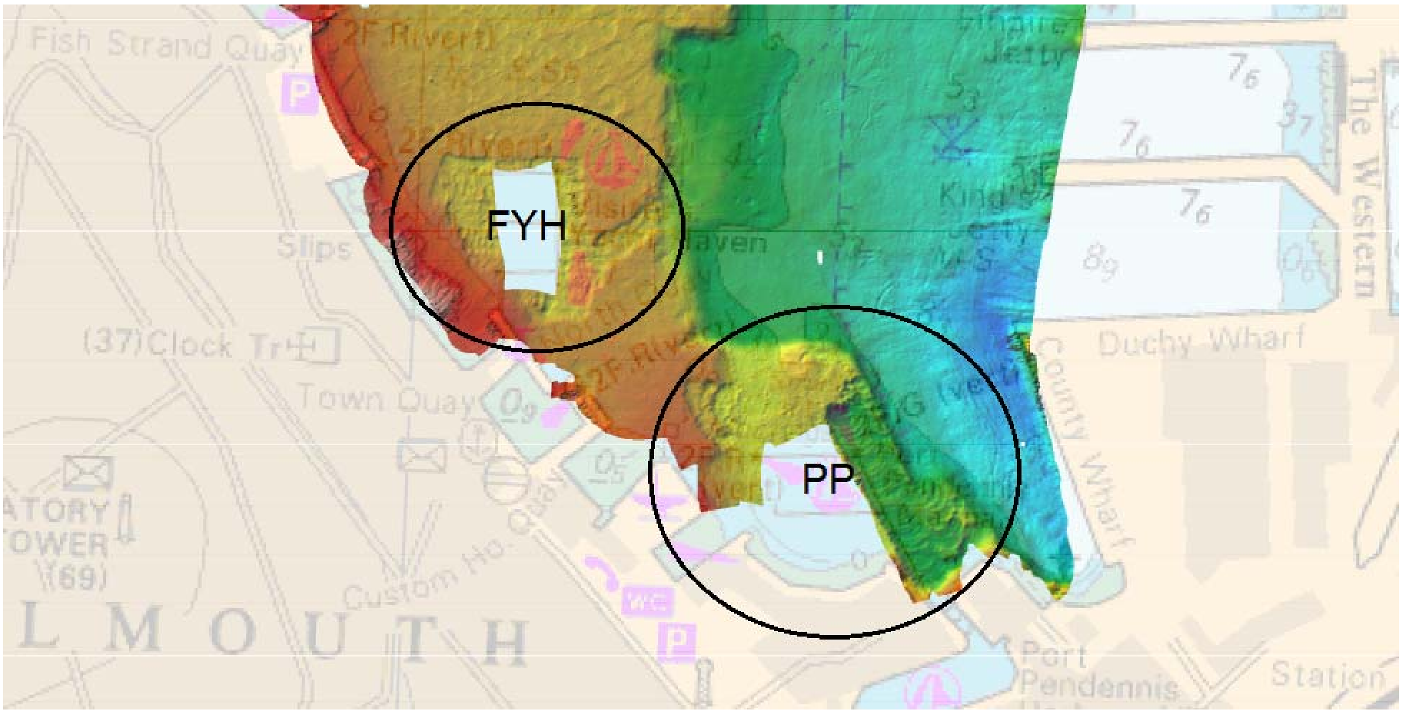

Figure 1 Bathymetry of the Falmouth Inner Harbour area showing the dredged areas around Falmouth Yacht Haven (FYH) and Port Pendennis (PP) marinas. Source: Falmouth Harbour Commissioners 2010 Coastline Survey. To indicate scale within this figure, the dredged area of Port Pendennis (PP) is approximately 25,000m^2. ©Crown Copyright and/or database rights. Reproduced by permission of the Controller of Her Majesty's Stationery Office and the UK Hydrographic Office (www.ukho.gov.uk).

3 Methodology

3.1 Infaunal Sample Collection

Infaunal samples were collected from the marinas using a hand-operable 0.01m^2 Van Veen grab[3], which allowed remote sampling of the marina infauna alongside the mooring infrastructure from the pontoons above. All grab samples were collected from Falmouth Yacht Haven (FYH) and Port Pendennis (PP) marinas between the 21st and 23rd September 2011 with the assistance of Harriet Knowles, Beth Wills, Ross Bullimore and Matt Ormond. External control samples and the FYH internal controls were collected from the FHC launch, "Motorboat".

The marina study contained 4 treatments (groups); these were split into sites physically impacted by the marina infrastructure, within the influence of the marina and non-impacted controls. Within each marina two physically impacted sites were chosen (site 1 and site 2). In Falmouth Yacht Haven sites were located at the point at which the anchor chains leave the seabed and physical disturbance of the sediment was apparent. In Port Pendennis the sites were located around the pilings. An internal control site was located in each marina, representative of the sediments within the dredged footprint of the marina but not physically influenced by the anchorage system. An external control site was positioned close to the marina in an area of minimal disturbance. Three replicate samples were collected within blocks of three around chains or pilings inside the physically impacted treatments. For the controls the blocks were groups of three replicate samples within the control site.

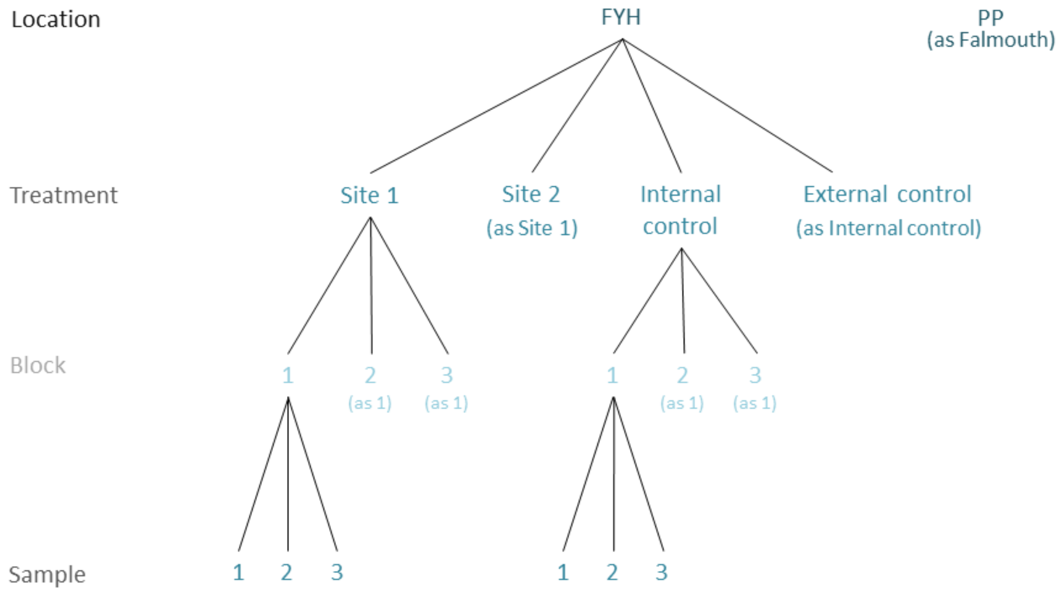

Figure 2 The experimental design for the marina study. Within each marina there were 4 treatments: 2 impacted (site 1 and 2) and 2 controls (internal and external). Within each of the treatments there were 3 blocks and each block consists of 3 replicate samples. The internal control is situated within the dredged footprint of the marina and represents the marina environment away from the physical impact of the anchorage system. The external control is located outside of the marina footprint and is subject to minimal disturbance while remaining close to the location of the marina. Treatments and blocks specified as '(as _)' indicate that lower levels on these branches are identical to those indicated elsewhere in the diagram. This diagram shows Falmouth, the design for Port Pendennis was identical.

Once collected, the infaunal grab samples were processed in the same manner as the infaunal core samples for the mooring study; for full details see the Fal and Helford Recreational Boating Study: Chapter 1 (Section 4.2). All samples were elutriated, preserved in 75% IMS and stained with Rose Bengal. The sub-sampling technique used for the moorings study was again employed on the marina samples to allow all samples to be processed within the time

[3] Provided by Ecospan Environmental Ltd.

available. Specimens were identified to intermediate taxonomic level (mostly family) and the abundances recorded. Nematodes (phylum Nematoda) were not recorded; only large specimens would be sampled with the macrofauna (0.5mm mesh) and this would not be representative of the actual abundance of this group. This study did not sample meiofauna.

3.2 Particle Size and Organic Content Samples

100ml sediment cores were collected at all infaunal sample locations to determine the sediment particle (grain) size and organic carbon content. An additional grab sample was collected within each sampling block and this was used to extract the sediment core. The procedures for storage, processing and analysis of the marina sediment samples mirrored those used for the moorings samples, outlined in the Fal and Helford Recreational Boating Study: Chapter 1 (Section 4.3). As far as practical, the collection of the particle size and organic carbon content samples followed guidelines outlined in NMBAQC's Best Practice Guidance: Particle Size Analysis (PSA) for Supporting Biological Analysis (Mason, 2011).

