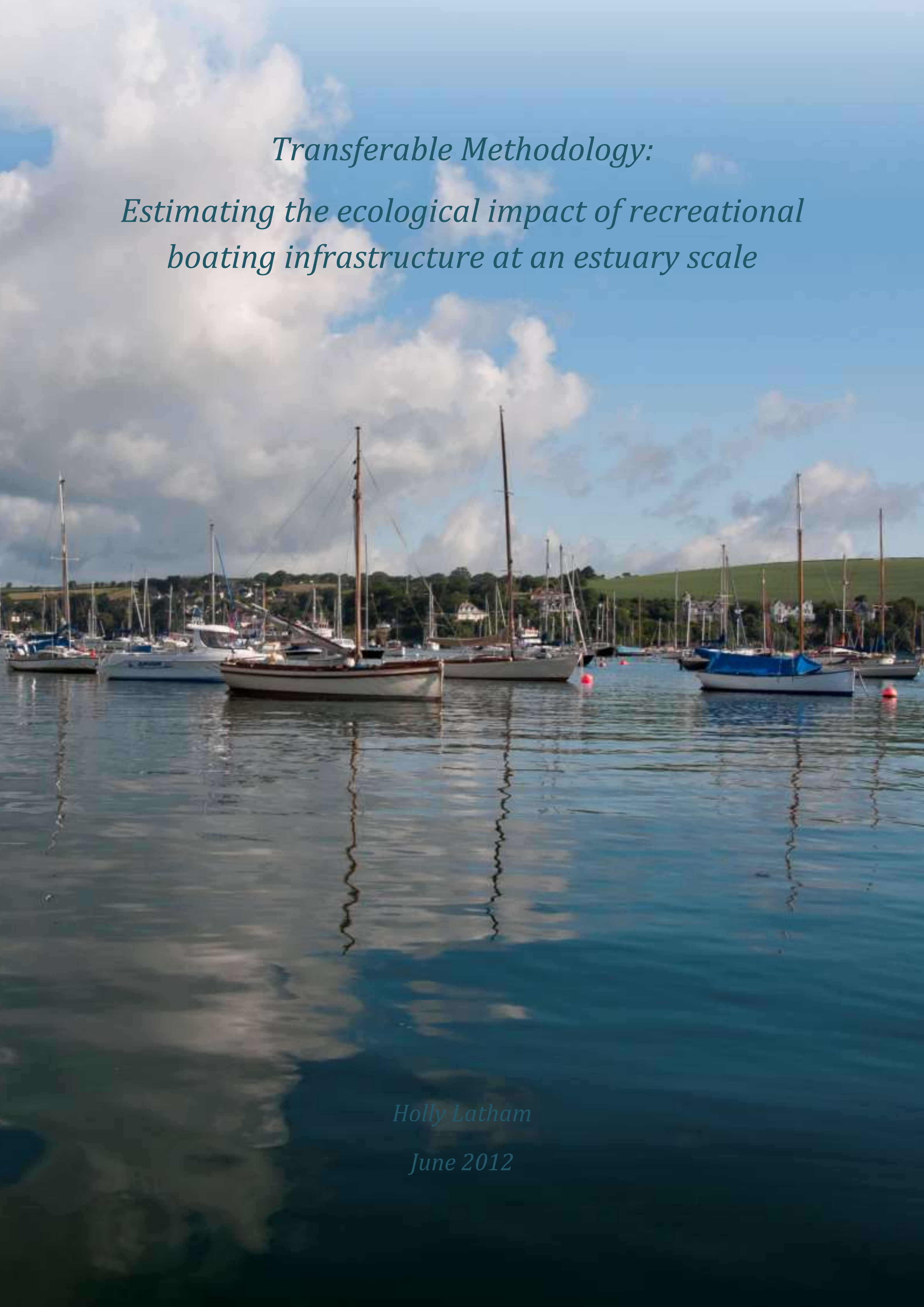
Transferable Methodology:

Estimating the ecological impact of recreational boating infrastructure at an estuary scale



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June 2012

This report should be referenced as:

Latham, H., Hoskin, P. and Knowles, H. (2012). *Transferable Methodology: Estimating the ecological impact of recreational boating infrastructure at an estuary scale*. Falmouth Harbour Commissioners, Falmouth, UK on behalf of the Fal and Helford Recreational Boating Study Project Partners.

The Fal and Helford Recreational Boating Study Project Partners are:

Falmouth Harbour Commissioners (FHC)

Cornwall Council (CC)

Natural England (NE)

University of Plymouth (UoP)

Environment Agency (EA)

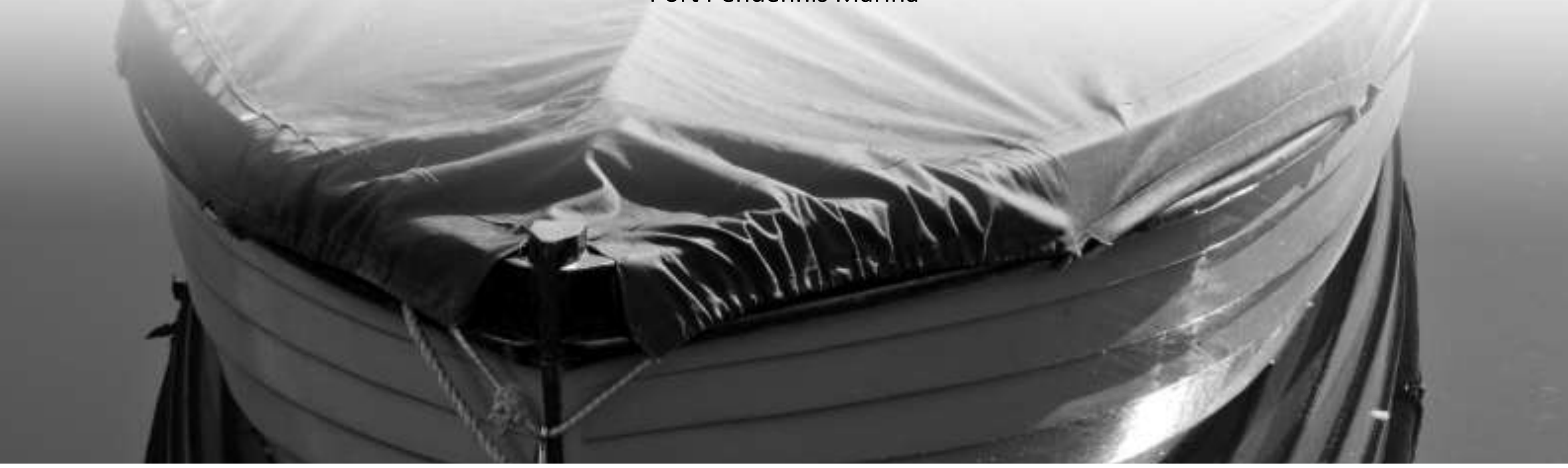
A&P Ports (A&P)

St. Mawes Pier and Harbour Company

Truro and Penryn Harbour Authority

Duchy of Cornwall

Port Pendennis Marina



Version	*Distribution*
Version 1.0	Independent sections to relevant Project Partners for initial comment.
Version 1.1	Distributed to all Project Partners for comment.
Version 1.2	Distributed to all Project Partners.

Executive Summary

Introduction

This Transferable Methodology has been written to describe the main phases involved in the Fal and Helford Recreational Boating Study. This report is aimed at those without a formal marine biological background but who may contribute to or be involved in similar studies. It summarises the relevant study phases in a way that aims to increase understanding of scientific approaches within maritime industry and allow future projects to build upon the successful aspects of the study. It is hoped that lessons learned in the completion of the Fal and Helford Study will assist in the progression of similar studies in harbours and estuaries on a nationwide scale. This report covers all broad aspects of the scientific study, highlighting relevant literature, methodologies and techniques, as well as explanations of successes and drawbacks encountered in the course of the Fal and Helford study.

Literature Research

A detailed review of available literature is essential to any project and a comprehensive approach here will guide project development and ensure strong progress at later stages. The information uncovered at this stage should provide the knowledge necessary to plan and design the practical study. The format of this work can be flexible to fit the resources and expertise available to the project; however information overlooked at this stage may cause delays or inaccuracies in the later practical work and therefore sufficient time should be allocated to this phase. All of the literature searches can be completed as a single review or, as in the case of the Fal and Helford Study, can be split into several independent projects. Information on the distribution of habitats, seabed bathymetry, infrastructure layouts and additional potential sources of impact within the study area is also gathered at this stage to identify the best available study sites. Partnerships with Harbour Authorities and informal interviews with local organisations offer excellent routes through which to acquire this information.

Experimental Design

The experimental design of a study needs to be carefully tailored to suit the project objectives and no one design will suit all projects, locations and resources. It is strongly recommended that expert scientific advice is sought early in the project development, through partnership or consultancy, to ensure an appropriate experimental design is used. Experimental designs to detect impact are often achieved through configuring comparisons of before and after surveys in areas of potential impact and corresponding control areas. Successful experimental designs are structured to account for the natural spatial and temporal variability of marine systems and the characteristics of the impact anticipated. An ideal experimental design will not necessarily be the most practical given real world scenarios and some compromise may be necessary due to practical and budgetary constraints; although this may have implications for the survey results.

Epifaunal Survey

Epifaunal surveys completed using remote video techniques can offer a cost effective means of unveiling the bigger ecological picture. A multitude of underwater video systems are currently available, each with distinct flaws and benefits and each suitable for different techniques and types of survey. Within the relative confines of harbour waters even a small system, such as the remotely operated vehicle (ROV) used in the Fal and Helford Study, has plenty of logistical and operational considerations to ensure a smooth and successful survey. Working in partnership with Harbour Authorities for surveys has proved a cost effective and viable option, allowing utilisation of local maritime knowledge and engaging Harbour Authority personnel in the study and their local ecology. While the quality of video footage may initially appear detailed, for some habitats video surveys may not reveal the true diversity of the seabed. The footage collected for the Fal and Helford Study was not of sufficient quality to allow a detailed analysis; however it was valuable for confirming the types of habitats present. Various methodologies are available to process the video footage and the type used will need to reflect the quality of the footage and the requirements of the study.

Infaunal Survey

Infaunal survey samples can be collected remotely or *in-situ* and the technique used will depend upon the study requirements, experimental design and resources available. Remote techniques have been used by similar studies to the Fal and Helford one with some success; however the decision with this study to detect differences in impact across a relatively small gradient of distance meant that an *in-situ* technique was chosen for its greater accuracy. The use of a contracted scientific dive team is relatively expensive and for the Fal and Helford Study this cost was met by in kind contribution from Natural England, supported by divers from local organisations and the use of suitably qualified volunteers. Scientific diving projects within the UK fall under the Health and Safety Diving at Work Regulations 1997 and Scientific and Archaeological Approved Code of Practice (ACoP) and excellent documentation explaining and interpreting the necessary legislation is available for those involved in planning such projects.

Infaunal samples, once collected, will need to be sieved and preserved prior to processing. The processing of infaunal samples is a time-consuming and labour intensive procedure and the time-scale required will vary dependent upon the experience of the taxonomist, the complexity and diversity of the samples, the level of resolution required and the quality of the resources available. Several techniques are available to speed up the process whilst maintaining sufficient resolution to detect impacts, but expert guidance and consideration of the potential influence of these procedures, and confirmation of the suitability of such techniques, is necessary prior to their use. Additional sampling may be employed alongside the main survey to investigate further factors of interest. As sediment characteristics have been strongly linked to infaunal community composition, sediment samples were collected alongside the main infaunal samples for the Fal and Helford Study. The characteristics of the sediment were then analysed to determine variation and potential influence. Standardised guidance is available on the collection and processing of sediment samples to ensure comparability across projects.

Analysis and Interpretation

Statistical analysis of the survey data and interpretation of the results will require expert scientific advice to get the greatest value from the survey. An extensive suite of statistical analyses are possible, offering multiple approaches to interrogate the data, but many have strict assumptions which should not be broken without a detailed understanding of the consequences. For the Fal and Helford Study all statistical analysis was completed in conjunction with competent scientists in this field, acting as consultants to the study.

An ecological impact may be any change in the normal state of the ecosystem and care should be taken in interpreting detected changes as either beneficial or deleterious. The results of scientific studies do not always give clear cut answers and in estimating an ecological impact within an area a range is likely to be more realistic than a single value. Where these values are extrapolated to include wider areas care should be taken to limit the extent of extrapolation and the inclusion of the level of confidence and inaccuracy within such values will help highlight the limitations placed in their use.

Content

1 Introduction

This Transferable Methodology has been written to cover the main phases involved in the Fal and Helford Recreational Boating Study: Environmental impact of recreational boating infrastructure on benthic fauna; referred to as the Fal and Helford Study. This report is aimed at those without a formal background in biological sciences but who may contribute to or be involved in the planning, establishment and coordination of similar studies.

The intention of this report is to inform future work, to avoid duplication of effort and to maximise cross-fertilisation of information and outputs nationally. It is hoped that lessons learned in the completion of the Fal and Helford Study will assist in the progression of similar studies in harbours and estuaries on a nationwide scale. The report summarises the relevant phases of the Fal and Helford Study in a way that aims to increase wider understanding of scientific approaches and rationale within maritime industries and allows future projects to build on the successful aspects of this work. It covers aspects of the study from funding and contributions through to statistical analysis and interpretation, with the intention of raising awareness of relevant sources of information, methods and techniques used but also highlighting the successes and potential drawbacks encountered in the Fal and Helford study.

