This report should be cited as:

Hoskin, M.G. (2014). A Marine ecological investigation of the seabed of St Mawes Harbour, Cornwall

Dr Miles Hoskin BSc (Hons), PhD, MCIEEM

Coastal & Marine Environmental Research (CMER)
3 Restormel Terrace
Falmouth
Cornwall
England

Tel: +44 (0)7976 437463
E-mail: miles.hoskin@cmer.co.uk

The St Mawes Marine Habitats Study

Foreword
by Philip Marsden,
Trustee of the St Mawes Harbour Conservation Trust

I have known St Mawes Harbour all my life. Like many others, I spent childhood days paddling in its shallows, poking about in its rock pools. I swam in its waters, learnt to sail in them; for the best part of twenty years I lived and worked in a studio which overlooked them. But only recently did I learn that - beneath the surface – lay a host of marine habitats of national and international importance.

Marine scientists have long been aware that these habitats existed in St Mawes, but because no detailed study has ever been made, there has been little wider appreciation of their significance. That is the principal reason why the St Mawes Harbour Conservation Trust commissioned this report. We wanted to discover exactly what we have, to celebrate it, and to share with the wider community our sense that such habitats can take their place beside those better-known features for which St Mawes is so loved.

Greatest of all St Mawes's marine habitats are its maerl beds. The largest surviving maerl bed in England can be found on St Mawes Bank, running between St Just and St Mawes castle with a tail that curls round into St Mawes Harbour. If at low tide you dive down into a few metres of water off Tavern beach, you will see dense accumulations of maerl. With sunlight falling through the shallows, the entire sea-bed glows reddish-purple. Fitting easily into the palm of your hand, each piece of maerl looks like a fragment of loose coral, a delicate filigree of calcified algae. When dead, and turned bone white, it remains to form beds many metres deep that continue to perform the ecological role for which it is most valued. Such is the architecture of tiny branches that the spaces in between offer protection for a great deal of marine life. That is the real importance of maerl: not so much the maerl itself, as the number of species that find shelter and sustenance around it.

Marine life is not spread evenly across the oceans. In certain areas dense concentrations occur where the conditions are just right for the development of zooplankton and phytoplankton, which in turn attracts an abundance of other creatures, which themselves become food for larger species. Such places are vital as nursery areas for commercially valuable fish. For some years now, the positive benefits of marine protected areas have been becoming much more widely understood. If conservation efforts focus on these areas, the entire ecosystem benefits, and thus the coastal fishing and leisure industries that depend on it.

Maerl in St Mawes Harbour (© Tony Sutton)

The waters of St Mawes offer such a hotspot - St Mawes Bank for its maerl, and St Mawes Harbour not just for maerl but for areas of sea-grass (*Zostera marina*) - the only flowering plant found in British seas, whose translucent green fronds offer a habitat similar to maerl in the abundance of its dependent species. What is interesting about St Mawes, from a conservation point of view, is that its marine habitats are found in a well-used harbour. The community and the local economy depend on the harbour, balancing the conservation of its natural features with public access. The St Mawes Marine Habitats Study will, it is hoped, contribute to sustaining that balance.

One evening in 2010, Dr Jean-Luc Solandt, Marine Protected Areas Specialist at the UK's Marine Conservation Society, visited St Mawes Sailing Club. He gave a talk about the Fal's marine environment. He spoke with obvious excitement about the diversity and rarity of the estuary's habitats. But the greatest accolade he reserved for the area around St Mawes. He explained how the maerl beds take hundreds of years to build up. The vast expanse of maerl on St Mawes Bank represents several thousand years of accumulated marine history. 'It might sound odd,' he said, 'but when I look at the maerl of St Mawes, I feel what other people feel when they see Stonehenge.'

The St Mawes Harbour Conservation Trust was set up in 2006 to help ensure the harbour's long-term protection. For some years, concern had been growing about the harbour, and particularly the gradual increase in moorings. It became apparent that although the harbour was widely perceived as a public amenity, there was no apparatus at the time to represent the public in its management. Since then, both the area of moorings and their quantity have stabilised.

Sole responsibility for the running of the harbour lies with the St Mawes Pier & Harbour Company, a private company with a limited number of shareholders. The Trust believes that a private company alone does not offer the ideal constitution for the long-term stewardship of the harbour. When an opportunity emerged, we raised money to buy a small quantity of shares. Our holding is about 11%, held in trust for the community of St Mawes and for the fulfilment of the Trust's objectives.

A few years before the Trust was established, the Fal estuary as a whole – including St Mawes Harbour and the Percuil River - was designated a marine Special Area of Conservation (SAC) under the Habitats Directive. The St Mawes Harbour Conservation Trust joined the Advisory Group that fed its views into the SAC and through membership of the group we began to understand more about what the SAC involved. One of the SAC's central tenets is to respect existing usage of the waters, the balance of commercial fishing, shipping and leisure – but also to consider any proposed developments against the impact they might have on the marine environment. It was during those early meetings that the remarkable nature of the ecosystems of the Fal became clear to us - and the particular importance of the area around St Mawes. We realised too that conservation of the marine habitats overlapped with our wider goal of ensuring the conservation of the harbour. Any future threat to the habitats would be a threat to the harbour as it exists now.

Finding out exactly what was there was in the harbour was the first stage; raising awareness was the next. Thus this project - the St Mawes Marine Habitats Study - was conceived. With the help of CMER and its director Dr Miles Hoskin, we put together a detailed proposal and applied – successfully – to the Esmée Fairbairn Foundation's biodiversity funding strand.

The first stage of work was the survey. Gathering data underwater is not the same as on land, where things tend to keep still and you can draw breath unaided. CMER developed a system of temporarily fixing a hundred-metre survey tape to the sea-bed, with buoys at each end precisely positioned with GPS. Every fifty centimeters along the tape, divers took a photograph of the seabed. The lines followed twelve transects across the harbour, totalling six and a half kilometres in length. The photographs – more than 13,000 of them - were then examined to establish both the seabed type and its predominant life-forms. The second stage involved taking sediment core samples from selected sites. The samples were then analysed for particle size and, using a powerful dissecting microscope and several weighty volumes of marine taxonomy, the fauna were identified.

The first thing the survey work revealed was that there is much more maerl and sea-grass in the harbour than was previously thought. Twenty-seven per cent of the sea-bed is either dense sea grass or maerl. Analysis of the core samples confirmed that maerl supports the greatest variety of marine life. Through a microscope, the sea-bed reveals itself to be a weird menagerie of micro-beasts – most of them worms and crustaceans. No-one can be accused of ignorance for not recognising the multitude of tiny, multi-jawed, multi-legged creatures that crawl or wriggle around on the seabed. There are dozens of different ones.

The Trustees believe that the long-term value of the St Mawes Marine Habitats Study is threefold. First, it provides an important tool for the environmental management of the harbour. Awareness of the most sensitive areas will help in the supervision of activities. Any monitoring of the condition both of maerl and sea-grass, and of the harbour's habitats as a whole, is now much easier with such detailed information. Proposals for any future development in St Mawes Harbour can be also assessed with reference to the study's data.

Second, the study offers a model for studies of other related areas – not just in the Fal & Helford but all around the coast, for all those harbours trying to achieve the balance between growing visitor pressure, the desire of those visitors for unspoilt seascapes, and the increasing awareness that conserving marine eco-systems is vital for our long-term future. The work conducted in St Mawes Harbour is a piece of pure marine science, contributing in a small way to the general understanding of marine environments. It is hoped that for students and marine scientists alike, the data collected here will continue to be used and analysed. For example, only a fraction of the possible information has been extrapolated from the 13,000 photos we took. Further core samples can also be taken from the harbour and the results compared with our own.

But the greatest long-term benefit of the study is less scientific. As the project has progressed, so has the sense of wonder at the harbour's submarine world. We are all familiar with the views of St Mawes – of Carrick Nath and its pines, or the wooded slopes of Amsterdam Point, or the profile of the castle. What happens underwater will never be so obvious – but knowing the sheer range of creatures down there, and their importance for the waters around the Fal estuary and beyond, having a sense of the maerl beds and their private world of microscopic creatures, it is hard to look out across the harbour in quite the same way.

Out of the project, it is hoped that public awareness and understanding of these habitats will grow. What they add to an appreciation of St Mawes will help ensure that the harbour retains its appearance and its spirit, and the many ways in which it is enjoyed, for generations to come.

Philip Marsden

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Introduction

The St Mawes Marine Habitats Study was an initiative of the St Mawes Harbour Conservation Trust, in collaboration with CMER and funded by the Esmée Fairbairn Foundation. The project was motivated by a desire to increase understanding and awareness of the rich variety of marine habitats present within the harbour and thereby promote their conservation for the use and enjoyment of future generations.

St Mawes Harbour is one of the few places in the UK where dense beds of the rare, coralline red alga called 'maerl' are found. Maerl beds generally support a high diversity of other species. The harbour is also notable for its seagrass beds, which are both biodiverse and highly productive. The main aims of the St Mawes Marine Habitats Study were *(i)* to accurately map the distribution of these and other seabed habitats within the harbour and *(ii)* to describe and quantify their biodiversity.

In 1999, St Mawes Harbour became part of the Fal & Helford Special Area of Conservation (SAC); a site for marine nature conservation designated under the EU Habitats Directive. Despite legislation requiring regular ecological surveys and assessments of human impacts in SACs, the available information for St Mawes harbour is fragmentary and pre-dates the SAC.

Compared to Falmouth Harbour on the western side of the lower Fal estuary, St Mawes Harbour is relatively undeveloped with a more-natural shoreline, less harbour and boating infrastructure and a much less urbanised catchment. Concern for the welfare of habitats within St Mawes Harbour is thus less compared to Falmouth, centering mainly on physical disturbance of the seabed from permanent boat moorings and temporary anchoring. Both maerl and seagrass are believed to be particularly vulnerable to this form of disturbance. Recent significant increases in moorings and anchoring activity within St Mawes harbour were an important impetus for the formation of the Trust and for the St Mawes Marine Habitats Study.

Habitat mapping - Materials and methods

The survey of seabed habitats within St Mawes Harbour was designed to encompass the entire harbour while also providing spatially accurate, fine-scale information. This was achieved by sampling along 12 parallel and evenly-spaced transects (200m apart) spanning the harbour from northwest to southeast. Data on the type of substratum and the flora and fauna present on the surface of the seabed were obtained via photo-quadrats of standard size that were taken by scuba-divers. Photo-quadrats were taken at 0.5m intervals along each transect with the aid of a graduated transect line. This survey design yielded over 13,400 photo-quadrats spanning 6,720m of the seabed of the harbour. The latitude and longitude of each photo-quadrat was determined from its distance relative to the two buoyed ends of the transect line, whose positions were fixed via a hand-held GPS unit.

Photo-quadrats were analysed in relation both the physical nature of the substratum (9 variables) and the flora and fauna present (74 species or groups of species). The large number of photo-quadrats meant that it was not possible to obtain highly-accurate data for every variable. Instead, variables were scored as either present/absent, or on semi-quantitative scales for relative abundance or percent seabed cover. The resultant multivariate data-set was used to assess the diversity of 'biotopes' present (*i.e* distinct combinations of seabed type and biological assemblage) and their extents within the harbour. These analyses were done using the PRIMER statistical software package produce by scientists at the Plymouth Marine Laboratory. The data were then used to generate a habitat map of the harbour using ArcGIS mapping software (with assistance from the Environmental Records Centre for Cornwall and the Isles of Scilly (ERCCIS)).

Habitat mapping - Results

The survey revealed eight broad biotopes. Named according to their dominant habitat-forming component, these were: *(i)* intermediate/dense live maerl, *(ii)* dense seagrass, *(iii)* rock, *(iv)* pebbles or cobbles, *(v)* various coarse materials (*e.g.* mixture of pebbles, dead maerl and shells), *(vi)* clean, fine sand, *(vii)* silty, fine sand and *(viii)* mixed sediments (an unsorted mixture of fine, intermediate and coarse materials).

Only four of these broad biotopes were present to any great extent within the harbour. In order of decreasing extent, these were *(i)* clean, fine sand (40.7% of the area surveyed); *(ii)* silty, fine sand (27.0%); *(iii)* dense seagrass (17.3%); and *(iv)* dense/intermediate live maerl (9.8%). Cumulatively, these four biotopes covered 94.8% of the area surveyed. Within each broad biotope, there was between two and five statistically distinct biotope sub-types, with 28 sub-types in total across the eight broad biotopes. Given the wider aims of the study, it was decided that it would be most meaningful and useful to map only the broad biotopes, and not sub-types (Figure A1).

Figure A1. Biotope map of St Mawes Harbour based on photo-quadrat survey.

Detailed investigation of benthic macrofauna – Materials and methods

The detailed investigation of the biodiversity of different benthic habitats focussed on animals >1mm in size living within four important habitats within the harbour. Two of these – *(i)* live maerl; *(ii)* sediment within seagrass beds – were selected based on their conservation importance. The other two – *(iii)* unvegetated clean, fine sand and *(iv)* unvegetated silty, fine sand – were chosen because of their great extent within the harbour. Animals were sampled from cores of sediment (10cm diameter x 10cm depth) collected by divers. For each habitat, macrofauna were investigated in three cores from each of two replicate sites several hundred metres apart. Immediately after collection, cores were bagged and placed on ice in an insulated box. Animals were extracted from all cores within 12 hours of collection and then preserved pending further investigation. Animals were identified and counted with the aid of a dissecting microscope (working in the range x10 to x70 magnification). Wherever possible, animals were identified to species level. To aid consistency of identification, photographs of reference specimens and close-ups of their diagnostic features were taken using a digital camera fitted to the microscope. Data on the abundances of different taxa (species or higher groups) were used to compare habitats in several ways. Differences among habitats in two univariate parameters, *(i)* the number of taxa per core and *(ii)* the total number of individuals per core (across all taxa), were tested using Analysis of Variance (ANOVA). Multivariate differences in the composition of assemblages were using the Analysis of Similarities (ANOSIM) routine in PRIMER and summarised graphically via non-metric multidimensional scaling (nMDS).

To help interpret differences in the composition of animal assemblages among the four habitats, the particle-size distribution and organic content of sediment samples were also determined. This involved separate analyses on two purpose-collected cores from each of the eight sites where cores for macrofauna were obtained. Environmental analyses of these samples were done at an accredited geotechnical laboratory using 'British Standards' methodologies. Differences among habitats in terms of particle-size distribution and organic content were then tested statistically using ANOSIM. The relationship between environmental and biological data was analysed using the BIOENV routine in PRIMER.

Detailed investigation of benthic macrofauna – Results

In terms of number of taxa per core, ANOVA revealed a significant difference between a group comprising two high-diversity habitats – live maerl (mean taxa per core = 28.5 $\pm$ 1.0) and silty, fine sand (18.5 $\pm$ 1.1 taxa) – and a second group of two low-diversity habitats – sand amongst seagrass (16.0 $\pm$ 1.5 taxa) and clean, fine sand

(6.7 ± 1.1 taxa). There were no significant differences between replicate sites of the same habitat.