3.3 Statistical Analysis

3.3.1 Sediment Analysis

Sediment composition is considered to be an important factor influencing the distribution of infaunal organisms within the seabed, potentially through influences on locomotion or burrowing activities (Frost, Attrill, Rowden, & Foggo, 2004; Probert, 1984; Sanders, 1958) and sediment characteristics were again included as part of the analysis for this study. As with the sediment data in the moorings study, laser data and sieve data were recombined to give final adjusted size (µm) values and basic granulometry statistics were calculated (Chapter 1, Section 4.3). The particle size data was analysed using GRADISTAT (Version 14.0) to give the mean method of moments (logarithmic ϕ) for all samples (Blott & Pye, 2001; Mason, 2011). This parameter was again chosen for its consideration of the entire sample population (Blott & Pye, 2001). A second measure of particle size, principle component analysis (PCA) was also employed. This analysis accounts for a range of variables (skew, kurtosis) rather than just the mean value. Principle component statistics were calculated in PRIMER based on the mean method of moments (logarithmic ϕ) output from GRADISTAT.

3.3.2 Analysis of Biodiversity Measures

To assess the impact of the marinas on infaunal biodiversity the following measures were calculated. Abundance (N), the total number of organisms in each sample; species richness (S), the total number of taxa represented in the sample, Shannon-Wiener and Simpson's Indexes, were all calculated using the DIVERSE routine (PRIMER 6). Shannon-Wiener and Simpson's Indexes both give a combined measure of the abundance and diversity of samples. Simpson's Index is less prone to artefacts given the small sample size and allows the signature of abundant species, such as the distinctly dominant Cirratulidae, Capitellidae and Cossuridae to have a greater influence in the analysis (Lande, DeVries, & Walla, 2000). Further measures of biodiversity were calculated, to interrogate abundances of the main taxonomic groups represented in the infaunal samples. These included abundances for annelids, polychaetes, crustaceans, amphipods, molluscs, bivalves and gastropods.

As in the mooring analyses, the influences of location and treatment on the biodiversity measures outlined above were assessed using generalised linear models (GLM) within SPSS 19 (IBM, New York)(Chapter 1, Section 4.4.2). Univariate analysis of variance (ANOVA) was used to identify the significance of the factors (treatment, location) on the abundance and species richness of samples. To compare the influence of distance on the biodiversity measures at different spatial scales, a series of a priori contrasts were used based upon estimated marginal means and Tukey's least significant difference (LSD). Standardised residuals were checked subsequent to all analyses to ensure all analytical assumptions for the GLM model were upheld.

.3.3 Multivariate Community Analysis

All multivariate statistics were performed using PRIMER 6 with the PERMANOVA extension (PRIMER 6 version 6.1.13, PERMANOVA+ version 1.0.3, PRIMER-E, Plymouth, UK). Datasets were fourth root transformed to reduce the effect of occasional, highly abundant species within the assemblage. Bray-Curtis resemblance matrices were constructed on the transformed data. Non-metric multi-dimensional scaling (MDS) plots of the whole data set were used to visualise similarities between the infaunal communities using PRIMER.

A permutational ANOVA (PERMANOVA) was used to determine if the infaunal community was affected by physical disturbance from marina infrastructure. A three factor PERMANOVA design was created using the factors location, treatment (nested within location) and block (nested within treatment). PERMANOVA was run in a Type III (partial SS) approach using unrestricted permutation of residuals and 10,000 permutations. The PERMANOVA analysis was also ran including the taxonomic group Polychaeta Indet. to check the potential influence of their inclusion. Planned pairwise comparisons maintaining the separate locations were not completed due to the lack of power (sample repetition) within the experimental design. A PERMANOVA design was used to test contrasts between various treatments. Locations were pooled and planned contrasts were completed within PERMANOVA to contrast site 1, site 2 and internal controls and site 1, site 2, internal controls and external controls to tease out the location of differences in the infaunal composition of the samples.

An analysis of covariance (ANCOVA) was employed within PERMANOVA to account for any potential influence of sediment particle size (mean method of moments (logarithmic ϕ) and principle component) on the infaunal community composition. PERMANOVA was run in a Type I (sequential SS) approach using permutation of residuals under a reduced model and 1,000 permutations.

4 Results

4.1 Sediment Analysis

Graphical visualisation of the raw data indicated no visible trend in the measured sediment characteristics. Univariate statistical analysis (ANOVA) of the sediment particle size and organic carbon content indicated no significant influence of treatment (site 1, site 2, internal control, external control), with P-values of P=0.147 and P=0.777 respectively. Additionally, neither variable indicated any significant large scale spatial variation between locations (FYH, PP) (particle size P=0.579, organic carbon P=0.205) (Appendix 3: Sediment characteristics ANOVA results tables and graphs).

4.2 Summary of Infaunal Taxa

Within the infaunal samples a total of 71 taxa were recorded across 10 phyla (Nematoda, Nemertea, Chaetognatha, Annelida, Arthropoda, Echinodermata, Cnidaria, Mollusca, Chordata, Porifera). Organisms within Nematoda (nematode worms), Nemertea (nemertean worms) and Chaetognatha (arrow worms) were recorded at phylum level only. Within Annelida (segmented worms) organisms were identified in 22 families, with the sub-class Oligochaeta recorded separately. Within Arthropoda organisms were split across 6 orders containing 21 families. This phylum also included Copepoda and Ostracoda, recorded at class level; caprellids, recorded as the superfamily Caprelloidea, and two broad groupings Tanaidacea Indet. (unidentified tanaids) and Amphipoda Indet. (unidentified amphipods). The only echinoderms (Echinodermata) encountered were very small brittlestars and these were recorded as Ophiuroidea Indet. Cnidarians (Cnidaria) included the family Edwardsiidae (burrowing anemones) and two indeterminate levels (Cnidaria Indet. and Actinaria Indet.). Mollusca (molluscs) split to the classes Bivalvia (bivalves) and Gastropoda (gastropods); Bivalvia contained 5 families and Bivalvia Indet.; Gastropoda contained a further 5 families. Phylum Chordata (chordates) contained only one representative, Ascidiidae (sea squirts). Porifera (sponges) contained a single family, Sycettidae. Full details of the families recorded are included in Appendix 4: List of Infaunal Taxa.

The mean abundance of the external control sites was 410, within the pooled mean abundance for the marinas considerably lower at 137 organisms per sample. Of the two marinas, Falmouth Yacht Haven had a higher mean abundance, 254, compared to 158 in Port Pendennis marina. Across both marinas, phylum Annelida was dominant with a mean abundance of 133. Within this phylum the most abundant families were Cirratulidae (mean abundance of 66) and Oligochaeta (40), followed by Capitellidae (14). Within the external controls phylum Annelida was still dominant with a mean abundance of 378; however the organisation of the most abundant families was different. Cirratulidae remained the most abundant with a mean of 256, this was then followed by Capitellidae (38), Cossuridae (33) and Oligochaeta (17). The mean abundance of Crustacea is 23 in the external controls and lower (3) in the marinas; of the marinas Falmouth Yacht Haven was higher (12) and Port Pendennis was lower (4). Mollusc (bivalves and gastropods) abundances were relatively low with a mean of 7 in the external controls and 1 in the marinas.

4.3 Biodiversity Measures

The biodiversity measures of abundance (number of organisms), species richness (number of taxa) and the Shannon-Wiener Index did not detect a significant influence at any level (Appendix 5: Abundance (N) ANOVA results table, Appendix 6: Species richness (S) ANOVA results table and Appendix 7: Shannon-Wiener Index (H'(Loge)) ANOVA results table). An analysis of variance (ANOVA) on the Simpson's Index data indicated a significant influence of treatment (site 1, site 2, internal control, external control) on the diversity of the samples (Table 1). This measure may better represent the patterns in the data as it is less prone to artefacts in small sample sizes and allows the signature of highly abundant species (such as the dominant Cirratulidae) to influence the analysis. Pairwise comparisons of pooled locations indicated some significance of physical impact, with differences between site 1 and the internal and external controls (Appendix 8: Simpsons Index pairwise comparisons (pooled locations)). Pairwise comparisons of the separated locations indicated differences lay between a mixture of treatments; site 1 and the internal control, and the internal control and the external control in Falmouth Yacht Haven; sites 1, 2 and the external control in Port Pendennis (Appendix 9: Simpsons Index pairwise comparisons (separate locations)).

Tests of Between-Subjects Effects

Dependent Variable:1-Lambda'

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Location	Hypothesis	.240	1	.240	.891	.415
	Error	.808	3.001	.269		
Treatment(Location)	Hypothesis	.809	3	.270	4.202	.046
	Error	.515	8.021	.064		
Block(Treatment)	Hypothesis	.136	8	.017	.264	.961
	Error	.513	8	.064		
Location * Block(Treatment)	Hypothesis	.513	8	.064	1.350	.243
	Error	2.234	47	.048		

Table 1 Table of results from the analysis of variance (ANOVA) on the Simpsons Index (1-Lambda') of the infaunal samples. Treatment (site 1, site 2, internal control, external control) was identified as a significant factor in influencing the abundance and diversity of the infaunal samples. Significance is indicated by grey rows.