1.1 The 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 2: Fal and Helford Audit of Recreational Boating Infrastructure). 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 1: Fal and Helford Recreational Boating Audit Form). 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.

1.1.1 Study Objectives

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)[1]. 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[2] (*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.

1.2 Funding and Contributions

The funding for the Fal and Helford Study was provided by the Project Partners, these include Cornwall Council, Falmouth Harbour Commissioners, Duchy of Cornwall, Environment Agency, Natural England, A & P Ports Falmouth and St Mawes Pier and Harbour Company. In the case of this study, the majority of Project Partners were also

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

relevant authorities within the Fal and Helford Management Forum and these partners formed a focussed Working Group influential in the development of the project. Prior to the appointment of a Project Coordinator, a project budget was drawn up, including costs and contributions covering salary, ancillary (travel and subsistence) costs, scientific consultancy, equipment and resources. At this stage the study had not been finalised and this resulted in a number of resource mismatches. For future studies this could be addressed by formalising the study objectives earlier in the process or by building flexibility into the project budget. The wide variety of Project Partners involved was beneficial to the project; it offered an extensive input of knowledge and resources from a wide suite of contributors and allows the project to consider activities within the estuary from a variety of different aspects.

In addition to monetary inputs, many of the Project Partners put forward in kind contributions of resources and several additional informal contributions were offered by other organisations around the estuary. The use of in kind contributions to complete the project was successful; however a number of important lessons were learnt. Many small organisations were positive about inclusion in the project and were amenable to providing data, knowledge and experience as the study ultimately offered a better understanding of potential impacts and habitats relevant to them. When acquiring commercial data care should be taken to meet data protection laws and many operators were willing to provide mooring information subject to the removal of personal data and under the proviso that it was for use as part of the scientific study only.

Any in kind contributions should be clearly defined early on, ideally with the details and limitations outlined in a memorandum of understanding to avoid issues later in the project. In the case of key contributions necessary for the completion of the project such measures are particularly prudent, ensuring that in the event a contributor recalls their contribution the overall project is not adversely affected. In kind contributions successfully employed as part of this project included extensive provision of local information, the use of Harbour Authority vessels, the scientific dive team and several vital pieces of survey equipment. When reliant upon in kind contributions additional contingency should be allowed to complete the project work. In kind contributions of resources and equipment are often dependent upon working around existing and arising contributor commitments, for example the use of Harbour Authority vessels was subject to the stipulation that they may be recalled as necessary for harbour duties.

1.3 Recommendations

- Developing the study through a **Working Group** can tailor the study to **local environments** and **issues**.
- Carefully **focus** broad initial research ideas into a study remit **realistically achievable** within the **timescale** available.
- Working as a **Project Partnership** can **increase** the availability of **funding, resources** and **'buy in'** to the outputs of the project through inclusion of multiple **local organisations**.
- **In-kind contributions** can be an effective means of **resource acquisition** and may **minimise** study **costs.**
- **Formal clarification** of in kind contributions and expectations will help **prevent issues** arising at a later date.

2 Initial desk study

A period of desk study is essential in establishing existing literature and current knowledge gaps on any given subject. It may be possible to successfully accomplish this work in house, minimising cost and maximising input of the Project Partners. This approach must be tempered with available expertise as incomplete data or insufficient depth in the literature review may necessitate the work being duplicated in greater depth during later stages. For the Fal and Helford Study the work was produced as three independent sections – an audit, a scoping study and a literature review. The audit was completed in house, while the scoping study and literature review were contracted externally.

The audit of recreational boating infrastructure within the estuaries was coordinated by Cornwall Council, with the relevant data for each area assembled independently by the individual Harbour Authorities and mooring operators using a standardised data form (Appendix 1: Fal and Helford Recreational Boating Audit Form). The end result was digitised and presented as a geographical information system (GIS) output by Natural England (Appendix 2: Fal and Helford Audit of Recreational Boating Infrastructure). The scoping study and literature review were then subsequently conducted by independent authors. While this approach did achieve the objectives required it lacked the continuity of completing the entire work package through one individual and required familiarisation periods as preceding material was passed on to subsequent authors. Ideally, involvement of either central consistent coordinator or project researcher throughout this initial work would maximise its effectual contribution towards the practical study. When such reviews are completed separately, timescales should allow all relevant contributions to be available as finalised reports prior to the start of the next phase. If the scientific researcher is not involved in the collation of relevant information, a handover period and a short desk study at the start of the practical phase is prudent to allow familiarisation with the preceding work, relevant literature and the study area.

2.1 Literature Review

A comprehensive review of current literature forms the fundamental groundwork of any study. Dependent upon the level of development and proposed direction of the project, this review may consist of either a highly detailed assessment of a specific impact or a wider summary of an activity and its potential impacts. For the Fal and Helford Study a brief scoping study identified current literature on potential impacts associated with recreational boating activities (Mather 2009). This work provided an excellent overall impression of the distribution of available literature and a summary of resources prior to the full literature review. The literature review for the Fal and Helford Recreational Boating Study covered an extensive range of potential impacts associated with recreational boating infrastructure and reviewed current international management practices and guidance to minimise these impacts (Neilly 2011). The direction of the literature review should ultimately reflect the information required as a precursor to the practical study, however if the remit of the study is still evolving, the literature review should aid in focussing this remit. Where a broad literature review is completed it is likely that an additional period of literature searches will be necessary to review the final study topic in greater detail. Within the Fal and Helford Study a secondary, more specific literature review would have been beneficial, as the study remit changed between the completion of the literature review and the start of the practical study. Additionally, where literature reviews are completed by separate authors, transfer of pre-sourced literature from the reviewer to the researcher would reduce duplication of effort.

The literature review should uncover valuable information on a wide range of topics, including any potential impacts and biological responses which may be anticipated, as well as suitable methodologies and appropriate variables to record. It is rare to find existing studies very similar to the proposed work, as the lack of available information is usually the reason for the study; however studies on a variety of literature topics may yield valuable relevant information. Literature may be available on the impact in question but across different habitats or covering activities causing a comparable impact on similar habitats or at differing scales. Relevant literature on related studies is important in highlighting previously used experimental methodologies and techniques, allowing consideration of the suitability of various methods within different experimental designs and highlighting the positive and negative aspects of each.

Literature reviews should predominantly comprise primary research papers as such work has been peer-reviewed externally by other experts within the field. There are also an increasing number of independent reports, otherwise referred to as 'grey literature', written by relevant statutory, commercial and conservation organisations. These reports may provide valuable information not present in primary literature; however they are rarely independently reviewed and care should be taken in their interpretation and results or conclusions should be cross-referenced where possible.

2.2 Moorings and Habitats Research

A detailed understanding of the habitats types and distributions and of the locations and types of infrastructure present is vital to successfully planning experimental work. Habitat distributions and infrastructure types need to be comprehensively researched, identified and clearly mapped to allow selection of the most appropriate study areas. The extent of habitat and infrastructure research required will depend upon the scope and the nature of the study and of the area in which the study is to be conducted. The habitat and infrastructure research for the Fal and Helford Study took a considerable period of time due to the multitude and size of the potential study locations and the multiple moorings operators and licensees involved.

The Fal and Helford recreational boating infrastructure audit was completed prior to this study and collated information on all of the recreational boating infrastructure types within the estuaries, using a standardised questionnaire-style form which was completed independently by Harbour Authorities or mooring operators (Appendix 1: Fal and Helford Recreational Boating Audit Form). This audit established total numbers for each type of infrastructure but locational information was only collected as either a central point or as locations of the extremities; as such the information from the audit was appropriate for a broad-scale overview of infrastructure within the estuaries but was not at sufficient resolution to plan the scientific study.

For the Fal and Helford Study mooring infrastructure and habitat research was conducted through two complimentary methods, literature searches and informal interviews, with the outputs of both supported by scoping surveys where necessary. Throughout this phase, clear project objectives were beneficial in gaining maximum participation of potential data contributors. Regular liaison with Project Partners, or appointed representatives, was also vital to continually develop the remit of the study to reflect the available infrastructure and habitats, to source practical survey methodologies for the environments encountered and to clarify any adjustments necessary to the project objectives or timescale.

2.2.1 Literature Searches

Literature searches for habitat distributions and infrastructure types can be easily completed alongside the literature review. The level of literature available for a geographical area will vary dependent upon its physical size, environmental designations, human activity and the level of ecological or conservation interest in the area. For the Fal and Helford, a good place to start for broad-scale habitat data within estuaries was with the Marine Nature Conservation Reviews (MNCR) produced by the Joint Nature Conservation Committee (JNCC) (Figure 1). These area summaries collated information on the benthic marine habitats, communities and species of coastal inlets around

Great Britain[3]. These reports collate information from prior studies and some of the original contributing reports are not electronically available and now quite hard to acquire. The Fal and Helford Study was conducted within an Special Area of Conservation (SAC) and it might be anticipated that a greater level of literature would be available. The SAC interest features are subject to condition monitoring by Natural England, with monitoring occurring on a six year cycle, but due to resource limitations the monitoring programme may only encompass sub-features of an area within each cycle.

Previous projects and surveys conducted within the area, even if superficially unrelated, often allow a piecemeal compilation of habitat types. In the case of the Fal and Helford such surveys included dredging reports and environmental impact assessments completed close to the potential study areas. Additionally, marine data networks both nationally, such as the Archive for Marine Species and Habitat Data (DASSH[4]), or locally, such as the Environmental Records Centre for Cornwall and the Isles of Scilly (ERCCIS[5]) are a good source of species and habitat records for an area. Both estuaries studied as part of the Fal and Helford Study have active and established marine conservation groups[6] which contribute towards such data networks; however work tends to focus on charismatic

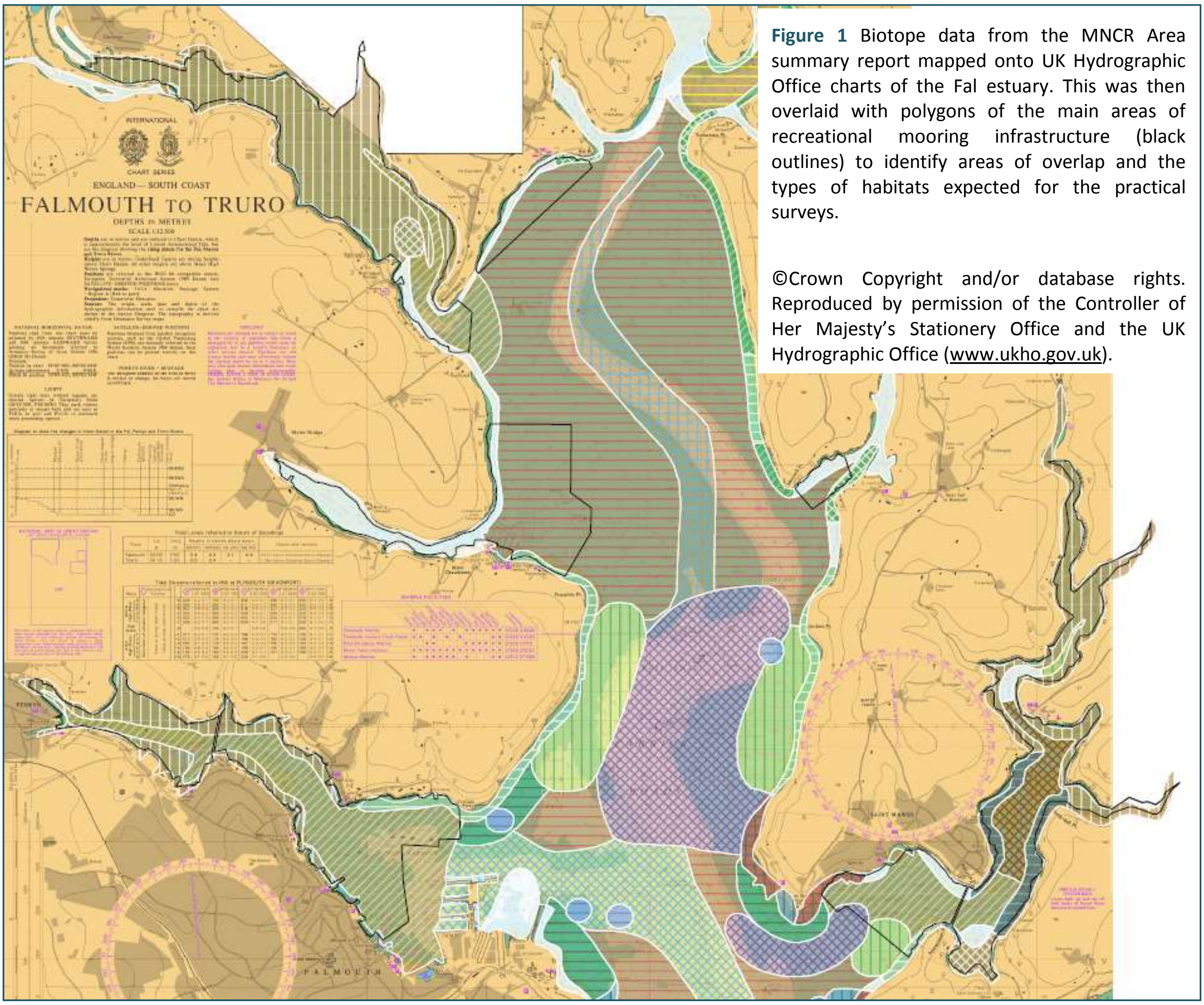


Figure 1 Biotope data from the MNCR Area summary report mapped onto UK Hydrographic Office charts of the Fal estuary. This was then overlaid with polygons of the main areas of recreational mooring infrastructure (black outlines) to identify areas of overlap and the types of habitats expected for the practical surveys.