In terms of the total number of individuals per core, ANOVA differentiated a group of three high-abundance habitats – silty, fine sand (mean number of individuals per core = 86.8 ± 9.0), live maerl (74.2 ± 10.9 individuals) and seagrass (52.2 ± 13.4 individuals) from one habitat, clean, fine sand, with low macrofaunal abundance (15.2 ± 4.5 individuals). As per number of taxa, there were no significant differences between replicate sites of the same habitat.

The multivariate analysis of assemblage composition by ANOSIM revealed significant differences among the four different types of benthic habitat, with each being significantly different from the other three assemblages. The greatest difference in assemblage composition was between maerl *versus* silty, fine sand (Dissimilarity = 58.92). The greatest similarity was between the assemblage in seagrass and that in clean, fine sand (Dissimilarity = 41.96).

The most characteristic taxa in each of the four sampled habitats are listed in Table A1, below.

Table A1. Short-lists of characterising taxa for each of the four habitats from which cores were sampled. The species in each list together accounted for 20% of the overall similarity among assemblages in replicate samples from the same habitat.

Live maerl	**Seagrass bed sediment**	**Clean, fine sand**	**Silty, fine sand**
Pisidia longicornis (long-clawed porcelain crab)	*Lucinoma borealis* (a bivalve mollusc)	*Angulus tenuis* (a bivalve mollusc)	*Chaetozone gibber* (a polychaete worm)
Capitellidae (a family of polychaete worms)	Maldanidae (a family of polychaete worms)	*Bathyporeia pelagica* (an amphipod crustacean)	*Apseudes latreillii* (a tanaid crustacean)
Amphipholis squamata (a brittle star)	Nematoda (a Phylum of unsegmented worms, commonly known as roundworms)	*Urothoe poseidonis* (an amphipod crustacean)	*Ampelisca tenuicornis* (an amphipod crustacean)
Janira maculosa (an isopod crustacean)	*Dexamine spinosa* (an amphipod crustacean)	*Urothoe brevicornis* (an amphipod crustacean)	*Phoronis muelleri* (a species of unsegmented worm-like organism, called a Phoronid)
Aoridae spp. (a genus of amphipod crustaceans)	*Apseudes latreillii* (a tanaid crustacean)	*Moerella pygmaea* (a bivalve mollusc)	
		Massilina secans (a forminiferan protist)	
		Nephtys longosetosa (a polychaete worm)	
		Mysella bidentata (a bivalve mollusc)	

The ANOSIM of data on particle size distribution and organic content also revealed significant variation among the four habitats. Each habitat was significantly different from every other habitat for all but one comparison, namely sand from seagrass beds *versus* clean, fine sand. The main subdivision of the habitats was between live maerl *versus* the other three sand habitats. This was mainly due to the large percentage of particles ≥1mm in the maerl habitat and its high organic content. BIOENV analysis showed that differences in composition of animal assemblages were strongly correlated with differences in granulometry and organic content.

Discussion

The St Mawes Marine Habitats Study has greatly increased knowledge of the types of habitats within the harbour, their distributions and the range of flora and fauna they support.

A previous Government-led mapping exercise in 1999 indicated that seagrass was present as a single large bed in the centre of the outer harbour. The present survey confirmed the continued existence of this bed, but also revealed significant areas of dense seagrass fringing the north and eastern shores of the harbour. Between these large beds of dense seagrass, there were also extensive areas of sparse seagrass that have not previously been mapped.

Living maerl was also much more extensive than previously supposed, but no new beds were found within the harbour. Our survey found the main bed of dense live maerl where it was previously reported, adjacent to the subtidal reef that extends south from Castle Point out to Lugo Rock. The main new findings were *(i)* that dense live maerl extends ~200m further east into the harbour than shown on the 1999 map and *(ii)* that this bed is surrounded by a roughly equal-sized area in which lower densities of living maerl were present in other habitats.

There were important findings for other subtidal habitats in St Mawes harbour also. The previous mapping exercise in 1999 indicated that the areas without rock, maerl or seagrass, supported muddy sediments – either 'muddy gravel' in the outer harbour or 'estuarine mud' in the inner area. Both classifications were incorrect. In the outer harbour, we found unvegetated sediments that comprised clean, fine sand with minimal silt or organic matter. Not muddy gravel. In the inner harbour, unvegetated sediments were also fine sand, but with slightly greater amounts of silt and organic matter, although far too little to qualify as mud, as indicated on the 1999 map. It is considered highly unlikely that these differences compared to the 1999 study reflect environmental change. The most likely explanation is that the earlier map was based on inaccurate data, due in part to the small number of sites studied. In this study, granulometry and organic content were determined via laboratory analysis, whereas in the 1999 mapping exercise they were assessed via casual observation by divers. The limited extent of surveys for the 1999 mapping exercise is also the most likely reason why it failed to record three other subtidal habitats found in this study, *i.e. (i)* a mixed sediment habitat, comprising a even mix of fine particles and small stones; *(ii)* a pebble/cobble habitat and *(iii)* a habitat comprising various coarse materials, such as dead maerl, stones and shells.

As predicted, the live maerl habitat had the most biodiverse animal assemblage of the four broad habitats that were investigated. This was attributed to the three-dimensional structure of maerl nodules (thalli), which interlock to form a complex lattice with spaces in between that provide a wide range of invertebrate niches. Seagrass is commonly thought of as a high-biodiversity habitat, but sediment amongst seagrass in St Mawes harbour supported slightly fewer animal taxa than the unvegetated silty sand dominating the inner harbour area. Had seagrass shoots and leaves been sampled as well as the underlying sediments, animal diversity would undoubtedly have been greater, but this would have confounded direct comparison with the other particulate habitats that were sampled. The greater diversity of animals in silty, fine sand in the inner harbour *versus* clean, fine sand in the outer harbour, is attributed to its less wave-exposed situation, offering more-benign conditions, and its greater organic content, which represents more food for deposit feeding invertebrates.

The finding that differences in assemblage composition among habitats were strongly correlated with differences in granulometry and organic content fits well with the findings of much research elsewhere indicating that these are key ecological determinants. Because each of these habitats supports a distinct animal assemblage, the loss of any one would have a very significant impact on the overall biodiversity of the harbour.

Surveys revealed four new species that are recognised officially as ‘species of conservation concern’ in the UK. These were *(i)* the sea anemone *Aiptasia mutablis* (‘nationally scarce’ and a Nationally Important Marine Feature); *(ii)* the bivalve mollusc *Callista chione* (‘nationally rare’); *(iii)* the amphipod *Leucothoe spinicarpa* (a Nationally Important Marine Feature); and *(iv)* the brown alga *Asperococcus compressus* (‘nationally scarce’).

The St Mawes Marine Habitats Study was not designed to formally investigate any potential human impacts, however, other sources of information did permit some discussion of findings in this context. For instance, shortly after the present study began, the University of Plymouth undertook surveys in the Fal & Helford SAC to assess the impact of chain moorings on a range of different habitats, including silty, fine sand within St Mawes harbour. The Plymouth study found gross ecological impacts on abundance and diversity within the zone scoured by mooring ground-chains (out to ~5m from each mooring block), and less severe, but still significant ecological impacts in a wider zone from ~5 to 11m radially. There are currently 150 chain moorings in St Mawes harbour, which would indicate that ~5.7 hectares – approximately 10% of the harbour – is impacted by moorings, with ~1.2 hectares being grossly impacted. It is estimated that around one third of this damage has occurred since St Mawes Harbour became part of a SAC.

There is no published information available on either the amount or distribution of anchoring activity within St Mawes harbour, or its impacts on seabed habitats. It is generally believed, however, that anchoring disturbance has increased significantly in the last 20-30 years due to increased provision of facilities for storing boats on the water, both locally and regionally (*i.e.* moorings, pontoons and marinas).

Broadly speaking, moorings and anchoring activity are concentrated in the more-sheltered inner (eastern) half of the harbour. Seagrass is distributed around the periphery of this area, but is sparse, patchy or, more often, absent in the central area where moorings and anchoring activity are concentrated. It is possible that this distribution of seagrass reflects the impact of moorings and anchoring within the harbour. In one area along the northern shore of the harbour, both live maerl and seagrass extend into an area with moorings. Neither species has survived within the sweep of mooring ground chains in this area.

Increased knowledge of the distribution and biodiversity of different habitats in St Mawes Harbour provides various opportunities for improving management of the harbour and for raising general public awareness about its marine life. For instance, the local harbour authority might wish to consider re-arranging some of the moorings in the harbour in order to minimise their impact on maerl and seagrass. Another possibility for protecting these habitats might to establish one or more no-anchoring zones, as exist in the nearby Helford estuary to protect seagrass beds. If there was sufficient local support for such moves, it would be highly instructive to monitor their effects on seabed habitats.

The findings of this study, particularly the habitat map, could also serve as useful baseline information for the assessment of potential impacts of any new activities or developments planned within the harbour.

Aside from its potential contribution to environmental management of St Mawes Harbour, the main value of this study is the opportunity it presents to raise general awareness of its ecology and the ways humans can affect it, for better and for worse. The Trust aims to present and interpret the results of this study in a variety of ways to engage and inform locals and visitors in these issues (*e.g.* via meetings, the media, publications, educational activities, etc.).

No scientific study is fully comprehensive and this is no exception. Thus, this study was confined to benthic habitats and ignored other aspects of the harbour's marine ecology, such as fish, plankton, seabirds, seals and cetaceans. Developing a more complete picture of the marine life of St Mawes Harbour would require these to also be studied. The present surveys were also limited in the sense that they were done during only one part of one year – late spring/early summer 2010. Hence, results provide only a snapshot of the habitats and species present at that point in time.

All of the habitats and species that were studied can be expected to show various forms of short-, medium- and long-term variation. Further research to investigate such changes would help refine understanding of the ecology of the harbour.

Amongst the random variation that is normal for populations of marine plants and animals, there would undoubtedly be various trends and cycles uncovered, which would be fruitful areas for further research on their potential causes.

The effects of human activities and disturbances within the harbour would also be worthy subjects for further research, with chain moorings and anchoring activity being the most obvious priorities for investigation. With regards to anchoring activity, the first step necessary would be to survey its distribution within the harbour to identify potential high- and low-disturbance sites to compare.

In the interest of promoting further research in the harbour, the Trust will be making available all of the raw data collected for this study to any individual or group that wishes to use it non-commercially. This includes the 13,000+ digital photo-quadrats of the seabed that were obtained, which contain much more information than it was possible to extract and use for this study.

1 INTRODUCTION

1.1 St Mawes Harbour

St Mawes Harbour is situated at the mouth of the Percuil River, which is one of the seven major branches of the Fal estuary in Cornwall (Figure 1). In statutory navigational terms, St Mawes Harbour is the area contained within lines drawn from Castle Point to Carricknath Point, to seaward, and from Polvarth Point to Amsterdam Point, further up-river. The harbour has an area of $0.6km^2$ and a maximum depth of ~3.7m at chart datum. The intertidal zone of the harbour is predominantly rocky, but navigational charts (Garmin BlueChart Atlantic v8.0) indicate a predominantly sandy seabed subtidally.

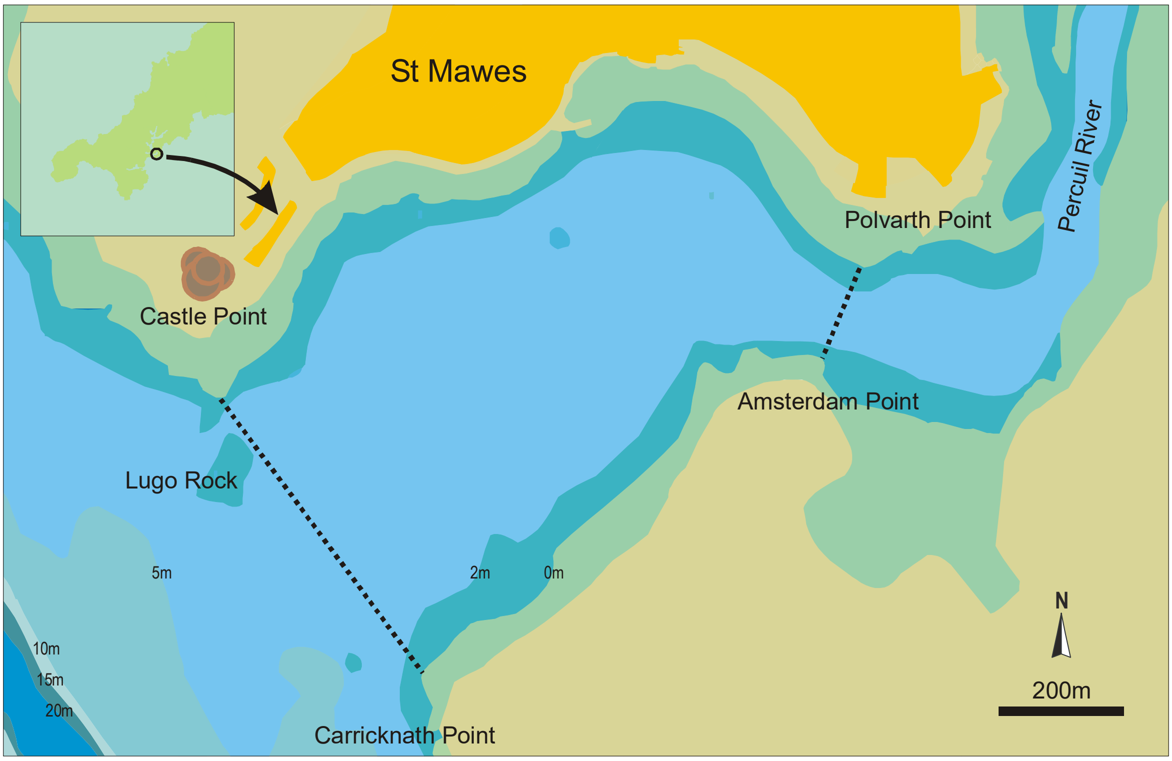

Figure 1. St Mawes Harbour at the mouth of the Percuil River, Fal estuary, Cornwall. Dotted lines indicate statutory harbour limits.

1.2 Origins of the project

The St Mawes Harbour Conservation Trust (hereafter, "the Trust") was formed in 2006 with the following long-term objectives.

a) To preserve the character and beauty of St Mawes Harbour (as delineated in the St Mawes Pier and Harbour Act 1854, including the land covered by water) for the benefit of the community of St Mawes and visitors to St Mawes.

b) To conserve the natural features of St Mawes Harbour and its environment including its vegetation, natural habitats and animal life which are of ecological and educational value.

c) To advance the education of the public about the conservation and protection of the environment of St Mawes Harbour.

d) To ensure for the benefit of the public that the history of St Mawes Harbour is documented and recorded.

To help it achieve these goals, in 2009/10 the Trust, in collaboration with CMER, secured funding from the Esmée Fairbairn Foundation for the 'St Mawes Marine Habitats Study'. The Trust describes this project as:

"a project to map the extent of seagrass and maerl bed habitats in St Mawes Harbour and its environs, to record their biodiversity, to assess certain human impacts upon them, and promote through an outreach programme the interest and importance of these habitats for nature conservation."