Univariate (ANOVA) analysis on the abundances of individual taxonomic groups indicated a significant influence of treatment (site 1, site 2, internal control, external control) on the abundance of Crustacea (crabs, shrimp, amphipods, isopods) (Table 2). A graphical representation of the grouped abundance of Crustacea shows significantly reduced numbers of crustaceans in the sites located within the marinas. Pairwise comparisons indicate the source of the significance lies between the external control samples and sites 1, 2 and the internal controls (Appendix 16: Crustacea abundance pairwise comparisons) and that this is driven primarily by the Falmouth Yacht Haven samples. The taxonomic groupings of Annelida, Polychaeta, Amphipoda, Mollusca, Bivalvia and Gastropoda all indicated no significant influence on abundance (Appendix 10: Annelida abundances ANOVA results table, Appendix 11: Polychaeta abundance ANOVA results table, Appendix 12: Amphipoda abundance ANOVA results table, Appendix 13: Mollusca abundance ANOVA results table, Appendix 14: Bivalvia abundance ANOVA results table and Appendix 15: Gastropoda abundance ANOVA results table).

Tests of Between-Subjects Effects

Dependent Variable:Crustacea ABUNDANCE

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Location	Hypothesis	1152.000	1	1152.000	1.071	.377
	Error	3227.000	3	1075.667		
Treatment(Location)	Hypothesis	3227.000	3	1075.667	5.405	.025
	Error	1592.000	8	199.000		
Block(Treatment)	Hypothesis	1972.444	8	246.556	1.239	.385
	Error	1592.000	8	199.000		
Location * Block(Treatment)	Hypothesis	1592.000	8	199.000	2.044	.061
	Error	4674.000	48	97.375		

Table 2 Table of results from the analysis of variance (ANOVA) on the abundance of Crustacea within the infaunal samples. Treatment (site 1, site 2, internal control, external control) was identified as a significant factor in influencing Crustacea abundance within the infaunal samples. Significance is indicated by grey rows.

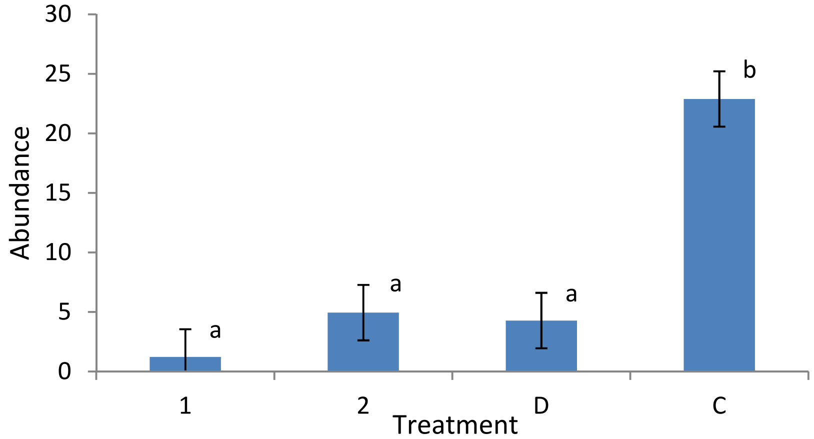

Figure 3 Graphical representation (estimated marginal means) of the abundance of Crustacea (crabs, shrimps, amphipods, isopods) in the infaunal samples. Sites 1 and 2 are influenced by the physical disturbance of the anchorage system, 'D' the internal control and 'C' the external control. A significant decrease in the abundance of crustaceans is visible in the samples within the marinas. Error bars are Standard Error. Significant differences are indicated by [a,b].

4.4 Community Analysis

PERMANOVA analysis of the infaunal data indicates a significant influence of treatment (site 1, site 2, internal control, external control) on the infaunal community present (Table 3). The analysis also indicates that the small scale spatial variation within the blocks (nested within treatment) is significant; however no significant difference was indicated between locations (FYH, PP). Pairwise tests did not identify significant pairwise comparisons, potentially as a result of low power.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Location	1	5983.2	5983.2	0.84343	0.4809	280
Treatment(Location)	6	42625	7104.1	2.1983	0.0043	9914
Block(Treatment(Location))	16	51773	3235.8	1.7868	0.0003	9811
Res	47	85114	1810.9			
Total	70	1.85E+05				

Table 3 Table of results of the PERMANOVA analysis on the infaunal assemblage data. The analysis identified treatment (nested within location) and block (nested within treatment, nested within location) as significant factors in influencing the composition of the assemblage present in the samples. Significance is indicated by grey rows.

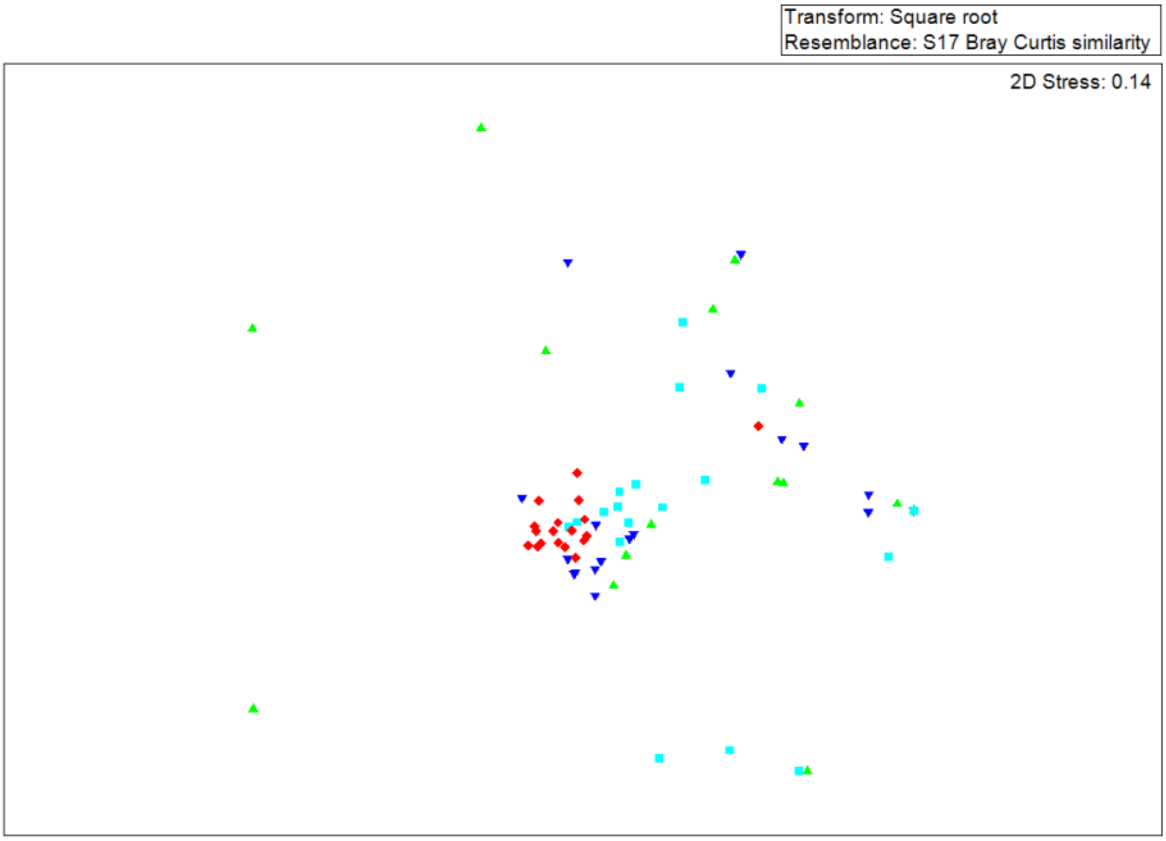

Figure 4 Multi-dimensional scaling (MDS) plot of the similarity of the infaunal communities across the different treatments (**green triangles** = site 1, **blue triangles** = site 2, **light blue squares** = internal control, **red diamonds** = external control). The external control samples group closely together indicating that the composition of the samples is similar. The single external control marker isolated from the remaining external control samples was identified as an incomplete sample (FYH CTZ 2 2).

An MDS plot of the infaunal data indicated greater similarity within the control samples (Figure 4) and this was consistent with the PRIMER similarity table output which indicated greater similarity within the control samples at both marina locations (Appendix 17: PRIMER similarity tables). Planned contrasts of the treatments were conducted within PERMANOVA to identify significant differences between sites. A contrast of sites 1 and 2 (influenced by the marina anchorage systems) and the internal controls indicated no significant difference between the treatments (Table 4). A PERMANOVA analysis ran on a reduced dataset, containing the internal and external control samples only, indicated a highly significant influence of treatment (internal control, external control) on the infaunal community composition (Table 5). Significant small scale variation within the sample blocks was also present. Planned contrasts of marina treatments (site 1, site 2 and the internal controls) versus the external controls identified significant differences (Table 6).

Contrast (1,2)v(internal)

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Location	1	5983.2	5983.2	0.84343	0.473	280
Treatment(Location)	6	42625	7104.1	2.1983	0.003	9901
C1(Location)	2	10850	5424.9	1.5221	0.1576	9881
Block(Treatment(Location))	16	51773	3235.8	1.7868	0.0001	9802
Block(C1(Location))	8	29549	3693.6	1.5155	0.0152	9859
Res	47	85114	1810.9			
Total	70	1.85E+05				

Table 4 Table of results from the PERMANOVA analysis contrasting sites 1 and 2 with the internal controls. The factors treatment and block are significant, indicating an influence of the treatment (impacted or control) and the block (small scale spatial variation). Significance is indicated by grey rows.