[3] The full list of summary MNCR reports is available through the JNCC website, available at http://jncc.defra.gov.uk/page-1596 . Site accessed June 2012.

[4] Further information available through www.dassh.ac.uk . Site accessed June 2012.

[5] Further information available through www.erccis.org.uk . Site accessed June 2012.

[6] Within the Fal and Helford estuaries Cornwall Wildlife Trust (www.cornwallwildlifetrust.org.uk) and the Helford Voluntary Marine Conservation Area (VMCA) (www.helfordmarineconservation.co.uk) are actively involved in survey activities.

habitats, notably maerl and seagrass habitats, which receive a higher level of attention and were relatively well studied in both estuaries. Typical estuarine habitats, areas of sub-tidal mud, gravel and sand, are on the whole less well studied. These habitats are also harder to record and categorise to the same level, fewer studies are conducted and distributions are often generalised and at a very broad scale.

Data mining, and subsequent collation, of species and habitat data from numerous networks and minor survey reports is time-consuming to conduct and difficult to collate concisely and the timescale for this phase should reflect sufficient time to collate and analyse the available literature at an appropriate level. For the Fal and Helford estuaries little recent, collated habitat information was available in the study areas and the timescale was not sufficient to allow detailed collation and mapping of data from a multitude of sources. The habitat data used primarily comprised of the MNCR biotope maps supported where available by additional information from smaller studies including environmental impact assessments, Oil Pollution Response Unit (OPRU)/ Field Studies Council (FSC) and English Nature[7] reports. Marine data networks, such as DASSH and ERCCIS, can collate available data upon request and completion of this as part of the preparatory work in advance of a study would be valuable.

2.2.2 Interviews

A wealth of first-hand ecological and historical knowledge of the project area is often available and can be of considerable valuable if it can be accessed. Informal interviews with relevant local organisations can yield broad habitat distributions and important technical details regarding mooring infrastructure, locations and other harbour workings within the study areas. As part of the initial planning phase of the Fal and Helford Study a range of local organisations were contacted, including representatives from Harbour Authorities, moorings operators, fundus owners, statutory nature conservation organisations and local conservation groups. In this respect, working as a partnership and being based within the Harbour Authority, provided a good pathway for accessing local knowledge and contacts through which to build a complete picture of the estuaries.

For the Fal and Helford Study, a basic contact list of organisations and local representatives was initially identified and this contact list grew quickly after contact with the first few individuals. Many of the organisations contacted were able to offer local knowledge and reports, often not widely available, detailing previous work within their area. Interviews with Harbour Authorities and moorings operators allowed direct access to moorings data and technical details of the types of infrastructure present. All relevant parties approached as part of this phase offered information valuable for the development of the project. Personal interviews were highly successful in acquiring detailed local information and it is possible that this method, used in conjunction with a detailed questionnaire, would have been a more effective means of completing the infrastructure audit.

2.2.3 GPS and Bathymetric Data

GPS locations of mooring infrastructure were provided by the main mooring operators within each area. This information was relatively easy to obtain within the main body of the Fal and Helford estuaries, where the most moorings were operated by few, large-scale organisations. In quieter creeks and inlets, scattered independent moorings may be operated by multiple mooring operators or licensees, or privately owned, making acquisition of detailed locations and numbers more difficult and time-consuming. Accuracy of GPS data varied between data sources, an important consideration if the study was to include sub-tidal remote sampling based on infrastructure GPS locations. With all moorings locations, discussions with the harbour operators and visual confirmation of mooring locations (on water or from shore) allowed identification of un-accounted for private moorings within the

[7] English Nature is now Natural England.

potential study areas. Alongside the locational data some mooring operators were able to provide names for the resident vessels, which made quick identification of moorings in the field easier.

Basic bathymetric data is available through the use of UK Hydrographic Office[8] navigational charts of the planned study area, which can be imported directly into geographical information system (GIS) software. Detailed bathymetric data can be valuable if available and may be sourced through the relevant Harbour Authorities. For the Fal and Helford Study it was possible to source detailed bathymetric data covering Falmouth Inner Harbour (Figure 3), St. Mawes and part of the Mylor moorings. This data enabled better visualisation of the seabed bathymetry and, in some cases, confirmation of the presence of mooring scour, as depressions in the seabed around the mooring blocks.

Where electronic locational and bathymetric data was available it was collated in GIS software. This approach enabled clear visualisation of mooring layouts and distances between the moorings in conjunction with habitat and bathymetric data, making interrogation of data relatively straight forward (Figure 2). The time required to collate and present this is dependent upon the coordinate system and format in which the GPS data is supplied. Additional transformation of data between coordinate systems (WGS84, OSGB36, etc.) and formats (e.g. degrees minutes seconds or decimal degrees) may extend the time required therefore it may be prudent to request all information in a standardised system and format. The GIS presentation of data layers was valuable in the selection of suitable moorings for inclusion in the study and allowed quick and easy explanation of the rationale behind area selection to Project Partners.

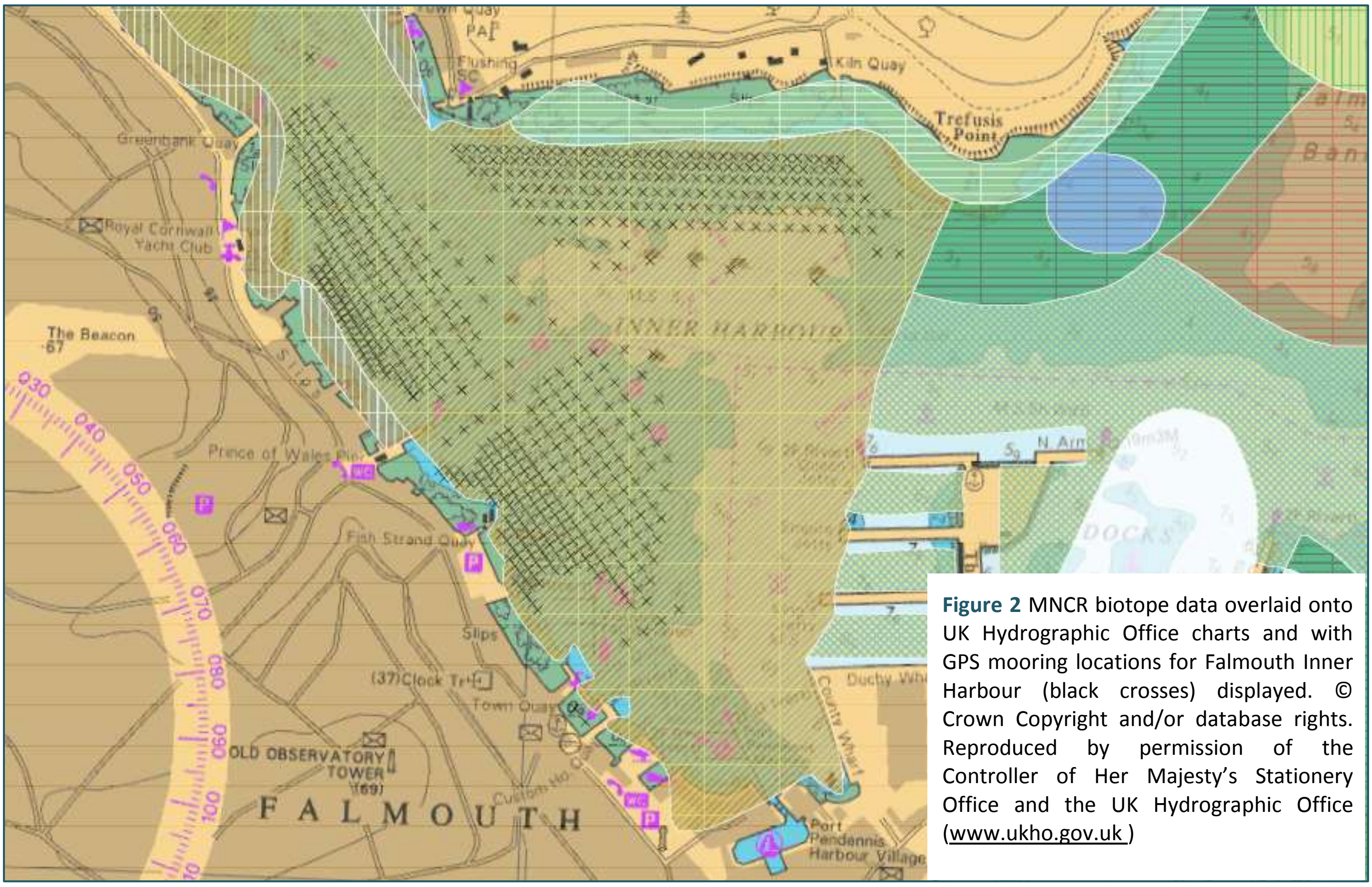


Figure 2 MNCR biotope data overlaid onto UK Hydrographic Office charts and with GPS mooring locations for Falmouth Inner Harbour (black crosses) displayed. © Crown Copyright and/or database rights. Reproduced by permission of the Controller of Her Majesty's Stationery Office and the UK Hydrographic Office (www.ukho.gov.uk)

[8] Further information on the UK Hydrographic Office is available online at www.ukho.gov.uk. Page accessed in June 2012.

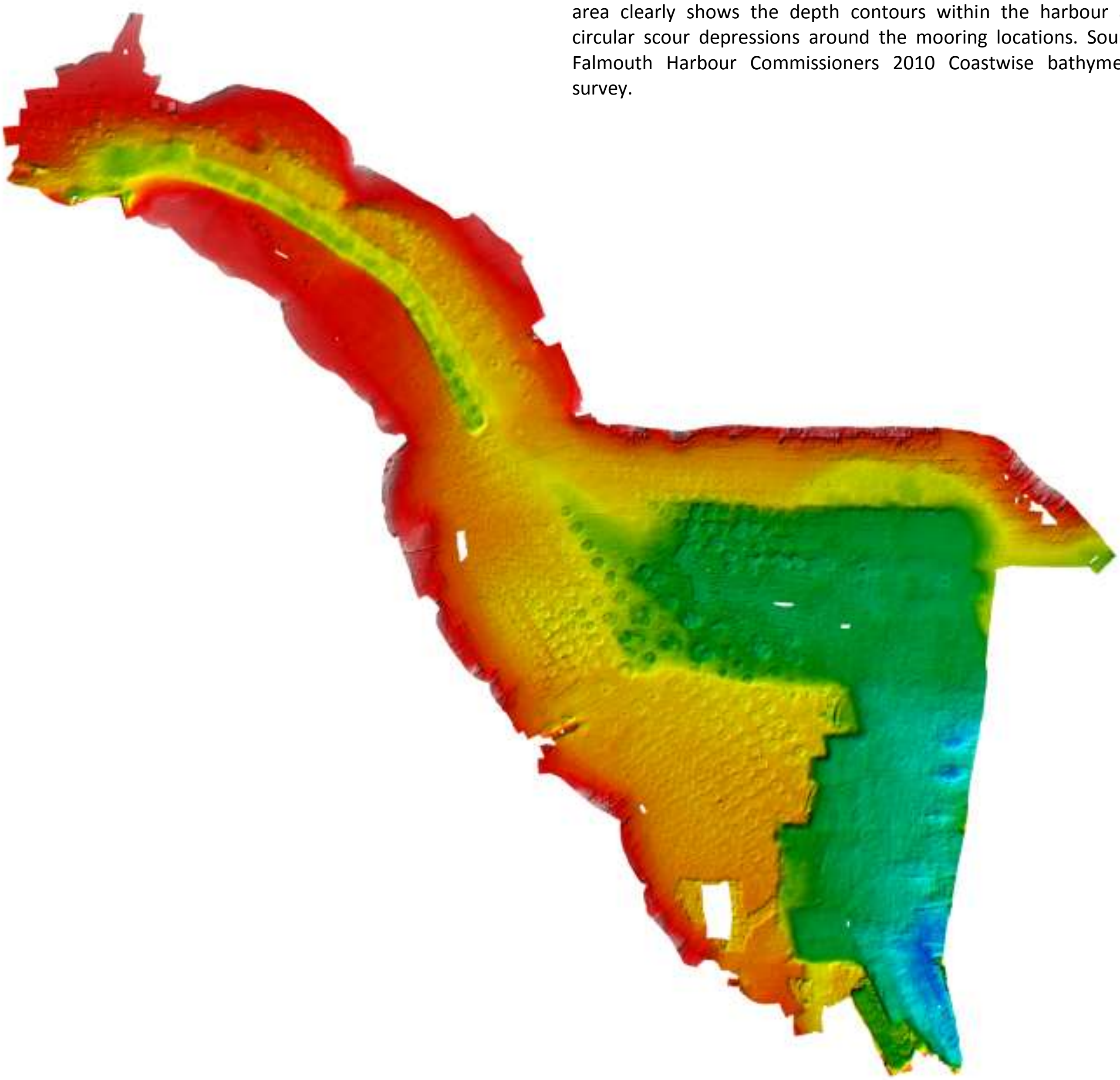


Figure 3 Detailed bathymetric data for the Falmouth Inner Harbour area clearly shows the depth contours within the harbour and circular scour depressions around the mooring locations. Source: Falmouth Harbour Commissioners 2010 Coastwise bathymetric survey.