This report presents the scientific component of the 'St Mawes Marine Habitats Study'.

1.3 Seagrass and maerl bed habitats

Seagrass and maerl bed habitats warrant special mention in the Trust's plan for this study because their presence in the harbour is one of its outstanding features. As well as being very interesting biologically, they are also very beautiful habitats.

Most people with an interest in marine life know something about seagrass. If they haven't seen it in the wild – perhaps while wading in the shallows at low tide or while snorkelling – they have probably seen it on nature programmes on television. If they do a lot of boating, they may have pulled up clumps of seagrass on their anchor in certain places. A key fact about seagrass is that it is not a seaweed (*i.e.* an alga), but a form of flowering plant adapted for life in the sea. There are two species of seagrass in England, *Zostera marina* and *Z. noltii*. It is believed that only *Z. marina* grows in St Mawes Harbour.

Maerl is generally much less well-known. Maerl is a species of red seaweed – an alga – but unlike nearly every other seaweed, it has a dense internal skeleton made from calcium carbonate. This is the same white mineral that forms the hard parts of corals and which coral reefs are thus built from. As with corals, the living part of maerl forms a thin layer over the outside of the stony skeleton. There are two species of maerl that live in the Falmouth/St Mawes area, *Lithothamnion corallioides* and *Phymatolithon calcareum*. They are very hard to tell apart as both form irregularly branched nodules that are pink/purple in colour and range in size (locally) from a few mm up to 5cm. In *L. coralliodes* the surface is smooth and glossy, whereas in *P. calcareum* it is dull and chalky (Hiscock 1986). Of the two species, *P. calcareum* is more likely to grow in a flattened form, with branching in only one direction. When maerl dies, the stony skeleton is left behind and breaks down to form maerl gravel and eventually sand. In some parts of the Fal system, there are deposits of dead maerl several metres thick that may be up to 8,000 years old (Birkett *et al.* 1998).

Neither seagrass nor maerl is widespread around the UK, but maerl is the much-rarer of the two. Particularly rare are places where maerl grows at high density, turning the whole seabed a dark lilac pink.

Where they grow in profusion, both seagrass and maerl are habitat-forming species, *i.e.* they provide favourable living conditions for other species. This is partly because they provide complex, three-dimensional structure on the seabed, which concentrates organic matter (food) and provides shelter for animals, both from the effects of waves and currents and the attentions of predators.

Because maerl has a hard mineral skeleton, some of its value as habitat persists even when dead. This gradually declines over time, however, as the initially branched skeletons are progressively eroded into smaller and smaller pieces until they are indistinguishable from normal sand. Conserving living maerl is the only way to sustain maerl habitats in the long term.

Seagrass also provides important physical habitat, though obviously of a different kind to maerl due to its different growth form. Unlike maerl, the habitat value of seagrass disappears rapidly if the bed dies for any reason (as would happen if a field of grass on land died). Another important difference between these habitats is that seagrass communities are much more productive photosynthetically than maerl communities, with seagrass 'fixing' more than three times as much carbon per day as the same area of maerl (Martin *et al.* 2005).

St Mawes Harbour, together with the adjoining lower Fal and Helford estuaries, are believed to be the only places in England where seagrass and thriving maerl habitats occur alongside each other. The most outstanding maerl bed in the area is that on the St Mawes Bank, immediately below St Mawes Castle. This is often described as the 'jewel in the crown' of the Fal & Helford Special Area of Conservation (SAC), which was designated in 1999 to protect the rich variety of local marine habitats. The Trust would like local people to cherish and protect these natural wonders 'on their doorstep'. It believes that increasing our knowledge of the distribution and ecology of these habitats is key to achieving and this.

1.4 Why more science?

The impetus for a scientific study was the Trust's recognition that, while St Mawes harbour currently has considerable aesthetic and ecological value, it is also increasingly subject to human pressures; most notably from the growing popularity of recreational boating. The Trust also saw that despite having statutory designations that place St Mawes Harbour amongst the most important marine sites in the country, there was very little comprehensive and up-to-date information available on its wildlife (see Section 2 for a detailed account of the harbour's conservation designations and a review of existing knowledge on its marine life). The Trust saw that this lack of knowledge was not only hampering effective environmental management of the harbour, but also limiting opportunities to educate and enthuse the public about its marine wildlife. This study was designed to address these issues.

1.5 Objectives

To update and build upon existing information on marine habitats and species in St Mawes Harbour, CMER undertook two significant new studies. The first of these was a spatially comprehensive and systematic survey of broad habitat types on the seabed of St Mawes Harbour. The second was a detailed investigation of the species living in each of the main habitat types within the harbour and a subsequent comparison among them in terms of assemblage composition and diversity.

The methods and results of these two studies are described in Sections 3 and 4. Section 5 discusses these results in light of existing knowledge about the harbour and the types of habitats and species it supports. It goes on to consider how the new information obtained might be useful to environmental management of the harbour and to make recommendations for future research.

2 BACKGROUND INFORMATION

2.1 Statutory conservation designations

St Mawes Harbour is an important part of two statutory sites for nature conservation: *(i)* the Lower Fal and Helford Site of Special Scientific Interest (SSSI) (Figure 2); and (*ii)* the Fal and Helford Special Area of Conservation (SAC) (Figure 3).

2.1.1 Lower Fal & Helford Intertidal SSSI

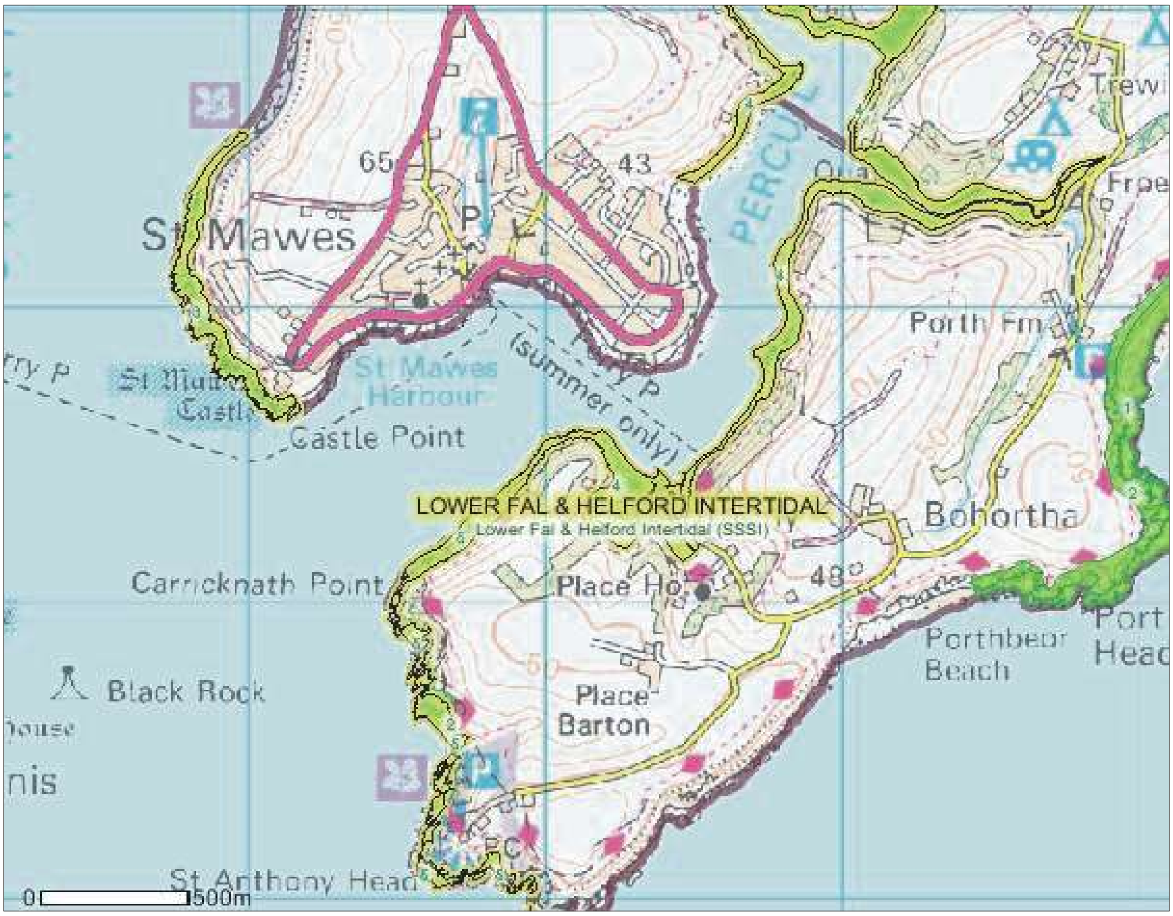

Figure 2. Map of St Mawes Harbour showing sections of foreshore (*i.e.* intertidal zone) that are part of the Lower Fal & Helford Intertidal SSSI (highlighted light green with black border).

The Lower Fal & Helford Intertidal SSSI was designated in 1997 (two years before the SAC) and is managed under the Wildlife and Countryside Act (WCA) 1981, as amended by the Countryside and Rights of Way Act 2000. This is one over 4,100

SSSIs in England, which collectively cover around 8% of the country's land area. SSSIs are said to be the *"country's very best wildlife and geological sites"* (Natural England 2012a).

The 'intertidal' zone can be defined in several slightly different ways, but in relation to intertidal SSSIs it is the zone between Mean High Water (MHW) and Mean Low Water (MLW).

The principal 'interest features' of the Lower Fal & Helford Intertidal SSSI are its rocky and sedimentary habitats and the algal and invertebrate assemblages they support. These habitats occur in a wide variety of conditions of salinity and wave-exposure, which are important factors affecting the distribution of many marine and estuarine organisms. As a consequence, the wide variety of environmental conditions found in the site is associated with a high level of biological diversity.

The Lower Fal & Helford Intertidal SSSI comprises five non-contiguous units, three of which overlap partially with St Mawes Harbour. The first of these is the Percuil River unit, which includes both shores of the upper river, and the southern shore of St Mawes Harbour as far as the western side of Amsterdam Point. This unit comprises both rocky and sedimentary shores. The second SSSI unit in the harbour begins where the Percuil River unit ends on the southern shore of the harbour and extends around Carricknath Point to St Anthony Headland at the mouth of the Fal estuary. The third is the 'Fal rocky shore' unit, which has two sub-units, one on the western shore of the lower Fal (Carrick Roads) and one on the eastern shore. The eastern sub-unit begins just inside St Mawes Harbour immediately south of St Mawes Castle and extends ~2km north around the southwest-facing shore of Castle Point.

Given that three of the five units making up the site are in the vicinity of St Mawes, it is not surprising that the special importance of this area is highlighted in the statutory notice (under Section 28 of the WCA 1981) identifying the site's scientific interest:

> [The Percuil River] is the most significant inlet of interest in the Fal, grading from rocky shores in the outer section to extensive areas of sediment in the upper sections. Rocky shores are represented by sections from west of Newton Farm to

Castle Point and from Zone Point to Amsterdam Point. Within a small distance (around 2 km) a great change in wave exposure occurs.

The contribution of SSSI-status towards environmental knowledge of St Mawes Harbour is discussed in Section 2.4.

2.1.2 Fal & Helford SAC

Figure 3. Map showing the boundary of the Fal & Helford SAC (shown as black line on yellow). The SAC incorporates all of the branches of the Fal estuary apart from the upper Penryn River and Mylor and Restronguet Creeks. NB: the two strips highlighted along the open coast eastwards of the Fal are annexes of the Fal & Helford SAC supporting the terrestrial plant Shore Dock, *Rumex rupestris*.

The Fal & Helford SAC was designated in 1999 under the Conservation (Natural Habitats &c.) Regulations 1994 (now amended and consolidated by The Conservation of Habitats and Species Regulations 2010). These laws, which also provide for the management of SACs, implement the requirements of the European Union's (EU) Habitats Directive (92/43/EEC) in England and Wales and adjacent territorial waters. Alongside Special Protection Areas (SPAs) for the protection of wild birds, SACs form the Europe-wide Natura 2000 network of nature conservation sites. Natura 2000 is the centrepiece of EU nature and biodiversity policy and aims to assure the long-term survival of Europe's most valuable and threatened species and habitats (European Commission 2012).

The Fal and Helford qualifies as a SAC for the following priority marine habitats (*i.e.* habitats listed in Annex I of the EU Habitats Directive):

- Large shallow inlets and bays;
- Atlantic salt meadows;
- Mudflats and sandflats not covered by seawater at low tide; and
- Sandbanks which are slightly covered by seawater all the time.

Of these 'features' of the site, only 'Atlantic salt meadows' is not present in St Mawes Harbour.

The feature 'Large shallow inlets and bays' includes the following additional sub-features:

- Rocky shore communities;
- Subtidal rock and boulder communities;
- Subtidal mud communities; and
- Kelp forest communities.

A narrative account of these habitats, their variations, notable species and locations of particular interest is provided in English Nature's (2000) advice for the Fal & Helford SAC, issued under Regulation 33 of the Conservation (Natural Habitats &c Regulations) 1994.

In the account for 'rocky shore communities', the Percuil River is noted for lower shore overhangs and gullies support communities characterised by red algae and a rich sponge fauna, bryozoans, hydroids and spirorbid worms. Kelp forest communities in the vicinity of St Mawes Castle are noted for high abundance of the south western kelp *Laminaria ochroleuca* and a dense understorey of red algae.

Under 'mudflats and sandflats not covered by seawater at low tide', Amsterdam Point at the northeast corner of St Mawes Harbour is noted for its 'Intertidal sand and gravel communities', which are said to comprise, *inter alia*, amphipods, polychaete worms, bivalve molluscs and the sea cucumber *Leptopentacta elongate*. More generally within the harbour, the same habitat is said to support a variety of echinoderms including the brittlestars *Ophiura ophiura* and *Amphiura brachiata* and the sea potato *Echinocardium cordatum*. The lower shore of Amsterdam Point is also noted for its 'intertidal muddy sand communities', which are said to support dense beds of the sand mason worm *Lanice conchilega*.

Two of the most important habitats in the SAC, both of which are notably well-represented in the St Mawes area, are its maerl beds and its eelgrass (= seagrass) beds. Both are sub-features of 'sandbanks which are slightly covered by seawater all the time'. Because of their importance to the Fal & Helford SAC and to this study, accounts of both sub-features from English Nature's (2000) 'Regulation 33' advice are reproduced in full, below:

> **Maerl bed communities** - Maerl beds are composed of accumulations of living and dead unattached coralline algae. They can harbour a very high diversity of organisms, particularly when compared to adjacent sediments, including some species more or less confined to this habitat. Maerl beds may also be an important source of calcareous material for other maritime habitats. The Fal maerl bed is the most south-westerly in Britain and largest outside Scotland, Brittany or Ireland. Two species of maerl occur, *Lithothamnion corallioides* which is nationally scarce and *Phymatolithon calcareum*. Exceptionally diverse biological communities are associated with the maerl; over fifty species of seaweed and many animal species are associated with the St Mawes Bank live maerl bed, including many rarities, for example *Gracilaria multipartita*, *Halymenia* spp. and the rarely recorded Couch's goby *Gobius couchi*. More common species include the burrowing anemone *Cerianthus lloydii*, other anemones, crabs, polychaetes, fish and crustaceans. Another live maerl bed has been recorded in the mouth of the Helford, off Bosahan Point, comprising up to 80% live *Lithothamnion corallioides* (Moore *et al.*, 1999). There are extensive areas of dead and crushed maerl, found south of Penarrow Point out into Falmouth Bay. These sediments are also rich in species and provide an

important habitat for, amongst others, deep burrowing species, attached seaweed, bivalves and crustaceans (Moore *et al.* 1999).