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Location	1	2843.5	2843.5	0.39881	1	3
Treatment(Location)	2	14260	7129.9	2.6396	0.0025	8924
Block(Treatment(Location))	8	21609	2701.1	2.164	0.0001	9851
Res	24	29957	1248.2			
Total	35	68669				

Table 5 Table of results from a PERMANOVA analysis on a reduced dataset, consisting of internal and external controls only. The factor of treatment (internal and external control) is significant indicating a difference between the internal and external controls. Significance is indicated by grey rows.

Contrast (1,2,internal)v(external)

Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Location	1	5983.2	5983.2	0.84343	0.4805	280
Treatment(Location)	6	42625	7104.1	2.1983	0.0037	9896
C1(Location)	2	23411	11705	5.6088	0.0008	9900
Block(Treatment(Location))	16	51773	3235.8	1.7868	0.0001	9831
Block(C1(Location))	8	15964	1995.5	0.84131	0.7966	9848
Res	47	85114	1810.9			
Total	70	1.85E+05				

Table 6 Table of results from a PERMANOVA analysis contrasting the marina treatments (site 1, site 2, internal control) against the external control. The contrast is significant indicating a difference between the grouped 'within marina' treatments and the external controls. Significance is indicated by grey rows.

Separate PERMANOVA analyses were also completed with the addition of mean method of moment (logarithmic ϕ) and principle component (PC) data as co-variables. Inclusion of neither co-variable gave a significant influence of sediment on the infaunal community indicating that within the marinas sediment particle (grain) size is not having a strong influence on infaunal composition.

4.5 Summary of Results

	Significance	Details
Sediment		
Particle (grain) size	✗	No apparent influence detected.
Organic carbon content	✗	
Biodiversity Measures		
Overall Abundance	✗	No apparent influence detected.
Species Diversity	✗	
Simpsons Index	✓	Significant difference between treatments. Limited indication of physical impact and wider influence.
Grouped Abundance of Crustacea	✓	Increased abundance of crustaceans in the external control areas.
Infaunal Assemblage		
PERMANOVA	✓	Significant difference in community composition between marina treatments (1, 2, internal control) and the external control.

5 Discussion

5.1 Impact on Sediment Characteristics

Analysis of the sediment characteristics measured as part of this study do not indicate a significant influence of physical disturbance from the marina infrastructure, nor the wider influence of the marina, on the sediment particle size or organic carbon content. This result indicates that neither the physical disturbance of the marina infrastructure nor the overall marina presence is significantly influencing the sediment characteristics relative to un-impacted control areas nearby.

These results are not in concurrence with other studies which have identified changes, both in organic matter deposition and sediment grain size, around pontoons, docks and coastal defences (Airoldi et al., 2005; Cantor, 2009; Putro, 2007). As sediment characteristics were not the primary focus of this study and replication of samples was limited, care should be taken in the interpretation of these results. Additional consideration should also be given to other sediment characteristics which could be influenced, such as anoxia levels and the presence of chemicals or leachates, which were not recorded as part of this study.

5.2 Ecological Impact

During ROV scoping surveys evidence of physical sediment disturbance was visible around both the piling bases in Port Pendennis marina and underneath the chains in Falmouth Yacht Haven (pers. obs. Holly Latham). Several infaunal analyses indicated a clear influence of treatment (site 1, site 2, internal control, external control) on the community present; however further interrogation of the data revealed the main difference to lie between the marina treatments (site 1, site 2, internal controls) and the external controls.

Pairwise comparisons within the Simpson's Index analysis identified the presence of a potential but limited physical impact; however community level contrasts of physically disturbed treatments (sites 1 and 2) and internal controls did not support the presence of a significant impact. This result could indicate that no ecological impact resulted from the physical disturbance, or that a physical disturbance impact was present but not clearly detected by this study, potentially due to small extent or magnitude. ROV observations did indicate that the visible extent of sediment disturbance may extend a metre or less from the infrastructure (pers. obs. Holly Latham). It is possible, that despite attempts to sample as close to the point of disturbance as possible, the necessity for remote sampling may have led to the sample removal occurring outside (or partially outside) the area most impacted by the infrastructure, which may in turn have influenced the results. It could also be argued that if the physical impact of the marina infrastructure is masked by the influence of wider impacts within the marina, that it is the wider marina impacts that currently represent a greater threat to biodiversity.

Planned contrasts of the internal marina treatments (site 1, site 2, internal control) and the external controls indicated a significant difference between the marina communities and the communities occurring nearby in similar, but less impacted areas. This would suggest the presence of a wider impact of the marina as a whole, potentially due to cumulative effects of other anthropogenic impacts (e.g. chemical inputs, water quality), a residual effect of the dredging (McCauley, Parr, & Hancock, 1977; Van Der Veer, Bergman, & Beukema, 1985) or a combination of both. The scope of this study was limited and it was not possible to quantify measures of chemical contamination (e.g. antifoul chemicals) or water quality to analyse and assess the potential influence of these variables. Previous studies within UK marinas have identified increases in dissolved copper concentrations (Jones & Bolam, 2007) and it is possible that chemicals gradients from marina inputs are influencing the infauna within the seabed below. Initial dredging of the marina areas would strip the sediments of infauna; while recovery would usually occur relatively quickly (Bonvicini-pagliai et al., 1985) the presence of additional anthropogenic impacts within the area could retard re-colonisation or adjust the composition of the 'recovered' community.

Several biodiversity measures (abundance, species richness, Shannon-Wiener) were unable to detect a significant influence of treatment, but it is possible that some of the simpler biodiversity measures may be confounded by the composition of the infaunal samples. The mean abundances of organisms were relatively high; however the groups Cirratulidae, Oligochaeta, and Capitellidae (all annelids) were dominant and represented the majority of the organisms present. Simpson's Index has been indicated to be potentially more representative of changes in dominance in response to environmental perturbations (Buckland, Magurran, Green, & Fewster, 2005; Purvis & Hector, 2000). Low biodiversity and large numbers of relatively few organisms are typical indications of disturbance within an ecosystem (Borowski & Thiel, 1998; Thrush & Dayton, 2002) and this supports the suggestion that the samples are impacted to some degree. The external control sites indicated increased consistency within the samples, with these samples clustering tightly in the MDS plot. Dis-similarity of samples is generally acknowledged to be an indicator of disturbance within a community (Warwick & Clarke, 1993), suggesting that the marina samples are subject to higher levels of disturbance than the surrounding ecosystem. This is consistent with the findings of (Lindegarth, 2001) who also identified greater variability in abundances in impacted (pontoon) samples.

Differential responses to impacts and rates of recovery are exhibited by different groups of organisms (Dernie, Kaiser, Richardson, & Warwick, 2003) and frequent or 'press' disturbances select for organisms that can tolerate the impact (Lee, Lee, & Connolly, 2011). Crustacea indicated a significant difference between treatments, showing a marked reduction in abundance in all internal marina treatments (site 1, site 2 and internal control). Visual comparison of the infaunal data suggests that crustacean diversity may differentiate also. Significance of the difference in abundance indicates that the marina is exerting a particularly strong influence on crustaceans. Lindegarth (2001) indicated the presence of pontoons to have a strong influence on crustaceans; however this study also did not elucidate a specific cause for the apparent reduction in numbers. Concurrent results indicating reductions in crustacean abundance do suggest that this group of organisms may be particularly susceptible to the impacts encountered in the vicinity of the marina.

Crustacea could be affected by a variety of factors. Physical changes in the environment (e.g. hydrology, sediment, temperature), chemical factors (e.g. antifouling, sewage) or biological interactions (e.g. predator, prey, competition) could all potentially influence the abundance of crustaceans present. Some crustaceans (e.g. tanaids) may be affected by factors which affect burrowing; this could be either by changes in the biological assemblage (Reise, 2002) or due to changes in sediment characteristics (Frost et al., 2004). This study does not indicate a difference in sediment characteristics, but this result is not conclusive enough to rule out this factor. A review of the environmental risk of antifouling substances does not appear to indicate that crustaceans are particularly susceptible to toxicity (van Wezel & van Vlaardingen, 2004); however this is based upon standard laboratory testing and is not specific to marine species of Crustacea. Differential sensitivities to antifoul chemicals have been identified within crustaceans due to differing capacities to metabolise chemicals, suggesting the possibility of differential impacts within this taxonomic group (Ohji, Takeuchi, Takahashi, Tanabe, & Miyazaki, 2002).

As this study did not include the collection of samples over a graduated scale, either from the point of physical impact or from the marina, it is not possible to calculate an area impacted as was done for the moorings in the Fal and Helford Recreational Boating Study: Chapter 1 (Section 7.1). Based on the results of this study the extent of any physical impact of the marina infrastructure appears minimal and previous studies of antifoul chemicals suggest that high concentrations may only occur very close to the source, dropping away quickly through dilution and reaction (Jones & Bolam, 2007). Marinas may be considered as a more effective use of space and a means of concentrating the impact in a smaller area. To put this into perspective Port Pendennis marina has an approximate dredged footprint of 24,200m^2, in which there around 80 boats are moored; a similar area of moorings within Falmouth Inner Harbour (25,400m^2) contains only 39 moorings. Obviously the number of boats within marinas will vary dependent upon the design of the marina, but this calculation serves to give a rough comparison of the space needed for each option. It suggests that a similar physical footprint may allow at least twice the number of vessels to fit in the same physical footprint.