2.3 Additional Considerations

Additional factors including sewage outfalls, mining effluent, industrial output, popular anchorage areas and historical use may also contribute to establishing the physical, chemical and biological characteristics of an area. Further investigation into additional influential factors is valuable and worth the minimal additional time required, as local knowledge of such influences is easily collated while researching the environmental factors and infrastructure of the survey locations. Whilst it may not be possible to avoid all secondary impacts, knowledge of potential factors which may influence the study outcomes is very valuable when it comes to assessing and interpreting study results.

Throughout the planning phase a clear view of the project objectives, proposed methodologies, anticipated outputs and potential management values, combined with regular communication with relevant parties, is vital in efficiently collating environmental, historical and local knowledge of the area. It is important to ensure that sufficient time is allocated for information collation and assessment, as well as for regular project meetings to discuss and adjust the study in response to the available information. For the Fal and Helford Study, all initial research interviews were conducted separately, often as a result of one interview indicating another potential avenue or contact for further information. If the project remit is identified early in the process an initial opening meeting with representatives from prominent organisations could speed up this process, with further individual meetings with additional contributors added subsequently.

2.3.1 Scoping Surveys

Scoping surveys allow the findings of the literature search and interviews to be field checked and the suitability of locations to be confirmed. This was particularly valuable in areas where habitat data was limited, missing or conflicting. Detailed, recent habitat data was not available at the scale of the whole Fal and Helford SAC. Broad-scale biotope data was available (Moore et al. 1999) and this was initially used to identify potential areas of study across broadly similar biotopes. In some areas this was supported by additional studies and observations; however high resolution habitat data was not readily available concurrent with survey locations. Once potential study sites had been narrowed down, scoping studies were used where practical to visually verify the habitats types present. The scoping surveys for the Fal and Helford Study also allowed visible confirmation of the presence of a physical disturbance due to the movement of the mooring infrastructure and an opportunity to trial of potential survey methodologies.

The scoping studies were completed using two techniques. A low cost 'SCUBAR' underwater scope (Iris Innovations Ltd., Hampshire, UK[9]) designed for recreational boating users, was initially trialled. This allowed quick visual assessment of the seabed type but was confined to working at a maximum working depth of around 4 metres. The equipment worked well for basic, passive survey however it was hard to control with precision. Secondly, a Video Ray Pro4 ROV[10] was used. This method allowed greater directional control and gave better resolution video footage but access to the ROV was limited. Partnership working and resource sharing with local organisations is strongly advised to minimise costs, although this did impose limited availability of resources. For the Fal and Helford Study local organisations and university departments could offer access to an ROV and Harbour Authorities had hydrographical survey equipment which could also be utilised if needed. Where scoping study data was collected, it was valuable in confirming the habitat types and distributions, allowing greater confidence in the optimal placement of the study sites. The scoping surveys with the ROV ruled out some of the potential survey areas identified during the Fal and Helford Study due to unexpected habitat types or practical limitations.

The ROV scoping work included limited time to trial and develop a suitable, epifaunal survey methodology. As the direct physical impact of recreational boating infrastructure was anticipated to be variable across the mooring area, it was important that the scale of transect used was sufficient to detect potential direct physical impacts as well as any general influence of impacts within the mooring area. This required a consistent methodology that would produce transects comparable within and between mooring locations. Initial ideas of utilising a physical, *in-situ* transect were quickly ruled out due to positioning inaccuracies and logistical issues in laying and recovering the transect. Time spent developing the survey methodology at this stage ensured viable and consistent survey methodologies were in place at the start of the full epifaunal survey.

Productive working relationships with local conservation organisations may minimise the need for scoping surveys. Within the Helford estuary, Natural England and the Cornwall Inshore Fisheries and Conservation Agency (IFCA) had completed a series of recent video transects, some of which overlapped with potential survey locations. While a

[9] Further information on the SCUBAR is available through Iris Innovations http://www.boat-cameras.com. Site accessed June 2012.
[10] Further information on the Video Ray Pro 4 ROVs is available at www.atlantasmarine.com/htm/product/details/videoray_pro_4. Site accessed June 2012.

report was not available, the raw footage was released, allowing quick comparisons of some potential study areas and of similar areas of habitat within the estuary.

2.4 Recommendations

- Conduct a **comprehensive scoping study** and **literature review** to **establish current knowledge** and appropriate methodologies relevant to the study.
- Maintain **consistency** in the project team or account for project handover periods to **minimise replication** of effort and **maximise knowledge transfer**.
- **Research** information through **multiple approaches** and a variety of project partners to **maximise incorporation** of information.
- Utilise Geographical Information Software (GIS) to quickly **interrogate** estuary **data** and **identify suitable study areas**.
- Conduct **scoping surveys** in areas where recent, detailed data is not available to **confirm suitability** of potential survey areas.
- **Trials** of potential methodologies can **identify problems** early on and ensure **consistency** throughout the full survey.

3 Experimental design

This section is not intended to allow a non-scientific individual to produce a successful scientific experimental design and as such does not cover all aspects or venture into great detail on experimental designs. This section is intended to assist non-scientific individuals in understanding the factors and considerations involved in planning a study and the rationale behind basic experimental designs. During planning the advice of a competent scientific advisor should be used to ensure that the design used is fit for purpose and will result in robust scientific outcomes. For the Fal and Helford Study scientific consultancy was provided by the University of Plymouth and this was budgeted into the project from the outset. This allowed contributions from highly competent experts in the field ensuring a suitable scientific study and adding considerable value to the outcomes.

3.0.1 Designs for the detection of environmental impact

The primary aim of environmental monitoring studies is the investigation into the effect of a perceived environmental impact on organisms within the affected habitat. The detection of the impact has often traditionally been achieved through a BACI (Before After Control Impact) experimental design, where studies compare an impacted site and a control site, sampled prior to and subsequent to the appearance of an impact. A commonly accepted flaw in this design is the comparison of a single impacted site against a single contrasted control, as these two sites may be naturally different (spatial variation). This design also relies upon the ability to sample prior to the installation of a potential impact, a requirement that is not always possible. The 'beyond BACI' principle addresses these two major issues in order to maximise the likelihood of correctly assessing the significance of the effect of an impact (Underwood 1992).

Firstly, the requirement for spatial replication and elimination of pseudo-replication in environmental monitoring studies need to be addressed. By collecting samples from multiple impacted sites and multiple control sites the likelihood of falsely identifying an impact due to natural spatial variation is minimised. Secondly, the requirement for collecting samples over a period of time, temporal replication, allows the study to address natural temporal variability present within populations. It is argued that strictly these temporal replicates should be assigned randomly to remove the influence of regular, anticipated patterns (e.g. seasonal fluctuations) (Underwood 1992). Addressing both of these variables allows the study to account for the normal, non-parallel fluctuations of populations which result in natural differences between samples. In an ideal world, an experimental design would collect samples at multiple, random intervals both prior to and following the installation of the impact sources and at multiple impacted and control sites to maximise the likelihood of correctly detecting a population change in response to the impact (Underwood 1992).

3.0.2 Natural variation in marine systems

Benthic organisms within marine soft sediments are widely acknowledged to display variation in their spatial distributions, i.e. communities in different locations may be naturally different in composition and relative organism abundances. Physical processes, such as sediment type or water depth, are generally considered responsible for large-scale distribution patterns, within which biological and physical factors, including disturbance, maintain a mosaic of communities. This heterogeneity (patchiness) may be evident at various spatial scales and it is unlikely to be known prior to conducting a study; however if not considered as part of the experimental design this natural heterogeneity may complicate and confound comparative abundance studies attempting to elucidate the effect of an impact.

Previous studies have addressed the need to consider natural spatial variation within studies. Natural spatial variability can be accounted for with the use of a nested sampling design and in careful selection of appropriate spatial scales at which to sample (Morrisey et al. 1992). A nested sampling design involves the collection of samples across a series of successively smaller spatial scales. The Fal and Helford study employed a variation on this design with a multiple sites nested within the mooring locations to identify potential differences between sites within a location.

3.0.3 Types of impact

An impact can be broadly categorised as one of two types. A pulse impact is acute and relatively short-term, an example of this relative to recreational boating activities would be a boat anchoring; the deployment and retrieval of the anchor creates a disturbance which is removed when the vessel moves on. A press impact is chronic, occurring over a longer period as a constant pressure on the ecological system, for example the disturbance anticipated from recreational mooring infrastructure whereby the mooring is present for a long period of time and constantly causing a disturbance on the seabed. Some impacts may include aspects of both types[11]. The type of impact anticipated influences the spatial and temporal replication required to detect it. If a pulse impact is anticipated sampling effort should be concentrated upon increasing the temporal replication within the study, whereas if a press impact is expected sampling effort is better directed towards expanding the number of locations studied (Underwood & Chapman 2003). Increasing replication in the manners identified above was indicated as more effective than increasing replication within specific sampling times or locations (Underwood & Chapman 2003).

3.0.4 Real world design and limitations

A fundamental starting point in experimental design is clarifying the detail of the question that you are trying to answer. Estimating the broad-scale ecological footprint across the whole moorings areas will use a different experimental design to identifying the graduated impact within the moorings areas. The design should reflect if the main aim of the project is broader scope or greater detail. At this stage, regular input from Project Partners regarding the anticipated outputs and the involvement of scientific advisors will aid in designing the most appropriate experiment design for the study. As the purpose of Fal and Helford Study was to assess and estimate the ecological impact of recreational boating infrastructure as a result of direct, physical disturbance it was important to use an experimental design that would detect detail of the extent and allow the effect of this impact to be teased out of any wider impact from the moorings infrastructure. The decision to investigate the ecological footprint in such a way strongly influenced the final experimental design. For the Fal and Helford Study, the influence of the Working Group dictated that the study cover a range of areas and habitats and was widely applicable to numerous Project Partners.

Spatial variation was accounted for by sampling multiple locations of recreational boating infrastructure throughout the Fal and Helford SAC, initially determined by the Project Partners involved and the areas of mooring infrastructure available; however this was confounded by the lack of detailed habitat information and the loss of a study location. Multiple study sites were nested within each location to allow for the detection of smaller-scale intra-location spatial variation. This involved using two sites per location, a reflection of the availability of comparable infrastructure and the timescale of the project. Multiple replicate moorings were then identified within each of the study sites. At each mooring, sample distances were selected to reflect the areas within the moorings potentially impacted to differing extents by the mooring infrastructure. These distances were selected, rather than arbitrarily, randomly or logarithmically assigned, to ensure that they were equivalent across locations. The selection of these distances was

[11] For further information on 'pulse' and 'press' disturbances and their detection see Underwood, 1991.

based on the technical specification of the mooring infrastructure and the tidal range within the area, targeting samples within the circumference of the ground chain, the riser chain and outside the reach of the mooring infrastructure. This led to the selection of distances of 2 metres, 5 metres and 11 metres from the centre of the mooring block. The sample hierarchy for the Fal and Helford Study is outlined in Figure 4.

The experimental design used in investigating the ecological impact needs to be tailored to match the required outputs of the study and the study location and resources. The design will vary with every study and a wide variety of literature is available covering experimental designs for environmental monitoring and the detection of environmental impacts, see Underwood 1991; Eberhardt & Thomas 1991; Underwood & Chapman 2003; Stewart-Oaten & Bence 2001 for further information. By necessity the experimental design of any study is almost always limited and compromise must be made between the ideal experimental design and practical capabilities, with time, budgetary and resource constraints imposing additional limitations. The importance here lies in the choice of a design that is 'fit for purpose' and is capable of successfully answering the questions posed by the study.

Whilst the experimental design of the Fal and Helford recreational boating study was by no means ideal, it represented the best experimental design possible, given the available information, resources and timescale. In any study it is highly likely that in hindsight there will always have been another way. It was possible to accommodate spatial replication, but not temporal replication, into the experimental design used for the Fal and Helford Study. Compromises in the experimental design must be considered carefully, as they have potential implications in the results. This does not necessarily mean that the results are not valid; more that care should be made to highlight compromises and limitations when interpreting the results.

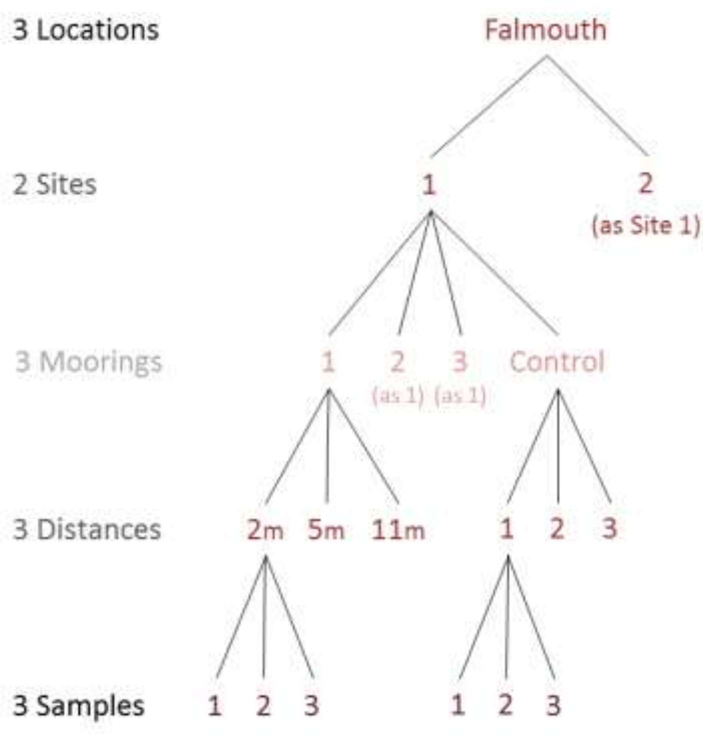


Figure 4 Sample hierarchy for the Fal and Helford study. 3 samples were collected from each of 3 distances at 3 moorings. A similar 3 samples were in 3 groups from the control area. The moorings and control area form a site and 2sites were nested within each location.