Eelgrass bed communities - Eelgrass beds are important not only as a habitat for a diverse community of species but also as nursery areas for various fish species, as stabilisers of sediment and as contributors to productivity. Subtidal eelgrass *Zostera marina* beds and their rich associated flora and fauna are found in the shallow sands bordering the St Mawes maerl bed, between Penarrow and Trefusis Point, between Durgan and Toll Point (Helford) and between Carricknath Point and Amsterdam Point (St Mawes Harbour) (Rostron, 1985; Rostron, 1987). Eelgrasses provide an important source of attachment for many small animals and plants. Animals commonly found include anemones, swimming crabs, hermit and shore crabs, heart urchins, brittlestars, cuttlefish and more unusually seahorses. Eelgrasses were once abundant and widespread around the British coasts, but serious declines have occurred, in particular as a consequence of a severe outbreak of 'wasting disease' in the early 1930s. Recovery of eelgrass beds since the 1930s has been slow and patchy, and this habitat is now considered a nationally scarce habitat in the UK, with the south-west providing an important stronghold.

A final note on site boundaries: with regards to tidal height on the shore, the default boundary of the SAC is at MLW; *i.e.* it excludes the intertidal zone. The exceptions are intertidal areas that are part of the Lower Fal & Helford Intertidal SSSI. As regards St Mawes Harbour, this means that intertidal habitats on the southern shore of the harbour are part of the SAC, but those on the northern shore (between Castle Point and Polvarth Point are not.

2.2 Current knowledge of marine habitats in St Mawes Harbour

In principle, the conservation designations attaching to St Mawes Harbour oblige Natural England (NE), the statutory nature conservation body, to undertake regular monitoring to assess the conservation status of its protected features. A feature is said to be in 'favourable' conservation status when it shows no significant changes, subject to natural variability – in other words, there are no significant human impacts. In practice, however, a lack of funding has meant that NE has done very little conservation monitoring within St Mawes Harbour.

Before reviewing current assessments of potential human threats to marine habitats in St Mawes Harbour, it is first worth giving an overview of the key studies that underpinned its SSSI and SAC designations.

2.2.1 Marine Nature Conservation Review (MNCR)

The first attempt to describe the marine ecology of St Mawes Harbour came with the 1987 launch of the Nature Conservancy Council's UK-wide Marine Nature Conservation Review (MNCR). After 1991, the MNCR was carried forward by the newly-named Joint Nature Conservation Committee (JNCC).

The MNCR's aims were to provide a comprehensive baseline of information on marine habitats and species, to aid coastal zone and sea-use management and to contribute to the identification of areas of marine natural heritage importance throughout Great Britain. The focus of MNCR work was on littoral and sublittoral benthic habitats and their associated communities.

The stated objectives of the MNCR were to:

- identify sites and species of nature conservation importance;
- extend knowledge of benthic marine habitats, communities and species in Great Britain, particularly through description of their characteristics, distribution and extent; and
- provide information through the data collected to support more general measures required to minimize adverse effects of development and pollution, particularly on sites and for species of nature conservation importance (JNCC on-line, cited 2012a).

The review pursued these objectives by drawing together existing information and combining it with the results of a large number of new surveys. Some of these were done specifically for the MNCR while others were done for different reasons and incorporated in the review secondarily. MNCR work in relation to St Mawes Harbour was done as part of an exercise for the wider Fal estuary system. The report on this work is presented in a single document alongside reports for the

Helford estuaries and 14 other marine inlets in the western English Channel (Moore *et al.* 1999).

The main sources of information on littoral and sublittoral benthic habitats in St Mawes Harbour that were used for the MNCR were as follows:

- 1986-89 MNCR general surveys of sector 8 – western Channel (MNCR, unpublished data).
- 1985 Harbours, Rias and Estuaries survey of the Fal Estuary carried out by the Field Studies Council Oil Pollution Research Unit (Rostron 1985).
- 1970-1980 Scottish Marine Biological Association/Marine Biological Association Great Britain intertidal survey (Powell *et al.* 1978).
- 1990 National Rivers Authority SW Region littoral and sublittoral survey of the Fal estuary (NRA 1992) (unpublished)
- 1994 English Nature/BIOMAR/LIFE Programme acoustic and grab-sampling survey of the lower Fal-Ruan estuary, Falmouth Bay and the east side of the Lizard Peninsula (Davies & Sotheran 1995).

None of these studies gathered data for the Fal estuary in a systematic and spatially-comprehensive way. Each collected data from what appears to have been a largely-haphazard selection of sites. The map from the MNCR report (Moore *et al.* 1999) showing the locations of these sites is reproduced in Figure 4, below.

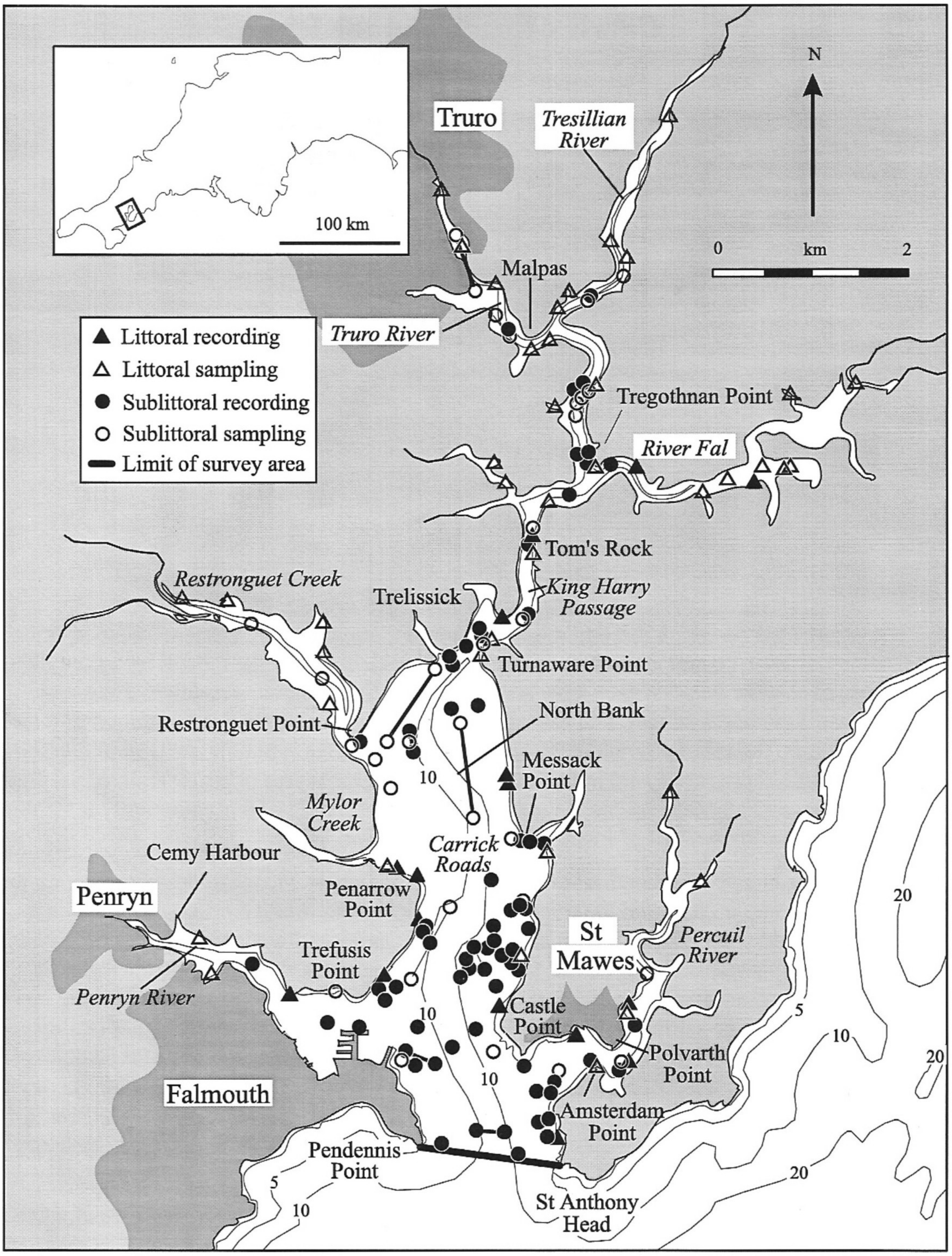

Figure 4. Sites in the Fal estuary system (including St Mawes Harbour) where the data used for the MNCR exercise were collected. Note: 'recording' means description of habitats and communities based on visual or photographic observation. 'Sampling' means physical collection of the substratum (typically sediments) and habitat materials biological material for sorting and identification in the laboratory.

The main outputs from the MNCR for the Fal estuary were a narrative account of the variety and distributions of different marine habitats and species and a map that attempted to summarise this information. In relation to St Mawes Harbour, the narrative account is essentially the same as appears later in descriptions of the Fal & Helford SAC and the Lower Fal & Helford SSSI. The focus of interest here is the MNCR map. Maps such as this are a key management tool, because they are used to inform assessments of the potential ecological impacts of human activities and developments.

A key aspect of the MNCR map for the Fal (reproduced in Figure 5, below) is that its creators sought to extrapolate beyond the discrete sampling points to predict the wider distribution and extent of patches of different habitats and species assemblages. In MNCR parlance, apparently consistent associations between particular habitats and predominant species are known as 'biotopes'. Each biotope in the survey area was given a distinct name from the official UK-wide biotope classification scheme that was developed for the MNCR (Connor *et al.* 1997a, b). The MNCR map in Figure 5 is a biotope map.

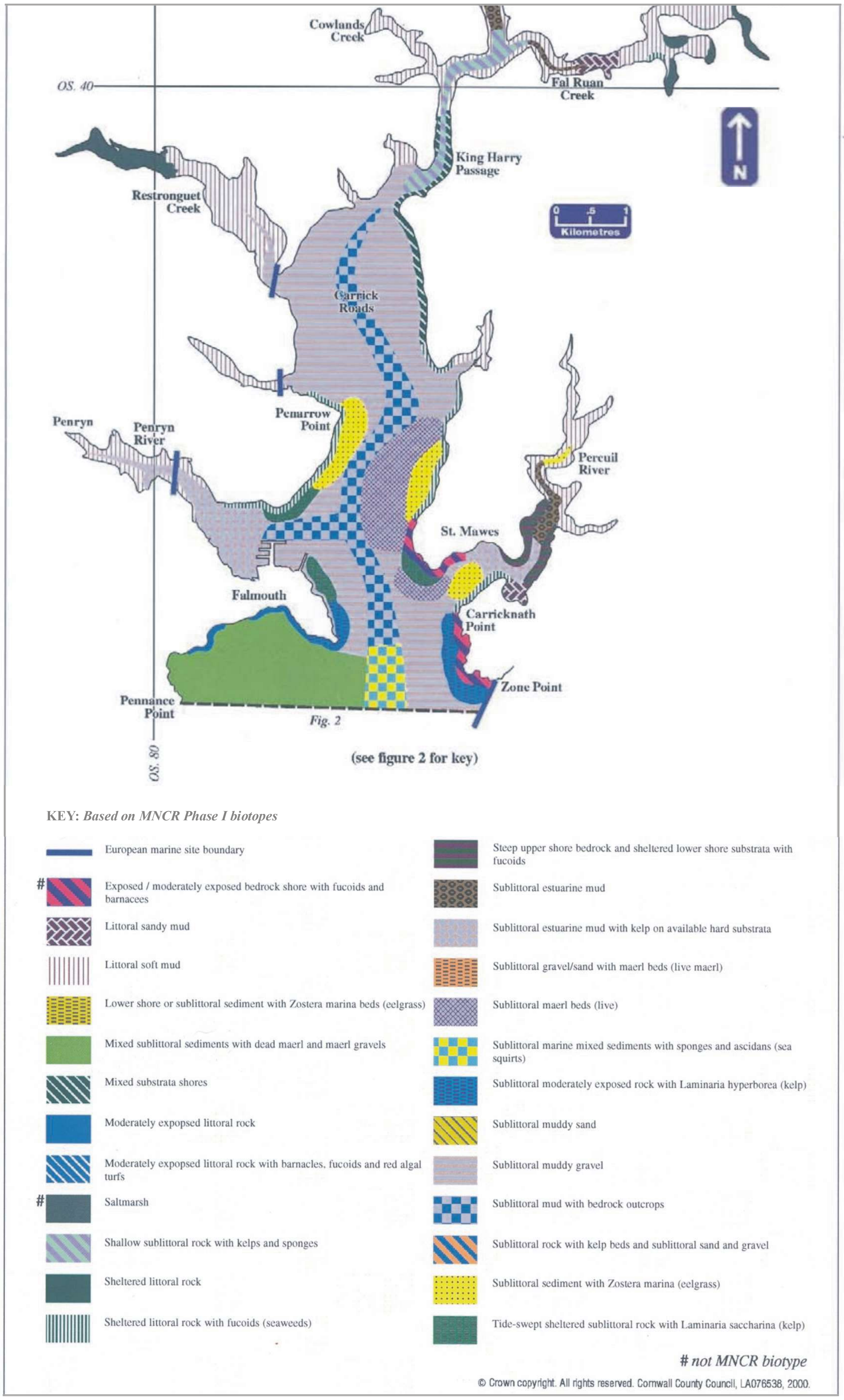

Figure 5. Biotope map for the lower Fal estuary system (including St Mawes Harbour), based on Moore *et al.* (1999). Reproduced from English Nature (2000).

Table 1, below, lists the eight biotopes that the MNCR recorded in St Mawes Harbour and provides a brief summary of the distribution of each biotope, based on the MNCR map (Figure 5).

Table 1. An account of the littoral and sublittoral biotopes in St Mawes Harbour based on the biotope map in the MNCR report by Moore *et al.* (1999). Biotopes are listed in approximate order of decreasing extent within the harbour.