Both marinas were located within Falmouth Inner Harbour on a biotope identified as 'sub-littoral estuarine mud (AphTub) with kelp on available hard substrata' (Section7.4 of the Fal and Helford Recreational Boating Study: Chapter 1). The description of this biotope largely matches that of the sediment and infauna present in the marina samples, suggesting that this biotope is an accurate description of the habitat present in these areas. This biotope was identified as having a low sensitivity to physical disturbance and abrasion (Section 7.3 of the Fal and Helford Recreational Boating Study: Chapter 1). This biotope is indicated to have a moderate sensitivity to several factors which may be altered by marinas; increases in water flow rate (propeller wash), decreases in salinity (fresh water deck washes) and the introduction of non-native species.

5.3 Further Study

A number of areas of further study would be likely to be beneficial. An ultimate aim in this area would be an accurate ecological cost-benefit analysis of different types of recreational boating infrastructure to compare associated ecological impacts and allow relevant organisations to plan for sustainable future management of recreational boating within the marine environment. To achieve this requires a thorough and detailed understanding of the level and extent of a myriad of potential anthropogenic impacts, many of which are not currently quantified in a comparable manner. Studies have previously correlated copper, tin and organotin contamination at differing distances and densities of vessels and with changing seasons (Jones & Bolam, 2007; Langston et al., 1987); however accurately calculating input and extent of influence is difficult and is likely to vary greatly with marina design, water flow and sequestration within sediments. Future work to model the movement and distribution of water-borne contaminants given varied environmental conditions may help detect how inputs are distributed in marina environments and thus predict the locations of highly impacted areas. Studies that incorporate a wide variety of variables (e.g. water flow, antifoul chemicals, grey water, sewage) at small-scale may also work towards the ability to model the cumulative effect of these impacts on marina communities. The minimal influence detected in response to physical disturbance from the marina infrastructure potentially indicates that further studies would generate more constructive outputs by focussing on the detection and reduction of alternate anthropogenic impacts which currently appear to pose a greater threat within marina ecosystems.

Based on the results of this study, investigating in greater detail the differences in community and crustacean assemblages, to identify the species affected and to elucidate why those species were impacted to a greater degree, may reveal greater insight into potential causal factors. Changes in diversity relative to feeding mechanism (e.g. deposit feeders, burrowers, filter feeders) and functional traits (e.g. motility, position, body design) have been reported in response to disturbance (Juan, Thrush, & Demestre, 2007; Whomersley et al., 2010) and investigating the infaunal changes identified within this study relative to the functionality of the species may yield interesting trends and aid in the future management of impacts.

Marina environments also hold great potential for research to develop procedures, structures and chemicals that can minimise the impact of recreational boating on the marine environment. It is anticipated that research in this area could investigate improvements in pontoon design to improve water flow, new antifoul chemicals or materials and innovations to minimise current chemical impacts, as well as the development of novel methods to detect and measure chemicals, inputs and impacts quicker. Alternative new anchorage techniques are currently in development, such as the use of SEAFLEX© risers in Mylor Yacht Harbour; however the relative ecological benefits of these approaches in temperate and highly tidal waters are currently un-quantified.

6 Draft Management Recommendations

A number of the draft management recommendations proposed for moorings impacts in the Fal and Helford Recreational Boating Study: Chapter 1 are also applicable to marinas. These include suggestions to establish baseline data enabling better understanding of the local marine environment (Section 8.1), the inclusion of areas within harbours with minimal disturbance to give ecosystems space to recover (Section 8.4), minimising additional external impacts to reduce pressure on impacted systems (Section 8.7), sharing best practise and resources to maximise output and minimise repetition (Section 8.8) and continual cycles of study and review to ensure that management decisions are based on the best current knowledge (8.9). Ideally, the management of all types of recreational boating infrastructure should be considered in a strategic, holistic manner encompassing recommendations based on best available evidence and adopting the most practical, balanced measures available. Additional recommendations, with marina specific examples, are given below.

6.1 Location

When planning a new marina the presence of a wider impact suggests that the entire physical footprint of the marina should be considered. It may be wise to favourably consider applications for marinas that utilise areas where the ecosystem is already considered to be depleted, in a similar manner to the idea of 'brown field' development (e.g. old docks or commercial premises), with development on such habitats favoured over development on more pristine areas.

6.2 Initiatives

Maritime businesses and water users should be encouraged to participate in current initiatives to reduce alternative impacts and inputs within marinas. Initiatives such as the British Marine Federation's Environmental Code of Practice[4] and the Royal Yachting Association's Green Blue[5] aim to reduce the pressure recreational boating puts on marine ecosystems and ensure clean, healthy and diverse marina environments. Further information on recreational interactions and the management of recreational boating activities within Special Areas of Conservation is available through Saunders, Selwyn, Richardson, May, & Heeps, 2000.

6.3 Alternative impacts

Some impacts identified by previous studies can be addressed with relatively easy and cost-effective options during standard refits or maintenance of the marina; a good example of this is the use of light-permeable grating and walkways to reduce the effect of shading beneath pontoons. Marinas can also participate in non-native 'early warning' schemes[6] which utilise settlement panels to detect potential biological invasions at early stages.

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[4] www.britishmarine.co.uk/other/environmental_code_of_practice.aspx
[5] www.thegreenblue.org.uk/boating_businesses.aspx
[6] Such as Cornwall Wildlife Trust's Marine Science Project
www.erccis.org.uk/invasivespecies/Investigate_Invasives_Marine/Settlement+panel+project

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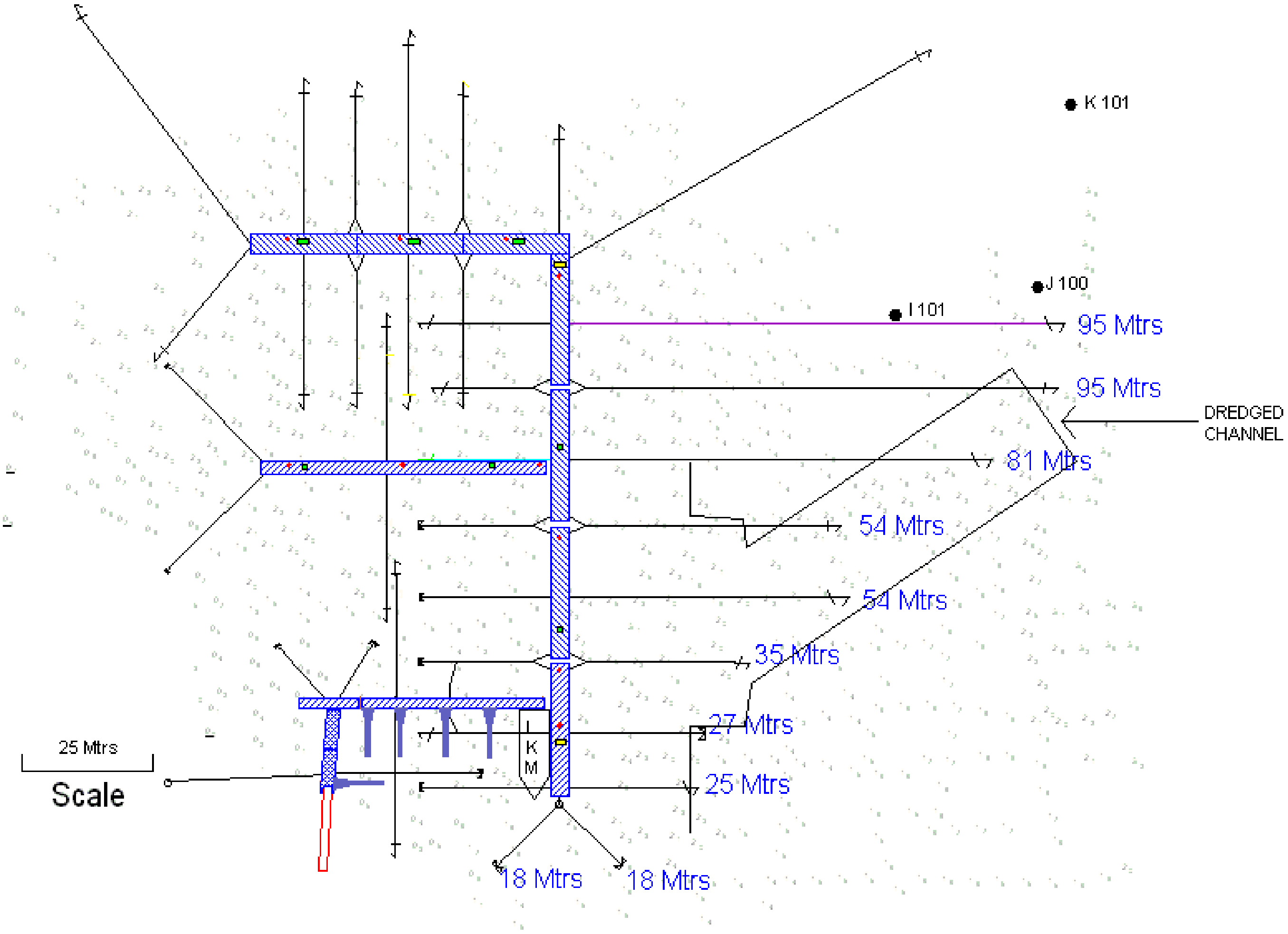
9 Appendix

Appendix 1: ROV screen grab of the marina chains

A screen grab from the ROV footage of the anchor chains beneath Falmouth Yacht Haven. The chains run from the pontoons, down to the seabed and then are laid out along the seabed (for up to 95m in Falmouth Yacht Haven). At low tide the chain beneath the pontoon piles up on the seabed, extending out again as the tide rises. The chain links where the chain first reaches the seabed move regularly with the movement of the pontoons above and disturb the sediment surface. Each chain link is approximately 12” long and the diameter of the metal links is 2”.