3.1 Recommendations

- **Engage scientific expertise** and **judgement** in planning the experimental design.
- Successful experimental designs account for the presence of natural **spatial and temporal variation** within ecosystems.
- Maintain **clear focus** on the objectives of the study, utilise scientific **advisors** and **review** available literature to ensure the **experimental design** suits the study.
- Aim for the **best experimental design** possible given the resource, budgetary and practical **limitations** of the study.

4 Epifaunal Survey

4.1 Underwater video techniques

Historically, knowledge of the structure and function of benthic communities has been gleaned from samples acquired by destructive remote sampling devices, including grabs, cores and dredges. These techniques allow physical collection of sample specimens from an area for detailed examination, but the orientation of the sample and its contents, and its context with regard to the bigger picture is often lost. Some cores and grabs retain the integrity of the sediment surface, but even this represents only a tiny fraction of the surface sampled. In comparison to traditional sampling techniques remote underwater videography is new and constantly evolving, but the use of these techniques has become firmly established as a cost-effective, low impact and minimal resource method for rapidly surveying large areas of seabed (Stevens & Connolly 2005; Attrill et al. 2011).

The type of underwater video system used for any particular project will be a function of the project requirements, available resources, funding limitations and a compromise of the quality required. For the Fal and Helford study, the use of a high definition towed video array was initially offered to survey the epifaunal assemblages within the mooring areas (see Attrill et al. 2011). The towed array itself consists of a frame which houses a high definition camera and light system, however in contrast to traditional video sled designs the towed array featured a finely tuned buoyancy system to allow minimal contact with the seabed and minimising disturbance, making it ideal for the use on the soft sediments encountered within the mooring areas. The relative simplicity of this type of video system, in comparison with remotely operated vehicles (ROVs), means that the specifications of the camera and lights will generally be higher for an equal or reduced cost. Although this option was available and offered the quality required, it was discounted as spatial limitations, tidal flows and the risk of entanglement within areas of recreational mooring infrastructure made it impractical for use within the harbours. Under these conditions encountered in the mooring areas, a reactive ROV system, capable of moving independently of the support vessel and of being manoeuvred around obstacles and entanglements, was more suitable than the passive, towed array, sacrificing a degree of resolution in the footage. The ROV available for the Fal and Helford Study was a Video Ray Pro 4 (Atlantis Marine Ltd., UK[12]) owned by the University of Plymouth.

4.1.1 ROV Considerations, limitations and modifications

The Video Ray ROVs have been designed with scientific research in mind and a number of scientific and conservation agencies, including the University of Plymouth, Cornwall Inshore Fisheries and Conservation Agency (IFCA) and Natural England use them for survey and monitoring purposes. ROVs at this level are relatively easy to operate, easily portable and operable from relatively small (~8 metre) survey vessel.

Even a relatively small ROV requires a stable platform, in the form of a vessel with sufficient deck and cabin space. The risk of entanglement with the mooring infrastructure necessitated that the base vessel be stationary. It had initially been envisaged that it would be possible to conduct several transects from a suitably located, vacant mooring; however a distance limitation imposed by the weight of the negative tether ruled out this technique. To achieve the full length of the transect (30 metres) it was necessary to raft alongside vessels on the mooring at the start of the transect. While operating from clearly marked Harbour Authority vessels this was not a problem; however this may cause issues if using private vessels. Rules and regulations which may affect survey work within harbour waters will vary between harbours; this should be checked and appropriate permissions gained as part of the planning for any fieldwork undertaken. Close collaboration throughout this phase with Harbour Authorities will

[12] Details available at www.atlantasmarine.com/htm/product/details/videoray_pro_4

greatly aid planning and practical survey operations. Extending information about the survey work, through pathways such as Harbour Master's notices, to other water users as a common curtsey is also often worthwhile. Throughout the survey itself, appropriate signals, in accordance with the Convention on the International Regulations for Preventing Collisions at Sea (1972) COLREGs[13], should be clearly displayed and a vigilant visual and VHF watch should be maintained.

During the course of the epifaunal surveys a number of points were raised with regard to the operation of an ROV within a busy harbour environment. Firstly, two types of umbilical cable were trialled – positively and negatively buoyant. Initial trials with the positively buoyant tether found that it did not disturb or snag on the seabed and it was easy to monitor the position of the ROV from the support vessel. Although the tether was bright and highly visible, it was quickly apparent that an additional cover vessel was required to provide watch and to steer vessels clear of the survey area and prevent vessel entanglement or prop damage to the umbilical. For this reason, from an operational perspective, the use of a negatively buoyant tether within busy harbour areas was considered more practical. With the ROV tether on the seabed, vessels can pass over the site without disturbing the survey and this removed the need for additional boat cover. The disadvantage to this was that on longer transects, and in areas with dense macroalgal cover, snags and the cumulative weight of the tether limited the performance of the ROV.

Modifications to the ROV can increase the value and use of the video output. A relatively simple, effective modification is the addition of external laser pointers to the ROV (Apinex.com Inc. BALP-LG05-B105 green lasers). The lasers used are laser pointers for divers; they are self-contained units and work to depths of approximately 90 metres making them ideal for this use. Lasers fixed parallel to the ROV frame give a constant scale to the footage

Figure 5 Stills photograph taken by the ROV representative of good quality ROV footage acquired through a Vide Ray Pro 4 ROV. The two green dots visible in the picture are the laser pointers (scale 18cm).

[13] Information on COLREGs available at www.dft.gov.uk/mca/msn_1781-2.pdf . Page accessed June 2012.

(see Figure 5) and allow later overlay of quadrats, but require calibration prior to deployments. An additional modification, not available for this work but considered of potential value for future studies, would be the attachment of self-contained, mini high definition cameras to the ROV body; for example the addition of a "Go-Pro" camera[14] or similar. The addition of such cameras would increase the resolution of the footage collected at relatively low cost and allow multiple views, wider transect coverage or stereo images of the transects to be collected.

The footage produced by the ROV offers real-time viewing of the seabed epifauna and the output is relatively clear with large and conspicuous organisms easy to spot on open seabed (Figure 5). In areas of seagrass cover, encountered on several Fal and Helford Study transects, the ROV is forced above the seagrass to prevent entanglement of the propellers and this obviously impacts the video resolution as well as altering the width of the transect[15]. Areas of seagrass or dense macro-algal cover also mask the organisms living under and within the bed and this reduced visibility may lead to significant underestimation of biodiversity within these areas (Figure 6).

Figure 6 ROV footage representative of areas seabed where an epifaunal survey conducted by remote video is likely to underestimate the biodiversity present. The screen grab shows footage from one of the Helford control sites where large areas of macro-algae were present.

[14] Further information is available from www.gopro.com. Page accessed June 2012.

[15] The presence of seagrass on a transect may require the ROV to be as far as 2 metres above the seabed to be clear of the seagrass cover. Source MarLIN:

4.2 Analysis of ROV footage

4.2.1 Types of analysis

The analysis of the video footage will depend on the resolution of the footage and on the ultimate aim of the survey. The footage collected for the Fal and Helford study was of relatively low quality, given the size of the majority of fauna encountered, and this work was completed as a supplement to the main infaunal study. Attempts were made to record abundances within the footage; however these were discontinued as organisms were not consistently and reliably identifiable throughout the video footage. Final analysis of the video footage recorded only presence or absence at intermediate taxonomic levels. The footage was however suitable for its main purpose; the confirmation of the types of habitats present and assignment of broad-scale biotopes.

If greater resolution footage is available or if the video is being used to investigate abundance or percentage cover of specific large and highly visible organisms a different method may be employed. Multiple stages of analysis may be used, including recording abundances for large and abundant organisms and frame grabs for quantification of abundant fauna or 'turf' coverage. The use of frame grabs extracted from the video footage can allow extraction of more detailed information, better quantification of species abundances and size estimations of organisms where the video quality is sufficient to allow use of this method. Frame extraction can be completed manually, however increasing use of these techniques has led to the development of frame extraction software to automatically extract frames at set intervals and to overlay calibrated quadrat grids (Attrill et al. 2011). Separate analysis is required to determination of the number of frame extractions required to accurately represent the whole transect and avoid autocorrelation issues, an example of this justification is given in Attrill et al. 2011.

4.2.2 Resources

The video footage files output from the ROV can be relatively large and appropriate data storage will be necessary, preferably as multiple copies in separate physical locations. As an indication, for the Fal and Helford study, videos of approximately 15 minutes resulted in file sizes of around 200-300MB each. The time required to process the video footage will vary considerably dependent upon the quality of the footage, the type of analysis required and the familiarity of the analyst with the species present and the analysis methods. For the Fal and Helford Study, with analysis restricted to the recording of the presence/absence of taxonomic groups, the time taken to process each video was approximately 2-3 times the length of the video; for 48 videos of approximately 15mins each this equates to between 24 and 36 hours to process. If greater resolution or more detail is recorded, or a frame extraction analysis is used, then these are all likely to increase the timescale required.

An initial trial run of a limited number of videos should be used to identify clear criteria for discarding or discounting footage and to identify a start and end point on transects, as these must remain consistent throughout the video processing. If using more than one analyst, clarification of these points is vital to minimise subjectivity and prevent unintentional influences on the results. Amongst other benefits, trial analysis of videos allows a standardised taxonomic database to be drawn up prior to the start of the main bulk of video processing.

4.3 Recommendations

- **Consider available resources** and anticipated **output** in selecting a suitable method for epifaunal survey.
- Where possible, **trial equipment and methodologies** prior to the survey to address potential issues early.
- **Liaise** closely with **Harbour Authorities** when planning surveys within harbours to **minimise disruption**.

5 Infaunal Survey

5.1 In-situ versus Remote Sampling Techniques

As part of the initial planning, both *in situ* (diver) and remote (grab or corer) techniques were considered as potential options for collecting infaunal samples around the mooring infrastructure. Remote sampling techniques have been employed previously in the collection of infaunal samples for the purpose of establishing potential impacts of mooring infrastructure. Smith 2000 successfully used a Craib corer to collect infaunal samples at specified distances from naval moorings within Plymouth Sound; however, the size and nature of the infrastructure involved denoted that the scale of the sample intervals was considerably larger than required for a study on recreational vessel moorings. As a result the locational inaccuracies in the sample technique were minimal when compared to the sample intervals (10, 20, 50, 100 and 250 metres from mooring centre). Smith 2000 also highlighted a number of issues resulting from the use of remote techniques during the sampling, including incomplete and lost samples as a result of movement of the surface vessel relative to the equipment on the seabed and failure of sampling equipment due to entanglement with mooring infrastructure. In investigating potential differential impacts between SEAFLEX® moorings and standard chain moorings at a recreational vessel scale, PML Applications employed the use of a mini van Veen grab in the collection of infaunal samples (Kendall et al. 2006). In this instance the study was not comparing graduated distances, instead comparing impact at the broader scale of within the swing area of the mooring infrastructure against external controls and therefore the accuracy of the sample position relative to the mooring centre was not as vital. Within this study, the presence of drifting macroalgae on the sediment surface was identified as an operational limitation, requiring repeated deployment of the grab to achieve successful sample collection.

The use of *in situ* sampling techniques for the collection of the infaunal samples allows increased accuracy of sampling when working with small separation distances, as the samples are taken directly from the seabed rather than from the vessel above. As the Fal and Helford Study was aimed at investigating variation in impact with gradual distances from the mooring, a highly accurate sampling method was required. Samples were needed from distances of 2 metres, 5 metres and 11 metres away from the centre of the mooring block, with minimal variation around the desired sample distances. To achieve this level of accuracy consistently across all locations, the use of divers to collect infaunal cores offered the best option. The use of remote techniques was discussed with Project Partners, as the use of differential global positioning system (DGPS) on Harbour Authority vessels would increase the accuracy of deployments; however even in areas with accurate DGPS locations for mooring blocks, the combination of potential error in mooring location, vessel position and sample position would lead to relatively large inaccuracies (1-2 metres) around the required distances.

5.2 Scientific Diving Projects

The full details involved in planning a scientific diving as part of a study are lengthy and guidance to assist in planning scientific diving operations is already available. The following information given below is only intended as a brief overview, for further information please refer to the relevant Health and Safety legislation and an comprehensive interpretation of these, written for the statutory nature conservation organisations, in Holt 2011. A further list of useful contacts and information is included in the Appendix (Appendix 4: Information for Scientific Diving Projects).

Any diving work completed as part of a scientific study must comply with the Health and Safety Diving at Work Regulations 1997 and should follow the Scientific and Archaeological Approved Code of Practice (ACoP); however installation and maintenance of underwater structures as part of any study may be subject to different ACoPs. Any diving project will require a Diving Contractor, registered with the Health and Safety Executive (HSE), who will nominate Diving Project Managers and Diving Supervisors. The Diving Project Manager is then responsible for the production of the Diving Project Plan. The Diving Supervisor is directly in control of the diving operations and is ultimately responsible for the all aspects of the diving operation taking place while on duty. Each diver involved in the project will need to be suitability qualified, hold a valid certificate of medical fitness and be approved by the Diving Project Manager. While volunteer diver requirements may be waivered in some situations, for inclusion in a full HSE dive team volunteers must be professionally qualified irrespective of lack of payment. Further situational guidance on this issue is covered by Holt 2011. For most situations a minimum dive team will consist of four divers – a Diving Supervisor, surface support (standby diver) and two divers working together and providing reciprocal in water support. Although an overall Diving Project Plan is produced, risks should be assessed daily and noted in writing. Guidelines on the contents of the Diving Project Plan and of diving equipment and safety requirements are not included here, see Holt 2011 for further details.