1. Sublittoral estuarine mud with kelp on available hard substrata
Reported to be continuous over most of the inner (eastern) half of St Mawes Harbour, spanning the full (sublittoral) width of the harbour in most places. At the eastern end of the harbour, this biotope is said to extend around Polvarth Point approximately 2-300m up the Percuil River.
2. Sublittoral sediment with *Zostera marina* beds
Reported to occupy a single patch, approximately 350m along and 200m perpendicular to the shore, in the south-western (sublittoral) sector of the harbour. The northern boundary of this patch lies in the middle of the harbour is said to adjoin an area of the 'sublittoral maerl bed' biotope (2.). To the east of this *Zostera* bed there is 'sublittoral estuarine mud with kelp on available hard substrata' (1.) and to the west there is 'sublittoral muddy gravel' (7.)
3. Sublittoral maerl beds
Reported to occupy a patch in the north-western sector of the harbour that is similar in size to the abovementioned eelgrass bed. This is said to be the eastern end of a larger patch of this biotope (approximately 900m long) that wraps north and west around Castle Point into the lower Fal estuary.
4. Exposed/moderately exposed bedrock shore with fucoids and barnacles
Reported to occur on two unequal-sized patches of shore within St Mawes Harbour. The larger patch (approximately 600m long) occurring on the northern shore of the harbour between Castle Point and ending approximately 200m west of the seawall protecting the inner harbour. The smaller patch (approximately 100m long) occurs on the north-facing shore of Carricknath Point. This is part of a larger patch that continues out around Carricknath Point south as far as St Anthony Headland.
5. Sheltered littoral rock with fucoids
Reported to occur only one section of shore within the harbour – a patch approximately 500m long on the mid and eastern sections of the stretch of shore between Carricknath Point and Amsterdam Point on the southern side of the harbour.
6. Sheltered sublittoral rock with *Laminaria saccharina*
Reported to occur only one section of shore within the harbour – a patch approximately 250m long on the south- and east-facing shores of Castle Point on the northern side of the harbour. A separate patch of this biotope of about the same size occurs on the western side of Castle Point.
7. Sublittoral muddy gravel
This is reported to be the predominant sedimentary biotope in the shallow sublittoral zone of the lower Fal estuary (Carrick Roads). This biotope extends a short way (approximately 250m) into the mouth of St Mawes Harbour, on the south side between the patch of 'sublittoral maerl bed' biotope (3.) to the north and the shore of Carricknath Point.
8. Sublittoral moderately exposed rock with *Laminaria hyperborea*
Reported to occur only one section of shore within the harbour – a patch approximately 100m long on the north-facing shore of Carricknath Point, on the southern side of the harbour.

Following on from the previous point that the MNCR biotope map was created by extrapolating between sampling points, it must be noted that the MNCR exercise appears to have collected new data from only eight sites within St Mawes Harbour (Figure 5, above) – six sublittoral sites and two littoral sites. If other information sources were used to create this map, they are not referenced. Clearly, therefore, it is hard to have much confidence in the reliability of this map, particularly in regard to the precise distributions of different biotopes. Despite these limitations, 13 years later this is still the only comprehensive map available of marine biotopes in St Mawes Harbour and the wider Fal estuary.

2.3 Human activities and potential impacts in St Mawes Harbour

As per the types and distributions of habitats and species within the harbour, information on actual or potential human impacts in St Mawes Harbour is fragmentary and dated.

The available information indicates that St Mawes Harbour and the Percuil River, while far from wholly natural, are not as severely impacted by human activities as other parts of the Fal estuary. Nor does there appear to be any acute environmental threat from activities or developments that are either currently taking place or likely to take place within the harbour and Percuil River. To the extent that there are threats to the natural environment of this area, they come mainly from outside – both locally, such as disturbances associated with the proposed dredging of a deeper approach channel to Falmouth docks, and globally, such as the threats posed by climate change and ocean acidification.

By the far the greatest disturbance to St Mawes Harbour and the Percuil River has been the imposition of hundreds of chain moorings for boats. The main concern being seabed scouring due to the sweep of chains. This and other disturbances to the area – both past and current – are discussed in more detail, below. The sub-headings are the main categories of human activity that are relevant to St Mawes Harbour and the Percuil River (these have been borrowed from a recent NE risk assessment for the Fal & Helford SAC (Natural England 2012b).

2.3.1 Fishing

The main forms of fishing that occur within the harbour and Percuil River are recreational angling and commercial potting for shrimps and velvet crabs (*Necora puber*). Fishing with either trawls, mechanical dredges or fixed gill-nets in this area are all illegal under various items of fisheries or environmental legislation. There is also some recreational spearfishing and commercial and recreational diving for scallops (*Pecten maximus*). No environmental study or review covering the area has reported any concerns in relation to fishing. NE's (2012b) risk assessment concluded that fishing currently presents only a low risk to features of the Fal & Helford SAC.

2.3.2 Mariculture

There are no mariculture operations taking place within St Mawes Harbour, although there is a designated bivalve mollusc production area (designated under the Shellfish Hygiene Directive 91/492/EEC) further upstream in the Percuil River. Permitted uses include production of native oysters (*Ostrea edulis*) and/or Pacific oysters (*Crassostrea gigas*). The area is believed to be used for re-laying and growing seed oysters brought in from elsewhere, rather than for harvesting wild stocks, but it is not currently in use (St Mawes Harbour Master, personal communication).

The only mariculture threat to the harbour identified by NE in their SAC risk review is a medium SAC-wide threat posed by recent resumption of Pacific oyster culture by the Duchy of Cornwall Oysterage in the Helford estuary. The threat is that Pacific oysters will reproduce and spread outside the Helford production area via planktonic larval dispersal and go on to proliferate to the detriment of natural habitats and species. Such 'invasions' of *C. gigas* have occurred in the vicinity of Pacific oyster farms on the coast of France and the Netherlands. Here, invasive Pacific oyster populations have formed extensive oyster reefs that have obliterated natural habitats on both hard and soft substrata (Miossec *et al.* 2009, Troost 2010). For several decades Pacific oysters were farmed in northern Europe, including the Fal and Helford estuaries, without this problem arising. This was because any larvae produced tended to be killed by low water temperatures during the winter. The increasing tendency of *C. gigas* to invade natural habitats in northern Europe is attributed to higher winter sea temperatures due to global warming. To mitigate this threat in the Fal & Helford, the Duchy of Cornwall Oysterage are required to use only sterile 'triploid' seed-stock – oysters that are artificially induced to possess three rather the normal two sets of chromosomes. There are legitimate concerns, however, that this safeguard does not guarantee entirely against the uncontrolled spread of Pacific oysters beyond the Helford, hence NE's (2012b) categorisation of this as a 'medium' risk.

2.3.3 Discharges

Various forms of discharges have created minor pollution problems within the harbour and Percuil River in the past, but it would seem that these have significantly diminished over recent years and continue to do so. NE's (2012b) risk review for the Fal & Helford SAC identified no medium or high risks due to current discharges into the harbour/Percuil river. There was, however, deemed to be a low risk due to septic tank discharges into the Percuil.

To the extent that there is any greater risk to the harbour from discharges it arises from persistent chemicals that were released into the Fal estuary in the past. For the most part these chemicals are now bound up in the sediments. Concern arises from activities that might physically disturb contaminated sediments causing them to be re-suspended in the water column and carried to relatively unpolluted areas by wind-driven and tidal currents.

The main concern (rated by NE as a 'medium/low' risk) is the antifouling compound tributyl tin (TBT). This organotin compound became notorious in the 1980s when it was described as *"the most toxic chemical ever deliberately introduced into the marine environment"* (Goldberg 1986). TBT has now been banned on all vessels (on vessels <25m in 1988; and on vessels >25m in 2008), but the legacy of its past use persists in local marine sediments. The site with most residual TBT contamination is the area in and around Falmouth Docks (Langston *et al.* 2003; Langston & Burt 2007; NE, unpublished report). This is mainly the result of hull-cleaning and painting operations at the docks. Until just over a decade ago, Falmouth Docks allowed TBT-paint flakes blasted from ships hulls to wash straight into the estuary. They now collect and treat this material, but the TBT from past activities remains in the surrounding sediments. Without intervention, this will remain there for many years to come. TBT degrades relatively quickly when exposed to light and oxygen, but around the docks TBT contamination extends as deep as 1m into the sediments. Under such conditions, it may persist for decades.

The area around the docks is by far the worst area in the Fal & Helford SAC for TBT contamination because of the scale of activities that took place there, but use of TBT paints on much smaller boats left significant residual contamination in other parts of the Fal & Helford SAC, including St Mawes Harbour and the Percuil River (Langston *et al.* 2003; Langston & Burt 2007; NE, unpublished report). In 1997, St Mawes Harbour, Percuil River, Penryn River and Mylor Harbour were all identified as TBT 'hotspots'. Levels of TBT in Mylor were close to those around Falmouth Docks, but levels in St Mawes Harbour, Percuil River and the Penryn River were generally around only 10% of these levels (Langston & Burt 2007). While TBT levels in the harbour and Percuil River in 1997 were low in comparison to these other locations, they were still sufficiently high that, had there been any navigational dredging in St Mawes/Percuil at that time, the resultant spoil would have been too contaminated for disposal at sea. Thankfully this is no longer the case. The last times these areas were sampled for TBT (2005/6), levels were below the relevant threshold (Langston & Burt 2007).

After TBT, the only other notable discharge concern is the issue of diffuse agricultural run-off. The main problem being cattle slurry, which farmers spread on their fields as a fertiliser. NE have rated this as a 'medium' risk to the Fal & Helford SAC. Concerns on this issue appear to be general, with no mention of any specific problem within the Percuil catchment. The principal problem with cattle slurry entering the marine environment is that it has the same fertilising effect in water as it does on land. In extreme instances this can stimulate microbial activity to such an extent that all dissolved oxygen is used up and active marine organisms like fish and crustaceans are suffocated. A secondary issue is that cattle slurry may contain bacteria that cause human health problems, mainly via shellfish consumption, but also potentially via inadvertent ingestion while swimming. These problems tend to be greatest in the upper reaches of estuaries. Not only are these areas closest to the source of pollution, the volumes of receiving waters are smaller than further downstream, meaning there is less capacity for dilution.

2.3.4 Shipping

Given the relative shallowness of St Mawes Harbour compared to other parts of the Fal estuary and the absence of deepwater berths, ships (*i.e.* large commercial or naval vessels) do not use the harbour. Thus, to the extent that shipping has impacted on the harbour in the past, or might do so in the future, it is only at a distance. There is, for instance, no problem of seabed scour within the harbour due to ships' anchor chains, as there is in other parts of the Fal & Helford SAC.

NE have identified two shipping issues that pose a general threat to the Fal & Helford SAC; these are *(i)* the introduction of alien invasive species from ballast water discharges; and *(ii)* the release of toxic chemicals from ships being repaired in dry-dock at Falmouth Docks. Both are classified as 'medium/low' risks by NE in their risk assessment (Natural England 2012b).

Another potential threat to St Mawes Harbour and the Percuil arises from the practice of ship re-fuelling (known as 'bunkering'). This usually takes place while receiving ships are at anchor in Falmouth Bay, but during strong winds from the south or east it takes place within the Carrick Roads. In 2007 there was a 300% increase in the frequency of bunkering operations in the port of Falmouth – up from an average of 30 to and average of 122 a month. This resulted from a new EU emissions and air quality Directive requiring that ships could only enter European coastal waters when running on low sulphur fuel. For ships heading eastwards up the English Channel, Falmouth provides the last opportunity for ships to take on low sulphur fuel. The main environmental threat posed by bunkering is the possibility of fuel oil being spilled during the transfer between the bunker ship and the receiving ship. There are strict regulations and procedures governing these operations, however, and the fact that there has not been a significant spill locally is testament to their effectiveness. It is presumably for this reason that NE characterise bunkering as a 'low' risk to the SAC. While the risk of a spill is relatively small, even a modest spill close to land in an sensitive area like the SAC could cause significant environmental impacts and adversely affect industries like fishing and tourism.

2.3.5 Recreational activities

In terms of human activities and developments that take place within St Mawes Harbour and the Percuil River, by far the greatest environmental threat to marine life on the seabed is from boat moorings, with anchoring activity a close second (English Nature 2000, Coyle & Wiggins 2010, Fal & Helford SAC Management Forum 2012). In both cases, the environmental concern is mechanical abrasion of the seabed from heavy metal ground-tackle; *i.e.* ground chains and anchors (*e.g.* Walker *et al.* 1989, Backhurst & Cole 2000, Montefalcone *et al.* 2008, Herbert *et al.* 2009). Moorings present the greatest concern because of their number and their permanence, but anchoring is harder to manage and potentially more widespread, albeit at relatively low intensity. Recreational boats are not the only source of pressure, but they do comprise the overwhelming majority of boats that moor or anchor in this area. At a public meeting in 2005 hosted by the St Mawes Pier & Harbour Company (the private Harbour Authority) a spokesman reported that from 1990 to 2005 the number of moorings in St Mawes Harbour had increased nearly threefold from 46 to 132 (P. Marsden, personal communication). There have been similar increases in the number of moorings in almost all of the moorings areas in the Fal and Helford estuaries (M. Hoskin, personal observation). Anchoring activity is not monitored anywhere in the SAC, but it is safe to assume that it has increased in proportion to the number of vessels with moorings or marina berths in the area. Like moorings, the number of marina berths has also increased dramatically in recent years, with new marinas at Mylor and Port Pendennis and the expansion of Falmouth Marina on the Penryn River.

In NE's (2012b) risk assessment for the SAC (Natural England 2010), the risk to St Mawes/Percuil from the laying of new moorings is classified as 'medium' and the risk from anchoring on sensitive habitats, such as seagrass and maerl, 'medium/high'.

A different type of threat connected with the numbers of small craft in St Mawes/Percuil arises from the individually small, but collectively numerous inputs of harmful substances associated with boat use. Some examples include accidental spillages of fuel or oil (either direct or via bilge pumpings), inputs of anti-fouling compounds (both leaching from hulls and from scrubbing of hulls on the foreshore in preparation for re-painting) and discharges of untreated 'grey water' (sewage plus drainage from sinks, etc) from vessels without holding facilities. NE have classified the risk to the SAC from these inputs as 'medium'.

2.3.6 Harbour dredging

Natural England's (2012b) risk assessment for the Fal & Helford SAC identifies no specific threat within St Mawes/Percuil from harbour dredging. The depth of this area is generally adequate for the vessels that currently use it, however, a small amount of maintenance dredging is required off the quay-end in St Mawes to remove banks built up by propeller wash from the various vessels that berth alongside. This involves the removal of about 100-150 tonnes (77-115m^3) every one to two years. There is a further requirement for dredging around 1,000 tonnes (769m^3) roughly every seven years from within the inner harbour (Carrick District Council 2005).

Whilst this relatively small amount of dredging around the quay in St Mawes is apparently deemed to not threaten the wider environment, there is a potential threat from the vastly larger dredging programme currently being proposed by Falmouth Docks (A&P Falmouth Ltd.) and the Falmouth Harbour Commissioners (FHC). Permission is being sought for capital dredging to deepen the approaches and berths at Falmouth Docks by approximately 3m in order to allow the Docks to receive bigger ships (principally so-called 'mega cruise-ships'). This would involve dredging an area covering approximately 330,000m^2 (Royal Haskoning 2009) and removing over 700,000m^3 of material. In relation to St Mawes/Percuil, the principal threat associated with this is the possibility that silt stirred-up by the dredging would be carried across Carrick Roads and into the harbour, which is only 800m away.