Appendix 2: Falmouth Yacht Haven layout

The design for Falmouth Yacht Haven marina showing the layout of the anchor chains for the pontoons. K101, J100 and I101 indicate moorings close to the marina. Italicised values indicate the depth in metres.



Appendix 3: Sediment characteristics ANOVA results tables and graphs

Mean method of moments (Log ⍰): ANOVA table of results.

Tests of Between-Subjects Effects

Dependent Variable:MMM LOG PHI

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Location	Hypothesis	1.191	1	1.191	.343	.579
	Error	20.828	6	3.471		
Treatment(Location)	Hypothesis	20.828	6	3.471	1.876	.147
	Error	29.601	16	1.850		

Table 7 Table of results from the analysis of variance (ANOVA) on the mean method of moments (logarithmic ϕ). Neither location nor treatment are significantly influenced.

Mean method of moments (Log ⍰): Graphical representation of results (estimated marginal means)

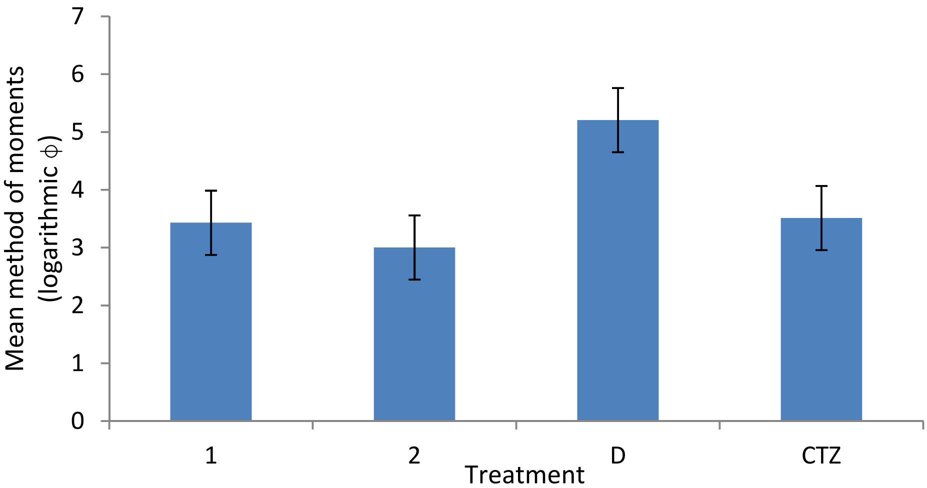


Figure 5 Graphical representation (estimated marginal mean) of the mean method of moments (logarithmic ϕ). Sites 1 and 2 are influenced by the physical disturbance of the anchorage system, 'D' is the internal control and 'C' is the external control. Error bars are Standard Error.

Organic carbon content: ANOVA table of results

Tests of Between-Subjects Effects

Dependent Variable:OC

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Location	Hypothesis	4.404	1	4.404	2.018	.205
	Error	13.093	6	2.182		
Treatment(Location)	Hypothesis	13.093	6	2.182	.530	.777
	Error	65.838	16	4.115		

Table 8 Table of results from the analysis of variance (ANOVA) on the organic carbon content. Neither location nor treatment are significantly influenced.

Organic carbon content: Graphical representation of results (estimated marginal means)

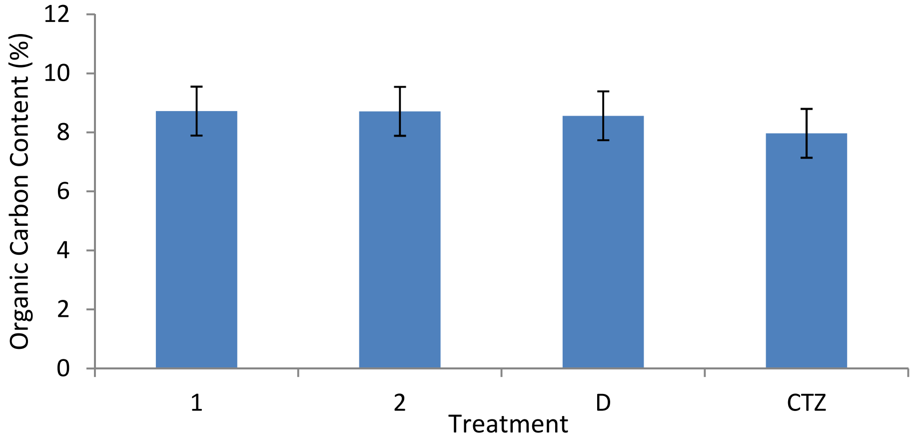


Figure 6 Graphical representation (estimated marginal mean) of the organic carbon content. Sites 1 and 2 are influenced by the physical disturbance of the anchorage system, 'D' is the internal control and 'C' is the external control. Error bars are Standard Error.

Appendix 4: List of Infaunal Taxa

PHYLUM	CLASS	ORDER	FAMILY	TAXONOMIC GROUP	COMMON GROUP NAMES
NEMATODA				NEMATODA	Nematode worms
NEMERTEA				NEMERTEA	Nemertean worms
ANNELIDA				OLIGOCHETA	Oligochaete worms
CHAETOGNATHA				CHAETOGNATHA	Arrow worms
ANNELIDA	Polychaeta	Terebellida	Ampharetidae	Ampharetidae	Polychaete worms
ANNELIDA	Polychaeta	Phyllodocida	Aphroditidae	Aphroditidae	
ANNELIDA	Polychaeta		Capitellidae	Capitellidae	
ANNELIDA	Polychaeta	Terebellida	Cirratulidae	Cirratulidae	
ANNELIDA	Polychaeta		Cossuridae	Cossuridae	
ANNELIDA	Polychaeta	Eunicida	Eunicidae	Eunicidae	
ANNELIDA	Polychaeta	Phyllodocida	Glyceridae	Glyceridae	
ANNELIDA	Polychaeta	Phyllodocida	Hesionidae	Hesionidae	
ANNELIDA	Polychaeta		Orbiniidae	Orbiniidae	
ANNELIDA	Polychaeta	Sabellida	Oweniidae	Oweniidae	
ANNELIDA	Polychaeta		Maldanidae	Maldanidae	
ANNELIDA	Polychaeta	Spionida	Magelonidae	Magelonidae	
ANNELIDA	Polychaeta	Phyllodocida	Nephtyidae	Nephtyidae	
ANNELIDA	Polychaeta	Phyllodocida	Nereididae	Nereididae	
ANNELIDA	Polychaeta		Paraonidae	Paraonidae	
ANNELIDA	Polychaeta	Terebellida	Pectinariidae	Pectinariidae	
ANNELIDA	Polychaeta	Phyllodocida	Phyllodocidae	Phyllodocidae	
ANNELIDA	Polychaeta	Sabellida	Sabellidae	Sabellidae	
ANNELIDA	Polychaeta	Spionida	Spionidae	Spionidae	
ANNELIDA	Polychaeta	Phyllodocida	Syllidae	Syllidae	
ANNELIDA	Polychaeta			POLYCHAETA Indet.	
ARTHROPODA	Copepoda[a]			COPEPODA	Copepods
ARTHROPODA	Ostracoda			OSTRACODA	Ostracods
ARTHROPODA	Malacostraca	Decapoda	Crangonidae	Crangonidae	Decapods (crabs, hermit crabs, squat lobsters and shrimps)
ARTHROPODA	Malacostraca	Decapoda	Galatheidae	Galatheidae	
ARTHROPODA	Malacostraca	Decapoda	Hippolytidae	Hippolytidae	
ARTHROPODA	Malacostraca	Decapoda	Palaemonidae	Palaemonidae	
ARTHROPODA	Malacostraca	Decapoda	Porcellanidae	Porcellanidae	
ARTHROPODA	Malacostraca	Decapoda	Portunidae	Portunidae	
ARTHROPODA	Malacostraca	Amphipoda	Aoridae	Aoridae	Amphipods
ARTHROPODA	Malacostraca	Amphipoda	Ampeliscidae	Ampeliscidae	
ARTHROPODA	Malacostraca	Amphipoda	Amphilochidae	Amphilochidae	
ARTHROPODA	Malacostraca	Amphipoda	Ampithoidae	Ampithoidae	
ARTHROPODA	Malacostraca	Amphipoda	Caprelloidea[c]	CAPRELLOIDEA	*Caprellids
ARTHROPODA	Malacostraca	Amphipoda	Corophiidae	Corophiidae	
ARTHROPODA	Malacostraca	Amphipoda	Dexaminidae	Dexaminidae	
ARTHROPODA	Malacostraca	Amphipoda	Ischyroceridae	Ischyroceridae	
ARTHROPODA	Malacostraca	Amphipoda	Oedicerotidae	Oedicerotidae	
ARTHROPODA	Malacostraca	Amphipoda	Stenothoidae	Stenothoidae	
ARTHROPODA	Malacostraca	Amphipoda		AMPHIPODA Indet.	
ARTHROPODA	Malacostraca	Isopoda	Arcturidae	Arcturidae	Isopods
ARTHROPODA	Malacostraca	Isopoda	Janiridae	Janiridae	
ARTHROPODA	Malacostraca		Nebaliidae	Nebaliidae	
ARTHROPODA	Malacostraca	Cumacea	Bodotriidae	Bodotriidae	Hooded shrimps
ARTHROPODA	Malacostraca	Cumacea	Diastylidae	Diastylidae	
ARTHROPODA	Malacostraca	Tanaidacea	Apseudidae	Apseudidae	Tanaids
ARTHROPODA	Malacostraca	Tanaidacea		TANAIDACEA Indet.	
ARTHROPODA	Pycnogonida	Pantopoda	Ammotheidae	Ammotheidae	Sea spiders
ARTHROPODA	Pycnogonida	Pantopoda	Phoxichilidiidae	Phoxichilidiidae	
ECHINODERMATA	Ophiuroidea			OPHIUROIDEA Indet.	
CNIDARIA	Anthozoa	Actiniaria	Edwardsiidae	Edwardsiidae	Anemones
CNIDARIA	Anthozoa	Actiniaria		ACTINIARIA Indet.	
CNIDARIA	Anthozoa			CNIDARIA Indet.	
MOLLUSCA	Bivalvia	Euheterodonta[b]	Solenidae	Solenidae	*Razor shells
MOLLUSCA	Bivalvia	Mytiloida	Mytilidae	Mytilidae	Mussels
MOLLUSCA	Bivalvia	Veneroida	Cardiidae	Cardiidae	*Cockles