When planning diving activities, early communication with relevant Harbour Authorities is prudent. Restrictions and guidelines covering diving activities within harbour areas will vary with different Harbour Authorities; some authorities include this information online. Harbour Authorities may need to issue permission to dive and if diving on infrastructure (e.g. on moorings, within marinas) additional permission is likely to be necessary from the mooring owners or licensees. Early discussions will allow issues to be raised and solutions to be sought well in advance of planned diving operations. In busy harbours and ports considerations of ship movements and water-based events are useful to avoid un-necessary conflict.

The infaunal samples for the Fal and Helford Study were collected by a scientific dive team coordinated in conjunction with Natural England and employing divers form Natural England, local conservation organisations (Cornwall Wildlife Trust), local SeaSearch volunteers and University of Plymouth students. Full details of the infaunal sampling methodology are included in the Fal and Helford report. A number of volunteers were included as part of the dive team; however in order to achieve consistent, reliable results divers were paired up according to experience and diving ability to achieve a capable team overall. The inclusion of volunteers in a dive team must be considered as potential extra risk.

5.3 Analysis of infaunal samples

5.3.1 Resources and techniques

Analysis of infaunal samples consists of the separation of organisms from the rest of the sample and identification of the separated specimens to an appropriate taxonomic level. Separation of the organisms from the sediment and detritus in the sample requires each individual specimen to be found and removed; specimens are then identified to the taxonomic resolution necessary and preserved in vials. This process is time consuming, even when only working at intermediate taxonomic level. The time to process infaunal samples is dependent upon a number of factors including the experience of the taxonomist, the size, complexity and diversity of the samples, the level of resolution required, the minimum size of organism, the quality of the microscope and light source, the availability of taxonomic literature and expert taxonomic support and the suitability of the samples for staining and sub-sampling.

The analysis of infaunal samples collected requires, at minimum, a suitably qualified and experienced benthic taxonomist, laboratory space, a good quality binocular dissecting microscope, light source and basic taxonomic materials. While picking samples to broad groupings requires relatively basic taxonomic experience, working to family requires at least a familiarity with benthic specimens, taxonomic works and distinguishing features. Readily available literature, such as Hayward & Ryland[16], is largely suitable for identification of infaunal organisms to family groups, although specialist texts prove very useful for some families and will be necessary at higher taxonomic levels. The taxonomy of marine organisms is constantly evolving with fauna being moved between taxa as new research uncovers links between different groups. The World Register of Marine Species[17] (WoRMS) contains global species databases and can be used to confirm the current taxa an organism is assigned to. The detail of literature required will depend upon the taxonomic resolution required, familiarity with the taxonomic groupings and the availability of additional taxonomic support to the project researcher.

Full identification to species across all organisms requires a considerably longer processing time and a higher level of taxonomic expertise. In ensuring suitable resolution for detecting an environmental impact the size of sieve mesh used (0.5mm or 1mm) and taxonomic resolution (species or family) were considered. The use of reduced level taxonomic resolution in applied environmental studies is not new and can reduce the timescale necessary while still allowing detection of ecological impacts (Ferraro & Cole 1990). Some studies have indicated sequential responses to stressors visible at both species and phyla level, suggesting lower taxonomic level identification distinctions may be sufficient to identify some broad effects of impacts (Gray et al. 1990). Previous studies have shown there to be little difference in spatial patterns detected by nonparametric multivariate analyses of infaunal assemblages and it is suggested that more information is lost with the use of a coarser mesh than a lower taxonomic resolution (James et al. 1995). The timescale, personnel and resource limitations for the Fal and Helford Study dictated that infaunal samples were to be processed and identified to intermediate taxonomic level, in most cases this was to family group[18]. The time required to process the samples can be further reduced by using sub-sampling techniques, where suitable, and organic stains such as Bengal Rose.

In the Fal and Helford Study the sheer number of replicates collected dictated the additional need to sub-sample the infaunal samples in order to process all samples within the relatively short timescale of the project. For the Fal and Helford Study a simple but effective sub-sampling technique was used, based on the methodology outlined in Sheehan et al. 2010. Prior to adopting a sub-sampling methodology, trial samples must be analysed to ensure that sub-samples truly represent the abundances and taxonomic diversity of the whole samples, thus ensuring that the use of sub-sampling techniques does not influence the project outcomes. In the case of this study five random samples were sub-sampled, recording the organisms present in successively smaller sub-samples (1, $^1/_2$, $^1/_4$, $^1/_{16}$). Multivariate analysis of these sub-samples was conducted to confirm that taxonomic patterns remain consistent at the size of sub-sample to be used, to ensure reliable representation of the original infaunal sample. The methodology used in the Fal and Helford Study is detailed in the full project report. Even when employing all of the above measures to reduce the time required, the infaunal analysis phase is likely to represent a major period of the study and this must be accounted for when planning the project.

The following is only intended to give a broad estimation of sample processing times and the time required will vary considerably in response to the variables identified earlier in this section. Processing of the Fal and Helford Study samples, utilising Bengal Rose stain and sub-sampling techniques, progressed at an approximate rate of 4-5 samples per day; however this figure does not account for any additional identification time necessary for organisms not immediately recognised and identified. The processing of the full 216 infaunal mooring samples required several months of full-time work.

[16] Hayward, P.J.; Ryland, J.S. (Ed.) (1995). Handbook of the marine fauna of North-West Europe. Oxford University/Oxford University Press: Oxford. ISBN 0-19-854054-X. XI, 800 pp.
[17] The World Register of Marine Species (WoRMS) is available online at www.marinespecies.org. Site accessed June 2012.
[18] The main exceptions were Nematoda, Nemertea and Oligochaeta. A full infaunal family list in Appendix 6: Full Infaunal Taxonomic List.

5.4 Recommendations

- The choice of **remote or *in-situ*** techniques will depend upon the **focus** and **scale** of the study.
- Scientific **diving studies** are subject to **HSE regulations** and **Scientific and Archaeological ACoP**. Separate literature is available giving detailed guidance on the conducting scientific diving studies.
- If using **volunteer divers** a **mixed team** is **recommended** to maintain scientific integrity and ensure diver safety.
- **Specialist equipment** is required to **analyse infaunal samples**.
- Various **techniques** and **levels of resolution** can be used to **reduce the timescale** of infaunal processing.

6 Sediment Survey

6.1 Sediment Characteristics

Sediment characteristics are considered to be an important factor influencing the distribution of infaunal organisms (Probert 1984; Sanders 1958) and sediment granulometry is linked in a bi-directional manner, whereby changes in sediment particle size influence the infaunal organisms present but the organisms present can also modify local sediment particle size distributions (Probert 1984). As the impact in question, the movement of recreational boating infrastructure exerts a physical disturbance which previous studies have identified as influential in determining particle size distributions (Herbert et al. 2009; Collins et al. 2010), sediment samples were collected to confirm if any such pattern was present around the infrastructure in the Fal and Helford Study; especially as these samples could be collected quickly and easily alongside the infaunal samples. Estuarine sediments are also known to act as sinks for chemical contaminants, with physical disturbance to the sediment potentially capable of releasing contaminants and increasing bioavailability (Eggleton & Thomas 2004); this may represent another variable of interest in future studies.

6.1.1Guidance and Standardisation of Samples

The National Marine Biological Analytical Quality Control Scheme (NMBAQC) have produced a detailed report, NMBAQC Best Practice Guidance: Particle Size Analysis for Supporting Biological Analysis (Mason, 2011)[19], which outlines recommendations and requirements for completing the collection and analysis of granulometry samples in accordance with various UK monitoring authorities and conservation agencies including the Environment Agency, Centre for Environment, Fisheries and Aquaculture Science (CEFAS) and Joint Nature Conservation Committee (JNCC). This standardises the data collected, allowing wider usage and potential comparisons across projects. This guidance was used for the processing of all sediment samples collected as part of the Fal and Helford Study.

6.1.2 Resources

The detailed processing of sediment samples requires specialist geography laboratory facilities including drying ovens, kilns, test sieves and laser particle size analysers. As the Fal and Helford Study was conducted in conjunction with the University of Plymouth the use of sediment analysis equipment, considered at the initial outset, was included in the resources budgeted for at the start of the study. These costs were then minimised by requiring the sediment samples to be prepared and analysed by the Project Coordinator. For a project not run in conjunction with a research institute, analysis of these samples would need to be considered as an additional cost to the study. External outsourcing of the analysis of samples is available through a number of commercial laboratories; however, this is likely to represent a more costly option.

6.3 Analysis

Initial granulometry analysis was completed using a freely available program, GRADISTAT[20] (Kenneth Pye Associates Ltd., Crowthorne, UK). This program allows rapid calculation of multiple sediment size statistics from the raw sediment size data and returns various granulometry measures and graphical outputs (Appendix 7: GRADISTAT Statistics). Standard statistical measures of size distributions used by sedimentologists are based on quartile measures, phi (ϕ) notation or method of moments. Of these, method of moments requires complex calculations but

[19] This documentation is available online at www.nmbaqcs.org/media/10839/nmbaqc%20best%20practice%20guidance_particle%20size%20analysis.pdf . Page accessed June 2012.
[20] GRADISTAT is available online via www.kpal.co.uk/gradistat.html . Site accessed May 2012.

accounts for every grain in the distribution (Poppe et al. 2000). This method of moments (logarithmic ϕ) was used in the Fal and Helford Study as it is considered to be the measure that most accurately represents the actual particle size distribution (Blott & Pye 2001). Within the Fal and Helford Study GRADISTAT was used to calculate the mean method of moments (logarithmic ϕ) data, this was then analysed using univariate statistics and included as a covariate in multivariate PERMANOVA analyses.

6.4 Recommendations

- **Sedimentary characteristics** are commonly **linked** to the infaunal **community composition**.
- **Analysis** of samples requires **specialist equipment** – for the Fal and Helford Study this was overcome by working in **partnership** with the University of Plymouth.
- **Guidance** is available from NMBAQC for the **standardisation** of particle size sample **collection and analysis** across UK monitoring bodies.
- Initial calculation of **sediment size statistics** can be completed with **GRADISTAT** open source software.

7 Statistical Analysis and Outputs

This section is <u>not</u> intended to allow a non-scientific individual to attempt to analyse scientific data and as such does not cover analysis techniques or go into any detail of statistical analyses. This section is intended to give a brief explanation of the types of statistics used in the Fal and Helford Study and as such to assist non-scientific individuals in understanding the initial preparatory statistics and a potential route for analysis which may be used by statistical analysts or suitably experienced researchers. Competent scientific advice should be sought to ensure that all data is analysed appropriately, assumptions of statistical analyses are upheld and thus robust and accurate study results are produced. For the Fal and Helford Study support for the scientific analysis was provided by the University of Plymouth and consultancy during this phase of the study was budgeted into the project costs. This allowed contributions from highly competent experts in the field ensuring a suitable scientific study and adding considerable value to the study outcomes.

7.1 Analysis

The statistical analysis used will vary dependent upon the original aims of the study, the experimental design and the data collected and, as such, this section will be necessarily brief. In supporting the Project Coordinator, detailed advice from scientific advisors or consultants to complete the analysis and interpretation of results should be used as necessary to ensure appropriate analysis and robust study outcomes. For studies similar to the Fal and Helford, where the aim was to detect a response at the level of the infaunal communities, the following may offer a useful starting point; however, there are alternative analyses not mentioned here which may better suit other approaches (e.g. regression analyses for gradients of impact) (Olsgard & J. Gray 1995; Eberhardt & J. M. Thomas 1991).

Initial summary statistics and calculation of biodiversity measures, such as total abundance, species richness and grouped abundances of prominent taxa, are easily calculable within MS Excel or using the PRIMER-6 DIVERSE routine (Clarke & Gorley 2006). These can be plotted out in histograms, with a measure of variance around the means (standard error or standard deviation), to give an indication of differences in the total numbers of organisms within the samples, the total number of different taxonomic groups and total number of organisms in prominent taxonomic groups. Significant differences in abundance or diversity, or a shift in the abundances of prominent taxa may all indicate the presence of an impact on the community. Initial summary statistics, plotting the means and standard deviations and histograms of the data, allows visualisation of the distribution of the data and will highlight any noticeable trends.

For community compositional data, where abundances of all recorded taxa are included, the equivalent summaries can be displayed in PRIMER, using resemblance matrices and multi-dimensional scaling (MDS) plots; these will help visualise similarities between different groups of samples. For the Fal and Helford estuary infaunal community abundances, the data was imported into PRIMER, square root or fourth root transformed and Bray-Curtis resemblance matrices were constructed. MDS plots were used to visualise similarities between different sample groups (e.g. locations, distances).

For the Fal and Helford Study overall abundances, species richness and grouped abundances of prominent taxa were analysed using univariate analysis of variance (ANOVA). The multivariate community analysis was completed using an analysis of covariance (ANCOVA) within the PRIMER-6 PERMANOVA add-in. Details of the statistical analysis used in the Fal and Helford study are available in the full report.