The environmental statement supporting this project (Royal Haskoning 2009) predicted that the sediment plume from this dredging would not cross to the St Mawes side of Carrick Roads. The computer modelling this was based upon, however, has been criticised on several grounds by the Chief Scientific Officer of the licensing authority, the Marine Management Organisation (MMO) (Austen 2010). A major problem was that the model of dredge plume movement was run for only two tidal cycles. For a large complex estuary like the Fal in which complete turnover of water takes several days, this would tend to underestimate the spread of the dredge plume. As such, it cannot safely assumed that the sediment plume created by this dredging would not enter St Mawes Harbour. Were it to do so, the greatest concern would be the harbour's live maerl beds, which are highly intolerant of silt smothering (Birkett *et al.* 1998).

2.3.7 Habitat loss

Within the Fal & Helford SAC there has been considerable habitat loss over the years, both before and after designation, due to encroachment of built structures into the marine environment; *e.g.* quays, jetties, slipways, etc. A good example of this was Falmouth Maritime Museum, which was built on land created by infilling Falmouth Harbour. A study by Spalding Associates (Environmental) Ltd (2000) for English Nature found during the period 1976-2000, intertidal habitat in the Fal and Helford estuaries was lost to development at an average rate of 615.3m^2 per year. This equates to loss of an area the size of a football field every 11 years.

Natural England's (2012b) risk assessment classified the overall risk to the SAC from habitat loss due to development as 'low/medium'. This risk review did not identify any concerns in this regard within either St Mawes Harbour or the Percuil River. Historically, this area has suffered less from intertidal habitat loss than other parts of the SAC (*e.g.* Falmouth Harbour).

Habitat loss due to the laying of mooring blocks was not considered in NE's risk review. A mooring block is typically a heavy block of granite or cast concrete, typically of the order of 1m^2. The greatest concern is when mooring blocks are laid on sedimentary habitats, which is typically the case for moorings areas in the Fal & Helford SAC. In this circumstance, not only is the natural habitat lost, it is replaced by an artificial one (*i.e.* the surface of the mooring block) that is physically entirely different.

A form of marine habitat loss that is of global concern is that due to sea-level rise due to man-made climate change. NE regard this as a 'high' risk to the Fal & Helford SAC (Natural England 2012b). This mainly relates to intertidal habitats. The main issue is that as sea level rises, human uses of coastal land will constrain the scope for intertidal habitats to migrate landwards – a problem known as 'coastal squeeze' (Doody 1992, 2004). The most extreme case would see the sea rising and falling against a vertical rock seawall, where previously it did so over a large expanse of gently sloping sedimentary seashore. In this case, reduction in intertidal area is accompanied by a fundamental change in the type of intertidal habitat. Natural sea cliffs formed from rocks that are resistant to erosion pose similar problems. The intertidal zone at the base of such cliffs is often less steep, sometimes almost horizontal, due to erosion over thousands of years. If sea level rises quicker than the rate of erosion, the intertidal zone again becomes narrower and more vertical. As well as reducing the overall extent of intertidal habitats, this is also likely to impact species diversity. It is a well known phenomenon that the number of species a given habitat can support reduces as the area of that habitat declines (Primack 1993).

By the late-20th century, due to a combination of thermal expansion of the oceans and increased freshwater inputs from the melting of continental ice masses, global average sea level had already increased by 20cm compared to the mid-19th century when records began. The Intergovernmental Panel on Climate Change conservatively predicts a further 18-59cm rise by 2095 (Parliamentary Office of Science and Technology 2010).

2.3.8 Other forms of human disturbance

The only other risk to the Fal & Helford SAC identified in Natural England's (2012b) risk assessment – classified as 'medium' – was the threat posed by some already well-established alien invasive species; notably the slipper limpet, *Crepidula fornicata* and the brown seaweed, *Sargassum muticum*. The concern is that climate change and other more localised human disturbances will enhance opportunities for these species to proliferate within the Fal & Helford SAC.

Slipper limpets were introduced to the UK in Essex in the late 19th century along with imports of an American species of oyster *Crassostrea virginica*. High densities of these filter-feeders can change the substratum via production of pseudo-faeces, which comprise tiny indigestible particles rejected from the food stream entering the gullet. This, combined with their demands for food and space, can have a marked detrimental effect on co-habiting native species. They pose a particular threat to populations of native oysters and the fisheries they support (Rayment 2008).

Sargassum muticum, commonly known as 'wireweed' or 'Japweed', is a large, fast-growing brown seaweed (with fronds often >1m in length) that lives in shallow waters on the open coast and in the lower reaches of estuaries. Because of its fast growth-rate, it is able to outcompete other native species such as seagrass, *Zostera marina* and the kelp *Laminaria saccharina.* It first appeared in the UK in the Isle of Wight in 1973, having spread there from France (Pizolla 2008). As with the slipper limpet, it is believed to have been introduced to Europe with imports of non-native oysters, in this case oysters from Japan or the Pacific coast of Canada (JNCC on-line, cited 2012b).

From personal observation, both *Crepidula fornicata* and *Sargassum muticum* are present in the St Mawes/Percuil area.

2.4 Statutory monitoring of SAC and SSSI features in St Mawes Harbour

A need for detailed scientific surveys of SAC- or SSSI-protected marine habitats arises from the objective of maintaining sites at, or restoring them to, so-called 'favourable condition'.

For any given 'attribute' of a site (*e.g.* the extent of a particular habitat, or the population size of a particular species), favourable condition is said to exist when its value lies within a target range set for it by the relevant statutory conservation agency (here, Natural England), based on its prior knowledge of the site. The width of the target range is deemed to encompass the normal variability of the attribute and any departure from this range is regarded prima facie as unfavourable. This approach to monitoring the condition of nature conservation sites, which is applied throughout the UK, is called 'Common Standards Monitoring' (CSM) (JNCC 1998). A key aspect of CSM is that the interpretation of condition includes a large element of expert judgement. This is because CSM is incapable of objectively distinguishing natural changes in attributes from those caused by human influences (English Nature *et al.* 2001).

Despite the requirement for condition monitoring of SAC and SSSI attributes, there has been very little scientific monitoring of such features in St Mawes Harbour, or elsewhere in England – particularly for sublittoral attributes. Inadequate state funding has prevented conservation agencies such as Natural England (NE) from carrying out the type of detailed scientific surveys that condition monitoring was supposed to be based upon (*i.e.* JNCC 1998). What has tended to happen instead is that formal surveys involving the gathering of data have been largely replaced by informal inspection by NE conservation officers. For a site like the Lower Fal & Helford Intertidal SSSI, this may involve nothing more than a low-tide walk across certain parts of the site once every few years. As a consequence, condition assessments are much more subjective than they were ever intended to be and there is little or no scientific data available to anyone who might wish to evaluate condition independently, or update biotope maps.

2.4.1 Current condition assessments for SAC and SSSI features in St Mawes Harbour

For the record, the three SSSI units that overlap partially with St Mawes Harbour were last assessed in July 2009 and all were said to be in 'favourable condition' (Natural England 2009). The only publicly available information to support these assessments is a comment regarding the 'Carricknath to St Anthony Head' unit (Unit 5) that *"the site has a mixed algal community exhibiting well defined zonation of species, little or no ephemeral green algae and no physical damage or litter"* (Natural England 2009). In light of concerns about the reliability of these assessments it is worth noting that the 2009 condition assessment for the Lower Fal & Helford Intertidal SSSI erroneously asserts that the 'main habitat' in all of five sub-units is littoral sediment – even for Unit 3, the so-called 'Fal Rocky Shore' unit.

As regards the SAC, the main designated feature within St Mawes Harbour is the subtidal sandbank feature. As of 2006, which was the end of the first reporting phase for UK marine SACs (under Article 17 of the Habitats Directive), there was insufficient scientific information to make any assessment its condition (JNCC 2006).

3 MATERIALS AND METHODS

3.1 Survey of sublittoral benthic habitats

3.1.1 Objective

The objective of the survey was to record spatial variations in both the nature of the physical substratum (*e.g.* rock, cobbles, gravel, sand, etc.) and the composition of biological assemblages within St Mawes Harbour. The survey method was chosen based on the following imperatives: *(i)* that the resultant data should be quantitative or semi-quantitative (*e.g.* presence/absence or abundance scale); *(ii)* that as much biological and habitat detail as possible should be obtained from individual sample points; *(iii)* that the resultant data should be 'fine-grained' – *i.e.* a high density of sample points – to precisely locate key features (*e.g.* boundaries of seagrass or maerl beds); *(iv)* that the scope of the survey should encompass the entire harbour; and *(v)* that data should be gathered in a systematic way with distribution of sampling effort as close to uniform as feasible, given the other requirements.

3.1.2 General approach

Sublittoral benthic habitats within St Mawes harbour were surveyed by scuba divers taking photo-quadrats (30.5 x 22.8cm) along a series of 12 parallel and evenly-spaced transects (200m apart) spanning the harbour from northwest to southeast (Figure 6). A photo-quadrat was taken every 0.5m along each transect.

With the exception of one short (~40m) transect in the south-east corner of the harbour (off Polvarth Point), transects ranged in length from ~450 to 700m. In the initial plan, the combined length of all transects was ~6.5km.

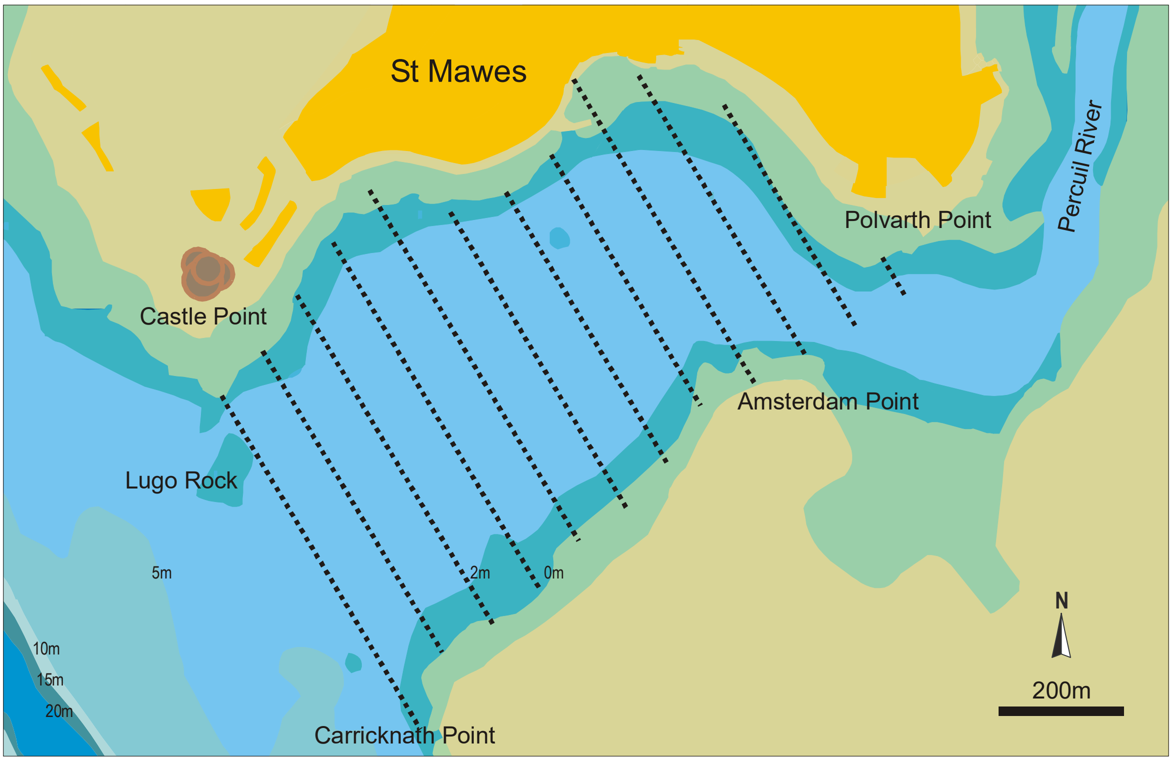

Figure 6. Map of St Mawes Harbour showing the pre-planned locations of the twelve transects across the harbour along which benthic habitats were surveyed.

3.1.3 Rationale for the chosen approach.

Surveys of this kind are usually done in one of two ways: either via direct observation and recording by divers, or by using video or stills cameras (either deployed by divers, or remotely using some sort of towed or 'drop-down' device) to obtain images for subsequent desk-based analysis. Combinations of these approaches may also be usefully employed. The pros and cons of a particular approach vary according to such things as the types of habitats and species being surveyed, depth of water, seabed topography and the number of variables being measured within each sample unit.

Because St Mawes Harbour is relatively shallow (<10m at all tidal states), diver observation and recording was a viable option. This was rejected at the outset, however, as the time per sample unit for observing, identifying, counting and recording multiple variables would have made it impossible, within the given budget, to obtain the large-number of samples needed for a 'fine-grained' quantitative survey.

Use of a towed stills or video camera was also rejected on the grounds that there are too many obstacles and snagging hazards in the harbour such as mooring chains and strings of crab pots. Another factor weighing against a towed device was the large amount of drift algae such as sea lettuce (*Ulva lactuca*) and kelp that typically accumulates within the harbour during the spring and summer, which was when work was planned for. This was expected to foul any towed device and obscure the view of any camera attached to it. Using divers to record video footage would obviate this problem, but this was also rejected. A diver cannot reliably maintain the camera at a constant distance and angle relative to the seabed. This would have made it impossible to maintain a constant area of seabed in view, which is a prerequisite for making counts per unit area.

A diver-operated stills camera mounted to a quadrat-framer (Figure 7) avoided all of these problems and was thus the obvious choice.

The particular camera outfit used comprised a Canon G5 (5 megapixel) housed in a Ikelite housing. Lighting, when required by the camera's light meter, was provided by a Sea & Sea Ikelite DS125 substrobe. Attached to the distal end of one arm of the quadrat-framer was a short (5cm) section of plastic ruler. This appeared in each photo-quadrat, thereby showing the size of other objects.