MOLLUSCA	Bivalvia	Veneroida	Semelidae	Semelidae	
MOLLUSCA	Bivalvia	Veneroida	Tellinidae	Tellinidae	*Tellins
MOLLUSCA	Bivalvia			BIVALVIA Indet.	
MOLLUSCA	Gastropoda	Cephaloaspidea	Retusidae	Retusidae	
MOLLUSCA	Gastropoda	Littorinimorpha	Littorinidae	Littorinidae	
MOLLUSCA	Gastropoda	Littorinimorpha	Rissoidae	Rissoidae	
MOLLUSCA	Gastropoda	Neogastropoda	Buccinidae	Buccinidae	Whelks
MOLLUSCA	Gastropoda		Pyramidellidae	Pyramidellidae	*Pyramid shells
CHORDATA	Ascidiacea	Phlebobranchia	Ascidiidae	Ascidiidae	Sea squirts
PORIFERA	Calcarea	Leucosolenida	Sycettidae	Sycettidae	Sponges

[a]sub-class

[b]infra-class

[c]super-family

*common names specific to a family group

Appendix 5: Abundance (N) ANOVA results table

Tests of Between-Subjects Effects

Dependent Variable:N

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	Hypothesis	2954016.667	1	2954016.667	75.070	.082
	Error	37182.990	.945	39350.111[a]		
Location	Hypothesis	164672.667	1	164672.667	3.100	.176
	Error	159512.888	3.003	53124.463[b]		
Treatment(Location)	Hypothesis	159433.832	3	53144.611	.895	.485
	Error	476045.952	8.014	59404.149[c]		
Block(Treatment)	Hypothesis	365193.429	8	45649.179	.768	.641
	Error	475675.206	8	59459.401[d]		
Location * Block(Treatment)	Hypothesis	475675.206	8	59459.401	2.089	.056
	Error	1337762.000	47	28463.021[e]		

a. .999 MS(Treatment(Location)) + .997 MS(Block(Treatment)) - .997 MS(Location * Block(Treatment)) + .001 MS(Error)

b. .999 MS(Treatment(Location)) + .001 MS(Error)

c. .998 MS(Location * Block(Treatment)) + .002 MS(Error)

d. MS(Location * Block(Treatment))

e. MS(Error)

Table 9 Table of results from the analysis of variance (ANOVA) on the overall abundance (N) of the infaunal samples. No significant influence is indicated.

Appendix 6: Species richness (S) ANOVA results table

Tests of Between-Subjects Effects

Dependent Variable:S

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	Hypothesis	5021.173	1	5021.173	1163.092	.835
	Error	.130	.030	4.317[a]		
Location	Hypothesis	37.500	1	37.500	2.351	.223
	Error	47.905	3.003	15.951[b]		
Treatment(Location)	Hypothesis	47.868	3	15.956	.309	.819
	Error	413.744	8.006	51.681[c]		
Block(Treatment)	Hypothesis	320.722	8	40.090	.775	.637
	Error	414.040	8	51.755[d]		
Location * Block(Treatment)	Hypothesis	414.040	8	51.755	5.007	.000
	Error	485.833	47	10.337[e]		

a. .999 MS(Treatment(Location)) + .997 MS(Block(Treatment)) - .997 MS(Location * Block(Treatment)) + .001 MS(Error)

b. .999 MS(Treatment(Location)) + .001 MS(Error)

c. .998 MS(Location * Block(Treatment)) + .002 MS(Error)

d. MS(Location * Block(Treatment))

e. MS(Error)

Table 10 Table of results from the analysis of variance (ANOVA) on the species richness (S) of the infaunal samples. No significant influence is indicated at location, treatment or block. The interaction between location and block (nested within treatment) is significant.

Appendix 7: Shannon-Wiener Index (H'(Loge)) ANOVA results table

Tests of Between-Subjects Effects

Dependent Variable:H'(loge)

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	Hypothesis	80.391	1	80.391	100.561	.018
	Error	1.327	1.661	.799[a]		
Location	Hypothesis	.753	1	.753	.723	.458
	Error	3.127	3.001	1.042[b]		
Treatment(Location)	Hypothesis	3.128	3	1.043	2.605	.124
	Error	3.208	8.013	.400[c]		
Block(Treatment)	Hypothesis	1.259	8	.157	.393	.896
	Error	3.205	8	.401[d]		
Location * Block(Treatment)	Hypothesis	3.205	8	.401	2.127	.052
	Error	8.855	47	.188[e]		

a. .999 MS(Treatment(Location)) + .997 MS(Block(Treatment)) - .997 MS(Location * Block(Treatment)) + .001 MS(Error)

b. .999 MS(Treatment(Location)) + .001 MS(Error)

c. .998 MS(Location * Block(Treatment)) + .002 MS(Error)

d. MS(Location * Block(Treatment))

e. MS(Error)

Table 11 Table of results from the analysis of variance (ANOVA) on the Shannon-Wiener Index (H'(loge)) of the infaunal samples. No significant influence is indicated at location, treatment or block.

Appendix 8: Simpsons Index pairwise comparisons (pooled locations)

Pairwise Comparisons

Dependent Variable:1-Lambda'

(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
1	2	-.122	.074	.106	-.272	.027
	CTZ	-.190*	.074	.014	-.339	-.041
	D	-.242*	.074	.002	-.392	-.093
2	1	.122	.074	.106	-.027	.272
	CTZ	-.068	.073	.357	-.214	.079
	D	-.120	.073	.105	-.266	.026
CTZ	1	.190*	.074	.014	.041	.339
	2	.068	.073	.357	-.079	.214
	D	-.052	.073	.474	-.199	.094
D	1	.242*	.074	.002	.093	.392
	2	.120	.073	.105	-.026	.266
	CTZ	.052	.073	.474	-.094	.199

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

*. The mean difference is significant at the 0.05 level.

Table 12 Pairwise comparisons of treatment within the Simpson's Index analysis. Significant differences are indicated between site 1 and the internal and external controls. Significance is indicated by grey rows.

Appendix 9: Simpsons Index pairwise comparisons (separate locations)

Pairwise Comparisons

Dependent Variable:1-Lambda'

Location	(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
FYH	1	2	-.195	.103	.064	-.401	.012
		CTZ	.011	.103	.912	-.195	.218
		D	-.279*	.103	.009	-.485	-.072
	2	1	.195	.103	.064	-.012	.401
		CTZ	.206	.103	.051	-.001	.413
		D	-.084	.103	.418	-.291	.123
	CTZ	1	-.011	.103	.912	-.218	.195
		2	-.206	.103	.051	-.413	.001
		D	-.290*	.103	.007	-.497	-.083
	D	1	.279*	.103	.009	.072	.485
		2	.084	.103	.418	-.123	.291
		CTZ	.290*	.103	.007	.083	.497
PP	1	2	-.050	.107	.642	-.265	.165
		CTZ	-.392*	.107	.001	-.607	-.176
		D	-.206	.107	.060	-.422	.009
	2	1	.050	.107	.642	-.165	.265
		CTZ	-.341*	.103	.002	-.548	-.135
		D	-.156	.103	.135	-.363	.051
	CTZ	1	.392*	.107	.001	.176	.607
		2	.341*	.103	.002	.135	.548
		D	.185	.103	.078	-.022	.392
	D	1	.206	.107	.060	-.009	.422
		2	.156	.103	.135	-.051	.363
		CTZ	-.185	.103	.078	-.392	.022

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

*. The mean difference is significant at the 0.05 level.