7.2 Interpretation

When interpreting the results, human preoccupation often rests with the idea that a decrease in a measured variable represents a deleterious environmental impact, while an increase represents a positive response and is beneficial (Underwood, 1991). Some ecological hypotheses, such as the Intermediate Disturbance Hypothesis (IDH), suggest that in areas of low natural disturbance with low species diversity, an anthropogenic disturbance may actually increase biodiversity. This has been suggested by previous studies, with the detection of greater homogeneity when a recreational boating impact was minimised (Kendall et al. 2006). Technically, this apparent difference still represents an alteration in the status quo of the habitat. It should not be assumed that a perceived positive impact is best for the environment.

In interpreting the results to calculate an area of impact, a range of values is more accurate and realistic than a single value. The detection of an impact at one sampled distance but not at the next does not give a clear cut distance for the extent of the impact, it simply indicates that an impact was present to beyond the first distance sampled but short of the next. This gives a higher and lower estimate of distance for the level of effect detected. In addition to these values, it is possible analyses of different biodiversity measures will identify effects at different distances. For the Fal and Helford Study the main measures of abundance, diversity and infaunal community composition all highlighted different distance and location combinations as significant, making a single visual spatial representation of impact difficult to display. It was decided to present the impact as a combination of significant effect and frequency, with graduated areas around the moorings coloured to represent multiple significant effects across multiple study locations through to no significant effect at any locations (Appendix 8: Impact Matrix).

In extrapolating the findings to estuary scale care should be taken over the extent of the extrapolation and to clarify the uncertainty in the estimation. For the Fal and Helford Study the results indicated an area of impact for one type of mooring infrastructure across three locations within the estuary. The information from this study allowed an estimated area of impact to be calculated with relative confidence for the three locations sampled. A further extrapolation was also made of the impact of this type of mooring infrastructure on similar habitats across the estuaries. This was strongly caveated due to the potential differences between the areas sampled and the areas included in the estimation and lower confidence can be placed in the value estimated. The extrapolation of findings on to different types of infrastructure (e.g. trot moorings instead of single point), different tidal influences (e.g. intertidal moorings) or different habitats from those sampled is not possible. In order to achieve this, further study must be completed studying the impact in these scenarios.

7.3 Recommendations

- Seek **expert** statistical **advice** through **partnership working** or contracted **consultancy**.
- **Statistical analysis** should be **considered early** on, during the development of the **experimental design**.
- Use statistics that **reflect** the **objectives** and **aims** of the study.
- Calculation of **biodiversity measures** and **basic histogram plots** of summary statistics can help **reveal potentially interesting trends** for further analysis.
- **Multivariate statistical analyses** allow the analysis of multiple variables, allowing **detailed analysis** of the **composition** of biological **communities**.
- In **calculating impact** a **range** is more **realistic** than a single value.
- **Extrapolation** of findings must be **limited** to **comparable** infrastructure and habitats only.

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9 Appendices

Appendix 1: Fal and Helford Recreational Boating Audit Form

Fal and Helford Recreational Boating Study

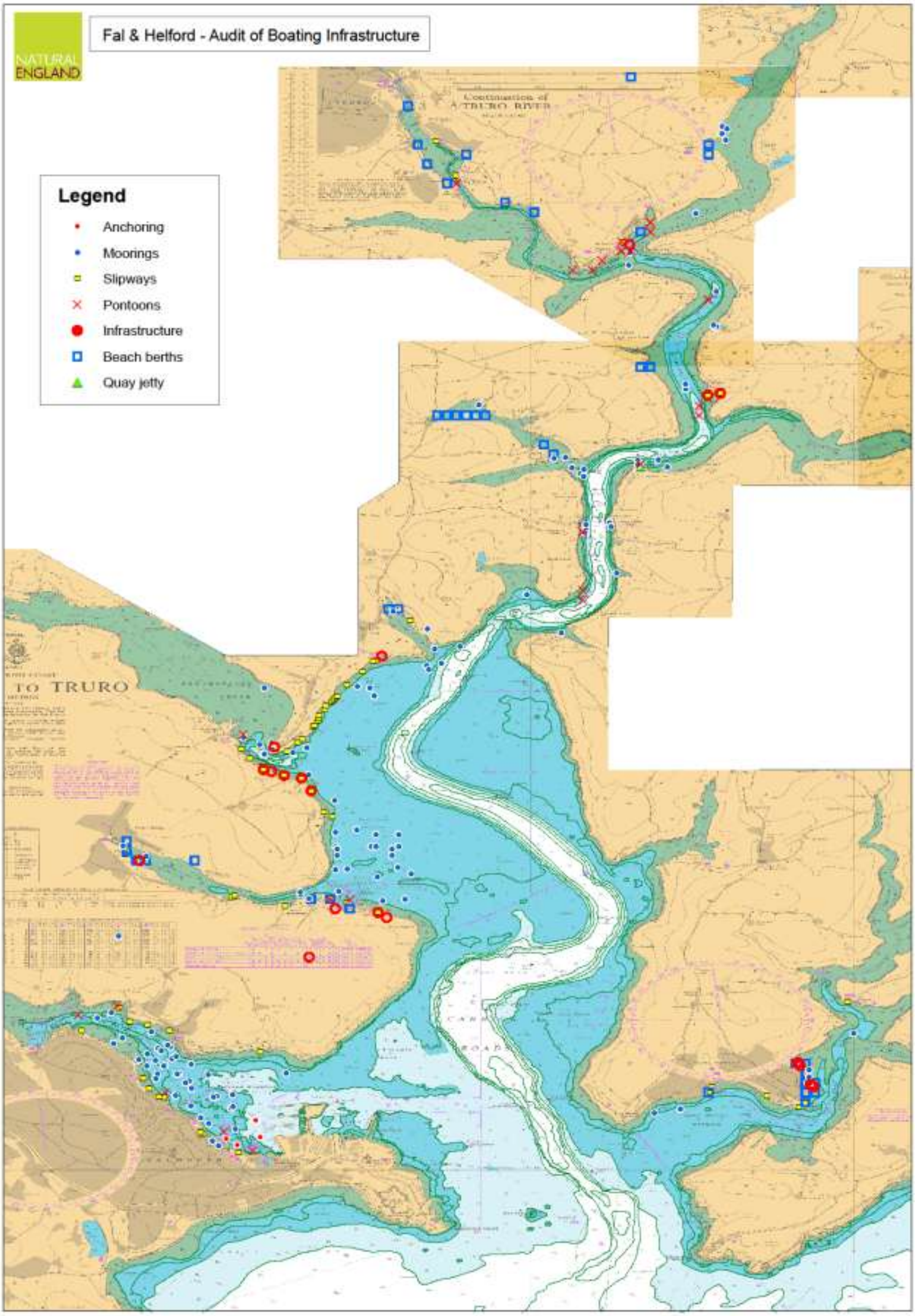
Audit of recreational boating infrastructure

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 2: Fal and Helford Audit of Recreational Boating Infrastructure



Appendix 3: Useful Web Resources

Species and Habitat Information and Records

The Archive for Marine Species and Habitats Data (DASSH) www.dassh.ac.uk/

The Marine Life Information Network (MarLIN) www.marlin.ac.uk/

The Marine Environmental Data and Information Network (MEDIN) www.oceannet.org/

The Environmental Records Centre for Cornwall and the Isles of Scilly www.erccis.org.uk/

Biotope Information

JNCC Marine Habitat Classification for Britain and Ireland http://jncc.defra.gov.uk/page-1584

The Marine Life Information Network (MarLIN):

2004 Biotopes List http://www.marlin.ac.uk/habitats2004codes.php

1997 Biotopes List http://www.marlin.ac.uk/habitats1997codes.php

Taxonomic Information

The Marine Life Information Network (MarLIN) www.marlin.ac.uk/

The Encyclopedia of Marine Life of Britain and Ireland (part of the National Museums Northern Ireland) www.habitas.org.uk/marinelife/

The World Register of Marine Species (WoRMS) www.marinespecies.org/

Marine Bivalve Shells of the British Isles (National Museum Wales) http://naturalhistory.museumwales.ac.uk/britishbivalves/home.php?

Crustacea.net www.crustacea.net/intro.htm

Annelida.net www.annelida.net/annelid.html

The National Marine Biological Analytical Quality Control (NMBAQC) Scheme http://www.nmbaqcs.org/scheme-components/invertebrates/literature-and-taxonomic-keys.aspx

Special Areas of Conservation (SACs)

JNCC Special Areas of Conservation Information http://jncc.defra.gov.uk/page-23

Journal Access

Google Scholar scholar.google.co.uk/

Science Direct www.sciencedirect.com/science/journals

Elsevier www.elsevier.com/wps/find/subject_area_browse.cws_home?collapseAll=y&sh1State=0&allParents=y

Journal of the Marine Biological Association of the UK /www.mba.ac.uk/jmba/

Nature www.nature.com/

Statistical Analysis

GRADISTAT Particle Analysis Software www.kpal.co.uk/gradistat.html

ESTIMATE S Biodiversity Estimation http://viceroy.eeb.uconn.edu/estimates/

Recreational Boating Activities

Royal Yachting Association (RYA) www.rya.org.uk

The Green Blue www.thegreenblue.org.uk/

Appendix 4: Information for Scientific Diving Projects

Important information for scientific diving projects

The Diving at Work Regulations 1997 (original statutory instrument) is available from www.legislation.gov.uk: http://www.legislation.gov.uk/uksi/1997/2776/made

The Scientific and Archaeological Approved Code of Practice (ACoP) is available to download from the Health and Safety Executive (HSE) website: http://www.hse.gov.uk/pubns/priced/l107.pdf

The UK Scientific Diving Supervisory Committee (SDSC) provide guidance and information on diving at work specific to the Scientific and Archaeological ACoP: http://www.uk-sdsc.com/advice.htm

Holt, R.H.F. (2011). *Rules and guidance for scientific diving in the country agencies*. Countryside Council for Wales. This report is available on request directly from Rohan Holt, CCW r.holt@ccw.gov.uk

HSE list of approved diving qualifications: http://www.hse.gov.uk/diving/qualifications/approved-list.pdf

Further useful information

Further guidance on diving at work is available from the HSE www.hse.gov.uk/diving/index.htm

Diving Diseases Research Centre (DDRC). DDRC operate hyperbaric chambers in Southwest England www.ddrc.org

List of Approved Medical Practitioners www.hse.gov.uk/diving/ameds.htm

Appendix 5: Equipment Requirements

Below is the list of equipment used in the collection and processing of the infaunal samples for the Fal and Helford Recreational Boating Study. Equipment in **red** was generally generic and low cost and was purchased. Equipment in **green** is generally more specialized and was loaned from the University of Plymouth for this study. This is by no means an exhaustive list and some additional items may be useful.

- **Infaunal cores** (x6) – The Fal and Helford study used plastic cores (10cm by 12cm). These are suitable for collecting cores in relatively soft sediments (muds, relatively fine mixed sediments and un-compacted sands) and can be easily manufactured from drainage pipe by cutting to length and chamfering off a cutting edge at one end.
- **0.5mm sieves** – These are used for sieving the infaunal samples prior to storage. As this phase can be time consuming, having several sieves available can speed up the process.
- **Wash bottles** – Used to rinse the samples off of the sieves and also to dilute the samples when processing under the microscope. Several are ideal and they should be clearly labeled with the contents (Ethanol/ IMS or water)
- **Large buckets** – These are used for elutriating infaunal samples, again several are suggested to speed up sample processing. Large catering buckets are ideal for this.
- **Large tape measures** – These form the physical transect for the divers underwater. To aid quick connection to the mooring block eyes karabiner clips were fastened to the loose end, removing the need for divers to tie knots. 30m tape measures with large handles are best.
- **Trowels** – These are used to dig out cores in coarse or sandy sediments where the sediment is not easily removed by hand. Standard garden trowels work fine.
- **Divers net bags** – These are to contain infaunal samples (in plastic bags) underwater.
- **Plastic funnel** - This is used to transfer infaunal samples from sieves into storage pots without loss of sample.
- **Heavy duty plastic bags** – These are to contain the infaunal samples from collection underwater until processing. These need to be large enough to easily place the whole core inside. Ideally they should also be clear (allows the divers to see the core) and heavy duty/ reusable.
- **Sample pots** – These are to contain the sieved infaunal samples collected. For the Fal and Helford study 100ml sample pots were used, these were sufficient in areas with clean sediment but in areas containing large amounts of organic matter, macroalgae, etc. several pots were needed per sample.
- **Plastic boxes** – To contain samples in locational groups and to act as a secondary bund in case of spillage.
- **Binocular microscope** – A good quality microscope is essential. For the Fal and Helford study a Wild M7 (www.wild-heerbrugg.com/microscopes.htm) was used.
- **Light source** – A separate light source is necessary to accurately pick and identify specimens. For the Fal and Helford study a cold light source with dual flexible heads was used.
- **Specimen vials** – To contain the picked and identified sample specimens. At least two per sample is recommended – one for large/ common organisms, one for fragile/unusual specimens.
- **Petri dishes** – To sort the samples under the microscope.
- **Ethanol/IMS** – For preservation and storage of samples. This will need to be at least 75% strength.

Appendix 6: Full Infaunal Taxonomic List

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 7: GRADISTAT Statistics

An example, from the Fal and Helford Study, of the GRADISTAT outputs and the sample statistics calculated.