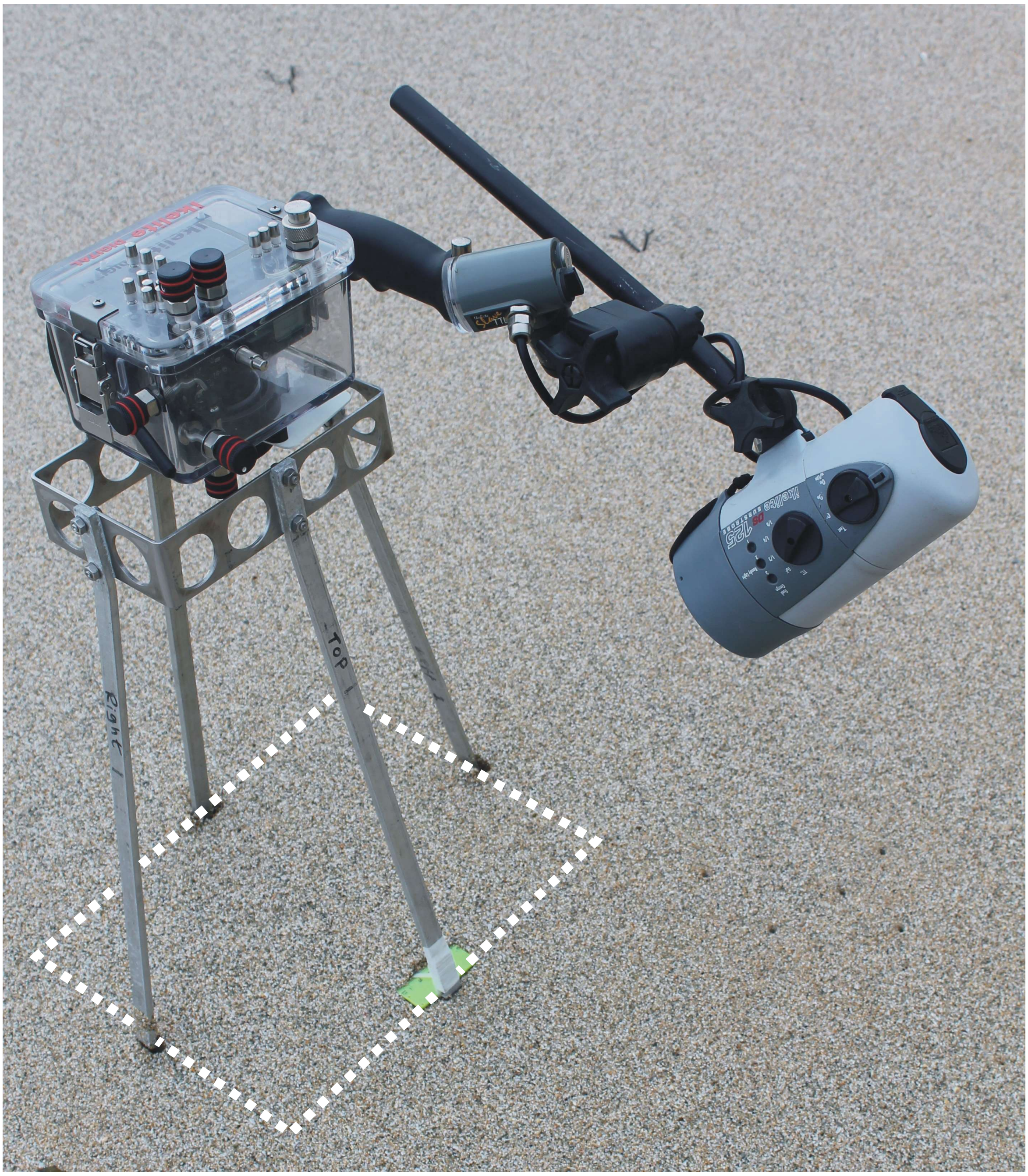

Figure 7. Waterproof housing for digital camera with attached quadrat-framing device. The dotted white line is superimposed on the photograph to indicate the perimeter of each photo-quadrat (30.5 x 22.8cm).

3.1.4 Survey dates

Photo-quadrat surveys of the twelve transects spanning St Mawes Harbour required 16 days of diving during the period April 22 to June 8, 2010.

3.1.5 Deployment and positioning of transects

A key requirement of the survey was that the latitude and longitude of each sampling point should be known as precisely as possible. This was achieved via the combination of a graduated transect line (a 100m surveyor’s tape-measure cable-tied to a length of leaded rope) and a hand-held Global Positioning System (GPS) unit (a Magellan Meridian Marine). The GPS unit was used to record positions (or ‘waypoints’) at the ends of each transect. Knowing these positions and the distance of a given sampling point along a transect, it was possible to calculate the position of the sampling point via interpolation. This assumed that that each transect was laid in a true straight line. To minimise deviations from a straight line, the transect line was laid under tension, using an anchor at the first end then pulling the line taught before dropping the second end.

Since a GPS signal cannot transmit through water it was necessary to devise an accurate means of determining the position of each transect end from the surface. This was achieved by attaching a specially-devised type of surface marker-buoy (SMB) to the end of each transect (Figure 7). This allowed positions to be recorded by holding the handheld GPS over the surface marker-buoy. The special aspect of this SMB was that it was designed to overcome the problem that wind and/or tidal drag tended to push the buoy away from its point of attachment on the seabed. Drag was minimised by using fine braid (2mm thickness) to tether the buoy to the transect anchor. Slack in the tether line, which would exacerbate lateral displacement, was reduced to almost zero via a simple pulley and counterweight system that automatically tensioned the line.

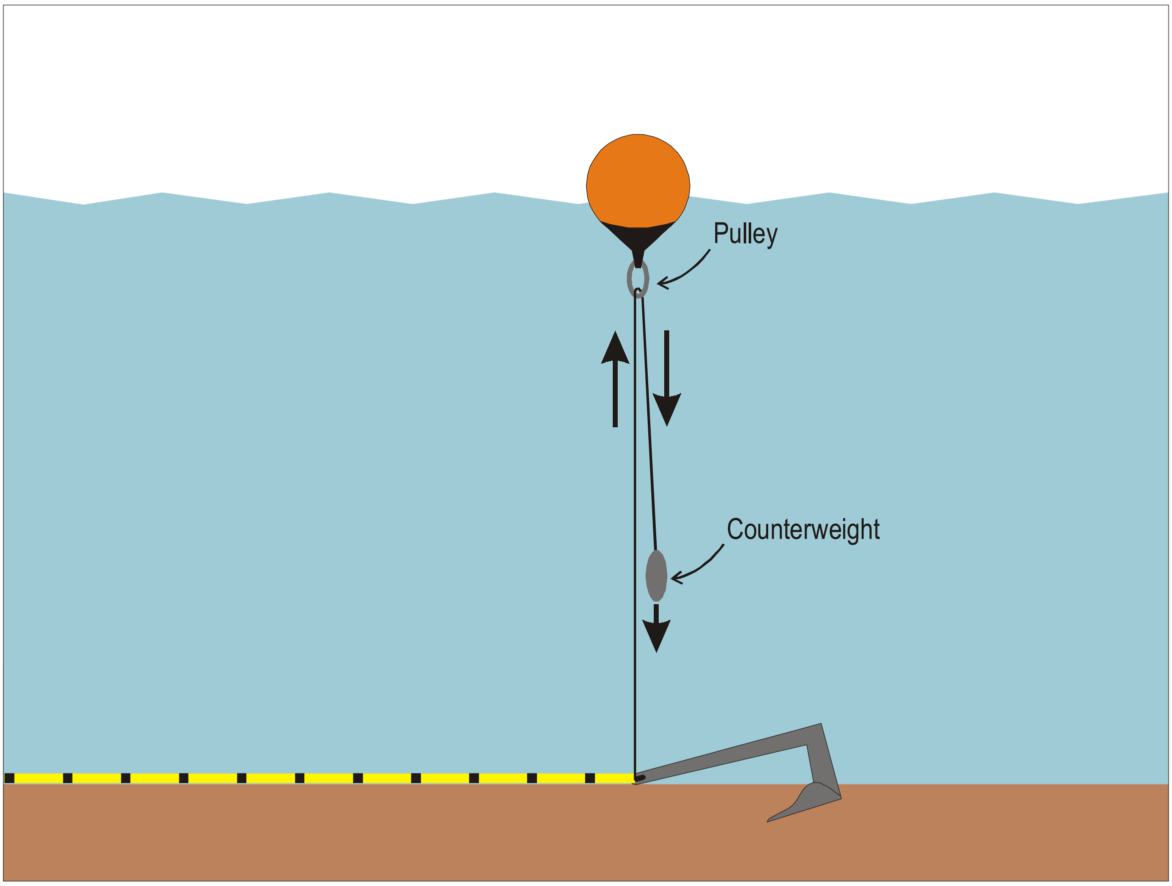

Figure 7. System for minimising slack in the line tethering surface marker buoy to the end of each transect. This was needed to ensure that the position of the marker buoy was a reliable proxy for the position of start of the transect on the seabed.

As shown in Figure 6, the pre-planned transects were all straight lines running across the harbour in parallel to each other. In practice, however, departures from this ideal were unavoidable for two reasons. First there was the difficulty of steering a steady bearing across the harbour while laying the transect lines; particularly if there wasn't a clear landmark to aim for and wind or tide were pushing the boat off-course (a complication that was exacerbated by the need to lay the transect line at slow speed). The second reason related to the need to survey each transect in a number of discrete sections (of maximum length 100m), which were often done on different days. It wasn't practical to try to precisely join the ends of adjoining sections of transect as this would have necessitated the considerable complication of involving a diver. Our method allowed the transect line to be laid and recovered entirely from the survey boat.

The method for linking adjoining sections of transects was as follows: having taken a waypoint at the end of a completed section of transect, the beginning of the next section was positioned by navigating back to this waypoint using the GPS unit, which provided a constantly-updated display of the distance and bearing to travel. The anchor at the start of the transect line was dropped at the point of closest approach to this waypoint, wind and tide permitting. Overall, we determined that the sources of inaccuracy and imprecision when using this method resulted in a typical distance between adjoining transect ends of around 5m. This placement error had no adverse scientific consequences whatsoever – the study was not compromised with respect to its aims in any way.

With transect lines layed as above, the survey resulted in 13,421 photo-quadrats spanning 6,720m of the seabed of St Mawes Harbour.

3.1.6 Diving operations

All diving operations were carried out in accordance with requirements of the Diving at Work Regulations 1997 and the Health & Safety Executive's (HSE) approved code of practice for scientific and archaeological diving. The platform for diving operations was the commercial fishing and survey-vessel *'Morvran'* FH745 – a 5.9m open fibreglass boat. This vessel was coded 'Category 6' by the Maritime & Coastguard Agency (MCA), which allowed her to support surveys up to 3 miles from land in daylight and favourable weather. (*NB:* Diving operations and the survey vessels safety equipment were inspected by the HSE and MCA during the project and found to be fully compliant with all requirements).

3.1.7 Analysis of photo-quadrats

Each photo-quadrat was analysed in relation to two sets of variables: *(i)* a set of variables relating to the physical nature of the substratum and (*ii)* a set of biological variables.

In relation to the physical substratum, photo-quadrats were scored for the presence and relative abundance (in terms of percentage cover) of nine types of materials, ranging from bedrock through to silt (Table 2). The materials listed in Table 2 were the only ones found in St Mawes Harbour.

Table 2. The different types of seabed materials that were recognisable in photo-quadrats from St Mawes harbour.

Physical substratum material	Explanatory notes
Rock	Bedrock or large boulders indistinguishable from bedrock
Silt/organic matter	Granular texture not apparent in photographs. Typically dark grey or brown.
Fine sand	<0.5mm - individual grains just visible in photographs
Coarse sand	0.5-2mm - individual grains clearly visible in photographs
Gravel/broken shells	2.0mm – 2.0cm
Pebbles	2.0-6.0cm
Cobbles	6.0-20.0cm
Dead mearl	Irregular shapes of broken maerl nodules clearly visible. White or yellow/brown in colour
Shells	Whole or nearly whole shells of gastropods and/or bivalves

The scheme in Table 2 is much simpler than particle-size classifications such as the Wentworth scale (Eleftheriou & McIntyre 2005), but this was necessary given that particle-sizes were inferred from photographs rather than being measured precisely using geological sieves.

In most parts of the harbour, the substratum was comprised of a mixture of the materials listed in Table 2. Given the large number of photo-quadrats, where such a mixture was present it was not possible to precisely quantify the amount of each type of material. Nevertheless, it was desirable to at least distinguish between a mixed substrata dominated by one type of material *versus* mixed substrata where no one material dominated. To achieve this, we scored each material on a three-point scale of relative abundance, with 0 = absent; 1 = present and 2 = dominant. For simplicity, only one type of material could be scored as dominant (*i.e.* 2) in any photo-quadrat. Where no single material was conspicuously dominant, all materials were simply scored as present (*i.e.* 1).

The scheme for scoring the flora and fauna shown in photo-quadrats was similar to that for scoring physical substratum materials. Three types of biological variables were scored: *(i)* individual species; *(ii)* groups of closely-related species that were hard to distinguish; and *(iii)* groups of similarly-looking, but not necessarily closely-related species. In all, there were 74 different biological variables (Table 3). Broadly speaking these were all species or groups that were common and/or conspicuous in photo-quadrats.

Because of the large number of biological variables, it was not possible to assess relative abundance in every case. Assessments of relative abundance were reserved for two key variables only: *(i)* seagrass (*Zostera marina*); and *(ii)* living maerl (*Lithothamnion corallioides* and/or *Phymatolithon calcareum*). All other biological variables were scored simply as either present (= 1), or absent (= 0).

Seagrass leaves were typically longer than the distance between the camera lens and the seabed (44cm), so there was insufficient perspective to assess the percentage cover of seagrass in photo-quadrats. The high density of seagrass also prevented reliable counts of leaves or shoots in many cases. Given the large number of photo-quadrats showing seagrass, it was decided to only distinguish between sparse *versus* dense seagrass, with sparse being defined as less than 10 leaves per photo-quadrat. Hence, the scoring scheme for seagrass was 0 = absent; 1 = ≤10 leaves ('sparse'); and 2 = ≥10 leaves ('dense').

The size of live maerl nodules (typically 0.5-3cm diameter) and their conspicuous colour meant that accurate measurement of percentage cover was possible, but for speed a simplified scheme with four abundance bands was preferred. Where live maerl was present, three categories of abundance were recognized: 1 = ≤20% cover ('sparse'); 2 = 20-80% cover ('intermediate') and 3 = ≥80% cover ('dense'). The ecological significance of the ≤20% cover or 'sparse' category is that at densities lower than this, maerl nodules tend to occur as dispersed individual nodules, rather than interlocked aggregations that could be regarded as parts of a true maerl bed (personal observation).

One would ideally have counted or measured absolute abundance for all species or groups of species seen in photo-quadrats, but this would have increased the time needed for scoring each photo-quadrat vastly beyond what the budget allowed. The aim was to spend no more than 1 minute scoring and recording data for each photo-quadrat. As there were over 13,000 photo-quadrats, even this would require 28 eight-hour days of continuous work. While results for individual photo-quadrats convey little or no information on the relative abundance of particular species or groups of species, this can nevertheless be gleaned from the number of photo-quadrats in which it is present. This is because high abundance within individual photo-quadrats is almost always associated with high occurrence among photo-quadrats.

Table 3. Biological variables whose relative abundance or presence/absence was recorded for each photo-quadrat.