Table 13 Pairwise comparisons of treatment within the Simpson's Index analysis, separated to location. Significant differences are indicated between site 1 and the internal control and the internal control and external control in Falmouth Yacht Haven; sites 1 and 2 and the external control in Port Pendennis. Significance is indicated by grey rows.

Appendix 10: Annelida abundances ANOVA results table

Tests of Between-Subjects Effects

Dependent Variable:Annelida ABUNDANCE

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	Hypothesis	2704750.347	1	2704750.347	63.473	.056
	Error	50674.230	1.189	42612.449[a]		
Location	Hypothesis	141955.681	1	141955.681	2.668	.201
	Error	159606.264	3	53202.088[b]		
Treatment(Location)	Hypothesis	159606.264	3	53202.088	.998	.442
	Error	426506.889	8	53313.361[c]		
Block(Treatment)	Hypothesis	341789.778	8	42723.722	.801	.619
	Error	426506.889	8	53313.361[c]		
Location * Block(Treatment)	Hypothesis	426506.889	8	53313.361	1.917	.079
	Error	1335086.667	48	27814.306[d]		

a. MS(Treatment (Location)) + MS(Block(Treatment)) - MS(Location * Block(Treatment))

b. MS(Treatment (Location))

c. MS(Location * Block(Treatment))

d. MS(Error)

Table 14 Table of results from the analysis of variance (ANOVA) on Annelida abundance within the infaunal samples. No significant influence is indicated at location, treatment or block.

Appendix 11: Polychaeta abundance ANOVA results table

Tests of Between-Subjects Effects

Dependent Variable:Polychaeta ABUNDANCE

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	Hypothesis	1832655.125	1	1832655.125	158.844	.339
	Error	3329.611	.289	11537.431[a]		
Location	Hypothesis	51467.014	1	51467.014	2.864	.189
	Error	53914.042	3	17971.347[b]		
Treatment (Location)	Hypothesis	53914.042	3	17971.347	.442	.730
	Error	325497.111	8	40687.139[c]		
Block(Treatment)	Hypothesis	274025.778	8	34253.222	.842	.593
	Error	325497.111	8	40687.139[c]		
Location * Block(Treatment)	Hypothesis	325497.111	8	40687.139	2.736	.014
	Error	713697.333	48	14868.694[d]		

a. MS(Treatment (Location)) + MS(Block(Treatment)) - MS(Location * Block(Treatment))

b. MS(Treatment (Location))

c. MS(Location * Block(Treatment))

d. MS(Error)

Table 15 Table of results from the analysis of variance (ANOVA) on Polychaeta abundance within the infaunal samples. No significant influence is indicated at location, treatment or block. The interaction between location and block (nested within treatment) is significant. Significance is indicated by grey rows.

Appendix 12: Amphipoda abundance ANOVA results table

Tests of Between-Subjects Effects

Dependent Variable:Amphipoda ABUNDANCE

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	Hypothesis	1691.681	1	1691.681	9.850	.064
	Error	438.570	2.554	171.736[a]		
Location	Hypothesis	231.125	1	231.125	1.338	.331
	Error	518.042	3	172.681[b]		
Treatment (Location)	Hypothesis	518.042	3	172.681	2.140	.173
	Error	645.667	8	80.708[c]		
Block(Treatment)	Hypothesis	638.111	8	79.764	.988	.506
	Error	645.667	8	80.708[c]		
Location * Block(Treatment)	Hypothesis	645.667	8	80.708	1.189	.326
	Error	3259.333	48	67.903[d]		

a. MS(Treatment (Location)) + MS(Block(Treatment)) - MS(Location * Block(Treatment))

b. MS(Treatment (Location))

c. MS(Location * Block(Treatment))

d. MS(Error)

Table 16 Table of results from the analysis of variance (ANOVA) on Amphipoda abundance within the infaunal samples. No significant influence is indicated at location, treatment or block.

Appendix 13: Mollusca abundance ANOVA results table

Tests of Between-Subjects Effects

Dependent Variable:Mollusca ABUNDANCE

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	Hypothesis	485.681	1	.	.	.
	Error	.	.[a]	.		
Location	Hypothesis	33.347	1	33.347	2.570	.207
	Error	38.931	3	12.977[b]		
Treatment (Location)	Hypothesis	38.931	3	12.977	.575	.647
	Error	180.556	8	22.569[c]		
Block(Treatment)	Hypothesis	54.333	8	6.792	.301	.945
	Error	180.556	8	22.569[c]		
Location * Block(Treatment)	Hypothesis	180.556	8	22.569	1.925	.078
	Error	562.667	48	11.722[d]		

a. Cannot compute the error degrees of freedom using Satterthwaite's method.

b. MS(Treatment (Location))

c. MS(Location * Block(Treatment))

d. MS(Error)

Table 17 Table of results from the analysis of variance (ANOVA) on Mollusca abundance within the infaunal samples. No significant influence is indicated at location, treatment or block.

Appendix 14: Bivalvia abundance ANOVA results table

Tests of Between-Subjects Effects

Dependent Variable:Bivalvia ABUNDANCE

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	Hypothesis	165.014	1	165.014	57.582	.595
	Error	.408	.142	2.866[a]		
Location	Hypothesis	48.347	1	48.347	4.639	.120
	Error	31.264	3	10.421[b]		
Treatment (Location)	Hypothesis	31.264	3	10.421	.852	.504
	Error	97.889	8	12.236[c]		
Block(Treatment)	Hypothesis	37.444	8	4.681	.383	.902
	Error	97.889	8	12.236[c]		
Location * Block(Treatment)	Hypothesis	97.889	8	12.236	3.215	.005
	Error	182.667	48	3.806[d]		

a. MS(Treatment (Location)) + MS(Block(Treatment)) - MS(Location * Block(Treatment))

b. MS(Treatment (Location))

c. MS(Location * Block(Treatment))

d. MS(Error)

Table 18 Table of results from the analysis of variance (ANOVA) on Bivalvia abundance within the infaunal samples. No significant influence is indicated at location, treatment or block. The interaction between location and block (nested within treatment) is significant. Significance is indicated by grey rows.

Appendix 15: Gastropoda abundance ANOVA results table

Tests of Between-Subjects Effects

Dependent Variable:Gastropoda ABUNDANCE

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	Hypothesis	84.500	1	84.500	14.127	.029
	Error	19.126	3.197	5.981[a]		
Location	Hypothesis	1.389	1	1.389	.904	.412
	Error	4.611	3	1.537[b]		
Treatment (Location)	Hypothesis	4.611	3	1.537	.401	.756
	Error	30.667	8	3.833[c]		
Block(Treatment)	Hypothesis	66.222	8	8.278	2.159	.148
	Error	30.667	8	3.833[c]		
Location * Block(Treatment)	Hypothesis	30.667	8	3.833	.697	.692
	Error	264.000	48	5.500[d]		

a. MS(Treatment (Location)) + MS(Block(Treatment)) - MS(Location * Block(Treatment))

b. MS(Treatment (Location))

c. MS(Location * Block(Treatment))

d. MS(Error)

Table 19 Table of results from the analysis of variance (ANOVA) on Gastropoda abundance within the infaunal samples. No significant influence is indicated at location, treatment or block.

Appendix 16: Crustacea abundance pairwise comparisons (pooled locations)

Pairwise Comparisons

Dependent Variable:Crustacea ABUNDANCE

(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1	2	-3.722	3.289	.263	-10.336	2.891
	CTZ	-21.667*	3.289	.000	-28.280	-15.053
	D	-3.056	3.289	.358	-9.669	3.558
2	1	3.722	3.289	.263	-2.891	10.336
	CTZ	-17.944*	3.289	.000	-24.558	-11.331
	D	.667	3.289	.840	-5.947	7.280
CTZ	1	21.667*	3.289	.000	15.053	28.280
	2	17.944*	3.289	.000	11.331	24.558
	D	18.611*	3.289	.000	11.998	25.225
D	1	3.056	3.289	.358	-3.558	9.669
	2	-.667	3.289	.840	-7.280	5.947
	CTZ	-18.611*	3.289	.000	-25.225	-11.998

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

*. The mean difference is significant at the 0.05 level.

Table 20 Pairwise comparisons of treatment within the analysis of crustacean abundance (locations are pooled). Significant differences are indicated between site 1, site 2 and the internal control and the external control. Significance is indicated by grey rows.

Appendix 17: PRIMER similarity tables

FYH Average Similarity between/within groups

	1	2	D	CTZ
1	22.629			
2	31.642	48.838		
D	26.037	37.7	43.687	
CTZ	21.711	38.498	35.196	53.763

PP Average Similarity between/within groups

	1	2	D	CTZ
1	24.478			
2	24.597	26.334		
D	20.21	29.724	29.405	
CTZ	13.942	32.507	36.673	65.057

Table 21 Similarity tables from the PRIMER infaunal community analysis for Falmouth Yacht Haven (FYH) and Port Pendennis (PP). In both locations the greatest similarity occurs within the external control sites.