		F1 M1 2M	F1 M1 5M	F1 M1 11M	F1 M2 2M	F1 M2 5M	F1 M2 11M	F1 M3 2M	F1 M3 5M	F1 M3 11M
	ANALYST AND DATE:	,	,	,	,	,	,	,	,	,
	SIEVING ERROR:									
	SAMPLE TYPE:	Trimodal, Poorly Sorted	Polymodal, Very Poorly Sorted	Unimodal, Very Poorly Sorted	Polymodal, Extremely Poorly Sorted	Polymodal, Very Poorly Sorted	Trimodal, Very Poorly Sorted	Polymodal, Very Poorly Sorted	Polymodal, Very Poorly Sorted	Polymodal, Very Poorly Sorted
	TEXTURAL GROUP:	Sandy Gravel	Muddy Sandy Gravel	Slightly Gravelly Sandy Mud	Muddy Sandy Gravel	Gravelly Mud	Gravelly Mud	Muddy Sandy Gravel	Gravelly Mud	Gravelly Mud
	SEDIMENT NAME:	Sandy Very Fine Gravel	Very Coarse Silty Sandy Very Fine Gravel	Slightly Very Fine Gravelly Very Fine Sandy Medium Silt	Medium Silty Sandy Very Fine Gravel	Medium Gravelly Medium Silt	Fine Gravelly Medium Silt	Medium Silty Sandy Very Fine Gravel	Very Fine Gravelly Medium Silt	Very Fine Gravelly Medium Silt
METHOD OF MOMENTS Arithmetic (μm)	MEAN $(\bar{x}_a)$:	2014.5	2715.2	163.3	4584.5	2110.0	334.6	5164.3	1617.6	806.2
	SORTING (σ_a):	1811.9	3250.8	602.4	7513.9	4549.9	1121.1	7720.1	2739.6	2154.8
	SKEWNESS (Sk_a):	2.355	1.730	5.717	1.907	2.026	4.484	1.742	2.349	3.238
	KURTOSIS (K_a):	10.05	5.461	37.43	5.179	5.278	23.39	4.571	8.832	12.59
METHOD OF MOMENTS Geometric (μm)	MEAN $(\bar{x}_g)$:	1242.5	787.2	26.78	583.2	91.09	33.92	912.7	201.3	55.93
	SORTING (σ_g):	3.550	8.810	4.730	14.53	14.37	6.156	11.91	12.03	9.175
	SKEWNESS (Sk_g):	-2.071	-0.989	0.960	-0.436	0.703	1.021	-0.663	-0.038	0.824
	KURTOSIS (K_g):	8.960	2.962	4.201	1.997	2.274	3.859	2.439	1.717	2.815
METHOD OF MOMENTS Logarithmic (ϕ)	MEAN $(\bar{x}_\phi)$:	-0.313	0.345	5.223	0.778	3.457	4.882	0.132	2.313	4.160
	SORTING (σ_ϕ):	1.828	3.139	2.242	3.861	3.845	2.622	3.574	3.589	3.198
	SKEWNESS (Sk_ϕ):	2.071	0.989	-0.960	0.436	-0.703	-1.021	0.663	0.038	-0.824
	KURTOSIS (K_ϕ):	8.960	2.962	4.201	1.997	2.274	3.859	2.439	1.717	2.815
FOLK AND WARD METHOD (μm)	MEAN (M_G):	1394.9	792.5	23.81	593.9	100.5	28.12	954.6	192.2	59.06
	SORTING (σ_G):	2.779	8.968	4.446	16.56	16.00	5.875	13.15	13.00	10.46
	SKEWNESS (Sk_G):	-0.304	-0.504	0.193	-0.345	0.397	0.253	-0.357	0.033	0.367
	KURTOSIS (K_G):	1.747	1.017	1.087	0.798	0.877	1.232	0.935	0.660	1.175
FOLK AND WARD METHOD (ϕ)	MEAN (M_Z):	-0.480	0.336	5.392	0.752	3.315	5.152	0.067	2.379	4.082
	SORTING (σ_I):	1.475	3.165	2.152	4.050	4.000	2.555	3.717	3.701	3.387
	SKEWNESS (Sk_I):	0.304	0.504	-0.193	0.345	-0.397	-0.253	0.357	-0.033	-0.367
	KURTOSIS (K_G):	1.747	1.017	1.087	0.798	0.877	1.232	0.935	0.660	1.175
FOLK AND WARD METHOD (Description)	MEAN:	Very Coarse Sand	Coarse Sand	Coarse Silt	Coarse Sand	Very Fine Sand	Coarse Silt	Coarse Sand	Fine Sand	Very Coarse Silt
	SORTING:	Poorly Sorted	Very Poorly Sorted	Very Poorly Sorted	Extremely Poorly Sorted	Very Poorly Sorted	Very Poorly Sorted	Very Poorly Sorted	Very Poorly Sorted	Very Poorly Sorted
	SKEWNESS:	Very Fine Skewed	Very Fine Skewed	Coarse Skewed	Very Fine Skewed	Very Coarse Skewed	Coarse Skewed	Very Fine Skewed	Symmetrical	Very Coarse Skewed
	KURTOSIS:	Very Leptokurtic	Mesokurtic	Mesokurtic	Platykurtic	Platykurtic	Leptokurtic	Mesokurtic	Very Platykurtic	Leptokurtic
	MODE 1 (μm):	1700.0	2400.0	12.09	3400.0	13600.0	12.09	3400.0	3400.0	12.09
	MODE 2 (μm):	650.9	9600.0		1700.0	12.09	6800.0	9600.0	12.09	57.53
	MODE 3 (μm):	9600.0	96.75		12.09	57.53	3400.0	115.1	96.75	2400.0
	MODE 1 (ϕ):	-0.743	-1.243	6.375	-1.743	-3.743	6.375	-1.743	-1.743	6.375
	MODE 2 (ϕ):	0.625	-3.243		-0.743	6.375	-2.743	-3.243	6.375	4.125
	MODE 3 (ϕ):	-3.243	3.375		6.375	4.125	-1.743	3.125	3.375	-1.243

D_{10} (μm):	341.2	20.37	4.598	9.711	5.144	4.661	16.46	7.169	5.041
D_{50} (μm):	1576.2	1695.7	21.58	1299.3	44.20	24.80	1819.4	173.7	34.38
D_{90} (μm):	3840.3	8147.8	162.4	17372.1	12079.8	408.0	18438.5	5167.4	2331.0
(D_{90} / D_{10}) (μm):	11.26	400.0	35.31	1789.0	2348.1	87.53	1120.0	720.8	462.4
(D_{90} - D_{10}) (μm):	3499.1	8127.5	157.8	17362.4	12074.7	403.3	18422.0	5160.2	2326.0
(D_{75} / D_{25}) (μm):	2.495	17.68	7.170	73.90	47.90	8.822	34.31	100.7	13.98
(D_{75} - D_{25}) (μm):	1490.2	3151.5	54.50	4258.4	536.4	71.81	4962.7	2207.5	137.2
D_{10} (ϕ):	-1.941	-3.026	2.622	-4.119	-3.595	1.293	-4.205	-2.369	-1.221
D_{50} (ϕ):	-0.656	-0.762	5.534	-0.378	4.500	5.333	-0.863	2.526	4.862
D_{90} (ϕ):	1.551	5.618	7.765	6.686	7.603	7.745	5.925	7.124	7.632
(D_{90} / D_{10}) (ϕ):	-0.799	-1.856	2.961	-1.623	-2.115	5.988	-1.409	-3.007	-6.251
(D_{90} - D_{10}) (ϕ):	3.493	8.644	5.142	10.80	11.20	6.452	10.13	9.493	8.853
(D_{75} / D_{25}) (ϕ):	-0.004	-1.382	1.714	-1.942	7.429	1.866	-1.167	-4.752	2.379
(D_{75} - D_{25}) (ϕ):	1.319	4.144	2.842	6.208	5.582	3.141	5.100	6.654	3.805
% GRAVEL:	36.0%	44.4%	2.6%	41.2%	19.1%	5.4%	48.2%	26.8%	11.1%
% SAND:	59.9%	39.1%	22.7%	33.3%	25.1%	24.8%	33.8%	36.3%	27.8%
% MUD:	4.1%	16.5%	74.7%	25.5%	55.8%	69.8%	17.9%	37.0%	61.1%
% V COARSE GRAVEL:	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
% COARSE GRAVEL:	0.0%	0.0%	0.0%	11.3%	0.0%	0.0%	12.6%	0.0%	0.0%
% MEDIUM GRAVEL:	3.0%	10.4%	0.0%	5.3%	13.8%	0.0%	6.8%	4.1%	4.1%
% FINE GRAVEL:	5.8%	8.4%	0.7%	9.7%	0.4%	2.9%	11.2%	9.7%	2.7%
% V FINE GRAVEL:	27.2%	25.6%	1.9%	14.9%	4.9%	2.5%	17.6%	12.9%	4.3%
% V COARSE SAND:	38.9%	20.6%	1.4%	13.2%	3.7%	1.8%	12.9%	8.2%	4.4%
% COARSE SAND:	10.6%	5.1%	1.5%	5.4%	2.6%	2.2%	5.3%	5.3%	2.6%
% MEDIUM SAND:	6.7%	3.6%	1.8%	4.9%	2.7%	2.3%	4.8%	6.0%	2.8%
% FINE SAND:	2.3%	4.1%	5.6%	4.5%	5.5%	5.9%	5.2%	7.6%	6.2%
% V FINE SAND:	1.4%	5.8%	12.4%	5.3%	10.6%	12.6%	5.6%	9.1%	11.8%
% V COARSE SILT:	0.8%	4.3%	15.5%	5.2%	11.6%	14.6%	4.1%	7.9%	12.9%
% COARSE SILT:	1.0%	3.5%	18.1%	5.8%	12.8%	16.3%	4.2%	8.7%	14.3%
% MEDIUM SILT:	1.1%	3.9%	19.4%	6.5%	14.1%	17.9%	4.5%	9.4%	15.7%
% FINE SILT:	0.8%	3.1%	14.4%	5.2%	11.2%	13.8%	3.4%	7.2%	12.0%
% V FINE SILT:	0.3%	1.5%	6.4%	2.5%	5.3%	6.2%	1.5%	3.4%	5.4%
% CLAY:	0.0%	0.2%	0.9%	0.4%	0.8%	0.9%	0.2%	0.5%	0.8%

Appendix 8: Impact Matrix

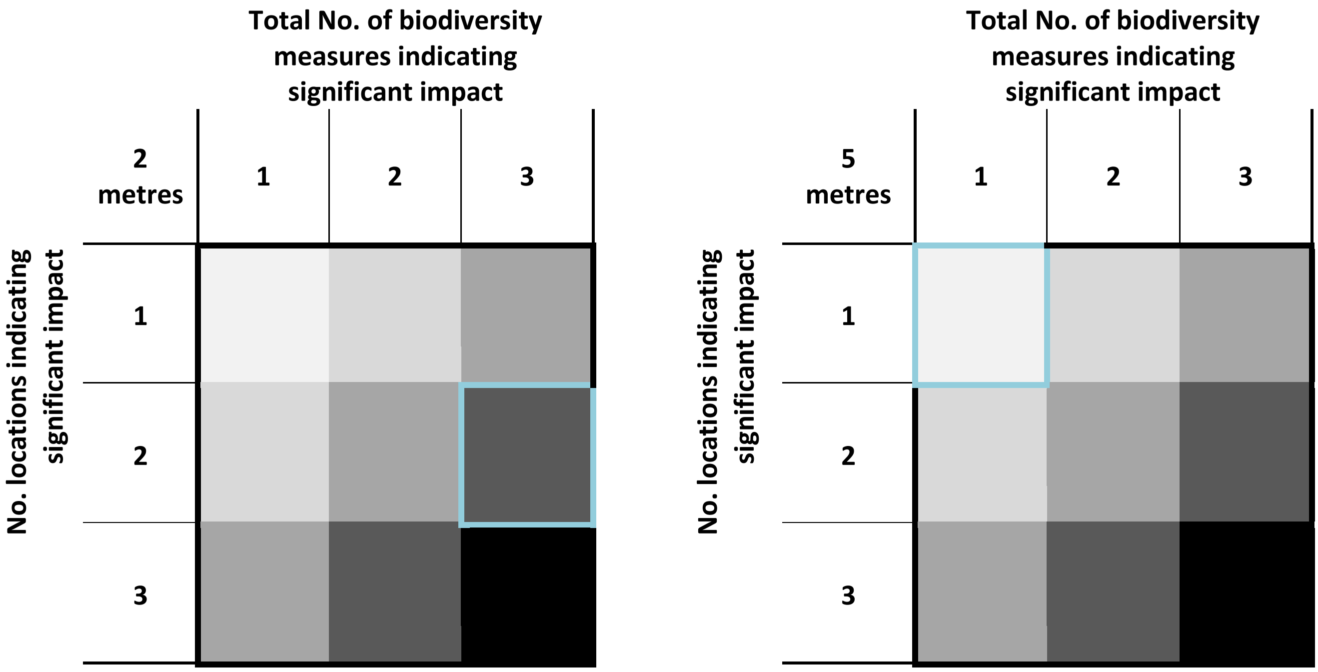


Table 1 Impact matrix to summarise the indicators of significance of impact as both number of locations and number of biodiversity measures (overall abundance, species richness and community composition) indicating significance of distances in determining the infaunal community.

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 was 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 (Tables 12, 13 and 14 in the full project report) and the visual representation of ecological impact (Figures 13, 14 and 15 in the full project report).