Flowering plants	**Brown algae - continued**	**Molluscs**	**Crustaceans - continued**
Zostera marina - Seagrass	*Ectocarpus* sp.	*Aplysia punctata* – sea hare	*Xantho incisus*
Red algae	*Fucus serratus* – Serrated wrack	Burrowing bivalve with visible scyphons	Small hermit crabs
Live maerl – *L. corallioides* &/or *P. calcareum*	*Fucus spiralis* – Spiral wrack	*Callista chione* - bivalve	**Echinoderms**
Asparagopsis armata	*Halidrys silquosa* – Pod weed	*Chlamys varia* – Queen scallop	*Astropecten irregularis* – Burrowing starfish
Callophylis laciniata	*Himanthalia elongate* – Thong weed	*Gibbula cinerea* – Grey topshell	*Marthasterias glacialis* – Spiny starfish
Chondrus crispus - Carragheen	Laminarians – unidentifiable kelps	*Gibbula magus* – Turban topshell	*Spatangus purpurea* – Purple heart urchin
Corraline crust	*Saccharina latissima* – Sugar kelp	*Littorina littorea* – Edible periwinkle	**Fish**
Corallina officinalis	*Sacchoriza polyschides* - Furbellows	*Nassarius reticulate* – Netted dog whelk	*Callionymus lyra* - Dragonet
Dilsea carnosa – Red rags	*Sargassum muticum* - Japweed	*Pecten maximus* – King or great scallop	*Pomatoschistus minutus* – Minute goby
Drachiella spectablis	Unidentifiable filamentous brown algae	*Scaphander lignarius* – A bubble snail	*Pleuronectes platessa* - Plaice
Gigartina stellata – False carragheen moss	**Green algae**	*Sepia officinalis* - Cuttlefish	*Raja clavata* – Thornback ray
Palmaria palmate - Dulse	*Ulva lactuca* – Sea lettuce	**Cnidarians**	*Syngnathus acus* – Greater pipefish
Phycodris rubens – Sea oak	**Sponges**	*Aiptasia mutablis* – Trumpet anemone	
Polyides rotundus	*Suberites ficus*	*Anemonia viridis* – Snakelocks anemone	
Brown algae	*Tethyia aurantium*	*Calliactis parasitica* – Hermit crab anemone	
Ascophyllum nodosum – Egg wrack	Unknown small orange sponge	*Cereus pedunculatus* – A burrowing anemone	
Asperococcus spp.	**Polychaete worms**	*Nemertesia antenninis* – A burrowing anemone	
Chorda filum – Sea whip	*Arenicola marina - Lugworm*	*Sagartia* sp. – A burrowing anemone	
Colpomenia peregrina – Oyster thief weed	*Chaetopterus variopedatus*	*Sagartiogen undatus* – A burrowing anemone	
Cystoseira baccata -	*Myxilla infundibuliformis*	**Crustaceans**	
Cystoseira tamariscifola	*Owenia fusiformis*	*Cancer pagurus* – Edible crab	
Dictyota dichotoma	*Pomatoceros triqueter* – Keel worm	*Carcinus maenas* – Green or shore crab	
Desmarestia aculeata	*Sabella pavonina* – Peacock worm	*Liocarcinus depurator* – Swimming crab	
Desmerestia ligulata		*Necora puber* – Velvet swimming crab	

3.1.8 Analyses of biotopes

The first analysis of photo-quadrat data determined how many statistically distinct biotopes were present in St Mawes Harbour during the survey. This involved analysis of photo-quadrats in terms of all nine physical and 74 biological variables, simultaneously; *i.e.* a multivariate analysis. This was done using the statistical software PRIMER 6.0 (Clarke & Warwick 2001).

Multivariate variability among samples (*i.e.* photo-quadrats) was quantified using the Bray-Curtis index of dissimilarity. This is a measure (on a scale of 0 to 100% dissimilarity) of how different two samples are in terms of the types and numbers of animals they contain. When Bray-Curtis dissimilarity is calculated using untransformed abundance measures, it is influenced most by species with the greatest abundances. Here, data comprised some variables that were scored in terms of presence/absence (*i.e.* score = 1 or 0) and others that were scored on semi-quantitative scales of relative abundance (*e.g.* the four-point scale of relative abundance of live maerl). The latter necessarily attained greater values, so to moderate their influence on estimates of Bray-Curtis dissimilarity, data were 4^{th}-root transformed prior to analysis (Clarke & Warwick 2001).

Insufficient computing power was available to compare all 13,421 photo-quadrats in a single analysis. The data-set was thus subdivided into a number of what were assumed to be ecologically meaningful subsets that were analysed separately. Reflecting the focus of this study, data were first subdivided on the basis of whether photo-quadrats contained either intermediate or dense live maerl (scores = 2 or 3, respectively) or dense seagrass (score = 2), and thereafter on the basis of the dominant physical substratum materials. In all, eight subsets of photo-quadrat data were created:

1. Intermediate/dense live maerl present
2. Dense seagrass present
3. Rock predominates
4. Pebbles or cobbles predominate

5. Coarse materials predominate (*e.g.* coarse sand, dead maerl, gravel/broken shells or whole shells predominate)
6. Clean fine sand predominates
7. Fine sand with silt/organic matter predominates
8. Mixed materials with none predominant

The assumption that the criteria for subdividing data were meaningful predictors of differences in assemblage composition was tested via ANOSIM. The test compared assemblages in 100 randomly-selected photo-quadrats from each of the eight subsets of data. For data subsets defined by the presence of either intermediate/dense live maerl or dense seagrass, the defining species in each case was excluded from the analysis to avoid circularity. Having done so, the analysis could be done without prior transformation of data because all remaining biological variables were scored on a presence/absence basis.

The analysis of significant biotopes within each of the eight subsets of photo-quadrats used a matrix of Bray-Curtis dissimilarity values for all pairwise combinations of photo-quadrats within each subset. Each matrix was then analysed within PRIMER using hierarchical agglomerative cluster analysis. As the name suggest, this analysis breaks down each data-set into multiple ‘clusters’ representing the different biotope sub-types within each habitat. Photo-quadrats within clusters are more similar to each other, on average, than photo-quadrats in other clusters. A problem with an analysis of this kind is that it will always find ways of splitting data, so clusters may or may not be statistically significant. ANOSIM was thus used to test the statistical significance of differences among the different clusters identified for each data set. Where differences among two or more clusters were non-significant, they were combined into a single larger cluster.

Having identified the significant clusters within each data-set, a further PRIMER routine called SIMPER was used to characterise the underlying physical and biological differences among clusters. SIMPER determined the percentage contribution of each variable to the average Bray-Curtis similarity among photo-quadrats within each significant cluster. Only variables contributing ≥1% to average similarity among clustered photo-quadrats were considered important enough to merit being reported.

One final point on the analysis of photo-quadrat data: it was decided that it would be inappropriate to compare the different biotopes (or sub-types) in terms the number of species present because photo-quadrats did not provide an accurate and unbiased means of measuring it. For instance, in photo-quadrats with dense seagrass or kelp, leaves or fronds dominated the field of view and obscured other smaller species that may have been present beneath them. This would have tended to make these biotopes appear to support fewer species than they actually did and thus give a misleading impression of their relative biodiversity compared to those with less vegetation.

3.1.9 Mapping biotope information from photo-quadrats

A key aim of this project was to generate a more informative, spatially-precise and current biotope map than that currently available for St Mawes Harbour (*i.e.* Moore *et al.* 1999). The photo-quadrat survey generated a large amount of biological and environmental information that could be mapped in a great variety of ways. The main objective here, however, was to produce a single map that would be useful for environmental management purposes. It was felt that the most useful map for this purpose was one based on the eight broad habitat-types defined in the previous section. There was one caveat to this, however, which was that individual habitats would only be mapped if they had been shown via ANOSIM to support a distinct species assemblage.

This map was produced using ArcGIS Geographical Information System (GIS) software. The Environmental Records Centre for Cornwall and the Isles of Scilly (ERCCIS) assisted with this as CMER does not own a licence for this software.

To compliment the map and aid its interpretation, the percentage cover of the eight broad habitat-types encountered in the survey were estimated based on their frequency of occurrence in photo-quadrats.

3.2 Detailed investigation of benthic macrofauna

3.2.1 Objective

The aim here was to characterise and compare the complete macro-faunal assemblages of the most important soft-substratum habitats within St Mawes Harbour. For this purpose, macrofauna were defined as animals retained on a 1mm sieve mesh. The need for a more-detailed investigation arose from the fact that only a small proportion of the fauna present within the harbour were visible and identifiable in photo-quadrats. Typically, many of the animals residing in soft-substrata spend a large part of their lives buried within the substratum and are only a few millimetres in size, or smaller.

Given budgetary constraints, it was not possible to investigate the macrofauna of every type ‘soft’ habitat within St Mawes Harbour. A subset of four were thus selected. Two of these – *(i)* live maerl; *(ii)* sediment within seagrass beds – were selected based on their importance in conservation terms. The other two – *(iii)* unvegetated clean fine sand and *(iv)* unvegetated silty fine sand – were chosen on the basis that they were very abundant within the harbour.

A secondary objective was to characterise the substratum materials themselves. Information was thus obtained on *(i)* the distribution of particle-sizes and *(ii)* percentage organic content (*NB*: the term ‘substratum materials’ is used instead of ‘sediments’ here because maerl nodules are not sedimentary in origin). This information was then used to help interpret differences in assemblage composition among the different types of soft-substratum.

3.2.2 Sampling design

Samples for these biological and environmental investigations were cores of substratum material 10cm in diameter and 10cm deep (therefore, volume = 785.4cm^3). To provide for meaningful comparisons among habitats within the harbour, replicate samples were collected from two sites of each type. At each site, five cores were sampled for investigation of macrofauna and two for investigation of organic content and particle sizes. Replicate cores at each site were all collected within 1-5m of each other. Replicate sites of each substratum type were 300 to 500m apart (Figure 8).

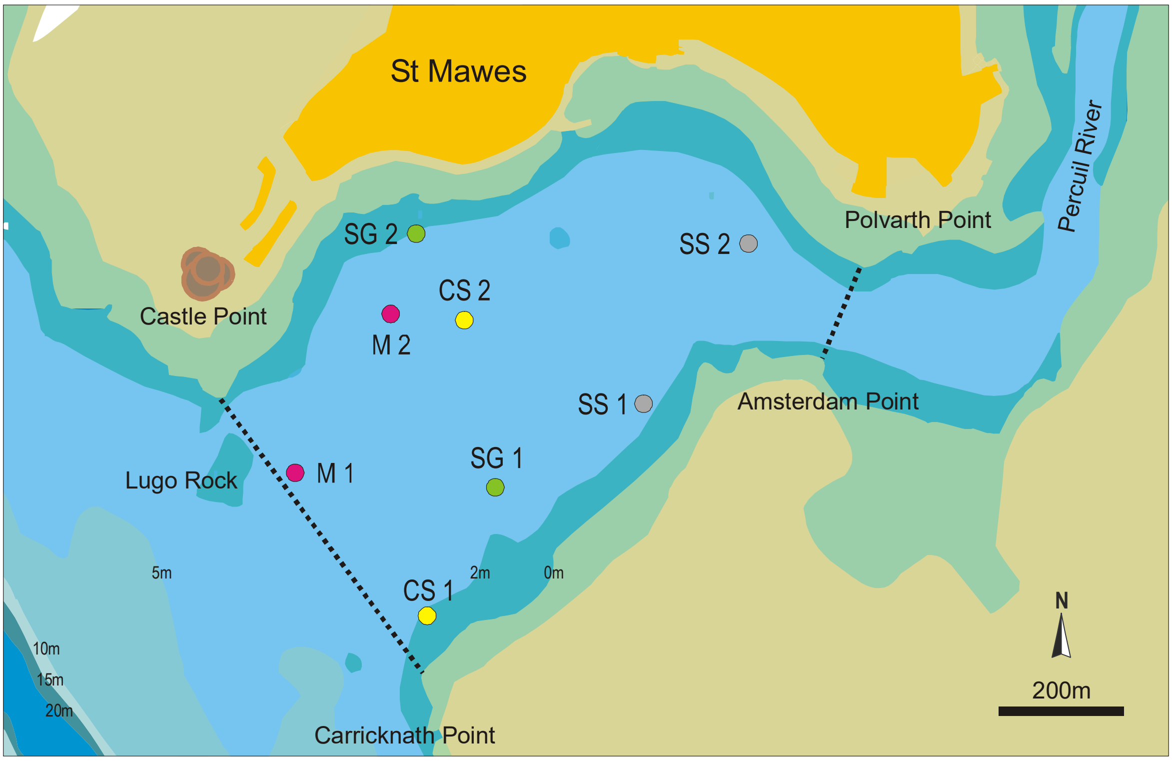

Figure 8. Locations of core sampling sites for macrofaunal and environmental investigation of four types of 'soft' benthic habitat in St Mawes Harbour.

3.2.3 Collection and processing of cores

Core samples were collected by a diver using a hand-held coring device of the kind shown in Figure 9, below. All cores were collected on 6 July 2010. To obtain a core, the diver pressed the corer into the seabed with a screwing motion. While the corer is being inserted, holes in its upper cap allow the seawater inside to escape. To prevent animals escaping, there is a layer of 0.5mm plankton mesh over the holes on the cap's inner-surface. Once inserted to the correct depth, the diver dug sand away from around the outside of the corer in order to place a hand over its lower end. This temporarily sealed the core within, allowing the diver to free the corer from the seabed. Once removed, the corer was inverted and a second cap was fixed quickly over the open end, sealing the core inside for transport to the surface.

For future reference it is important to note that core-samples from within seagrass beds were collected from within small clearings amongst the shoots and leaves, often no bigger than the diameter of the core. Seagrass roots were frequently present in these cores, but no above-ground parts were included. Seagrass core-samples were collected in this way so that only animals living on and within the sediments were sampled, not those present on the seagrass leaves, which constitute a separate micro-habitat.

At the surface, the contents of each corer were emptied into a heavy-duty plastic storage bag together with a sample label written on waterproof paper. Each bag was sealed with an elastic band wrapped tightly around the folded top of the bag. Samples were returned to CMER's premises in an insulated ice-box with a small amount of loose ice to keep them cool. Stored in this way, most macrofauna will stay alive within core samples for at least 24 hours.

Figure 9. Hand-held coring device used in this study for sampling benthic sediments and associated macrofauna. The corer on the left is buried to the required depth for sampling. The corer on the right has been capped to retain a sampled core.

3.2.4 Extraction of macrofauna

The extraction of macrofauna from core samples was done within 12 hours of collection. Two steps were involved. The first involved sieving the sample through a 1mm geological sieve to separate the macrofauna and particles >1mm from the fine sediment fraction. In samples from all habitats except maerl, sieving removed the vast majority of sediment.

Macrofauna were then extracted from the material retained on the sieve by a process called elutriation. The first step was to carefully wash the material off the sieve into a 5L plastic jug (taking care to ensure that no animals were left on the sieve mesh). Fresh water was then introduced to the bottom of the jug via a plastic hose while simultaneously swirling the water and sample material vigorously inside the jug. The resultant water-vortex lifted animals to the surface from where they were captured by pouring onto a 1mm sieve-mesh. The process was repeated until no further animals were seen to be separated. The materials remaining in the jug were then carefully examined at low magnification for larger, heavier animals that had not been elutriated (*e.g.* large bivalves, gastropods, etc.). In the case of maerl, this included animals that were either attached to, or lodged within, maerl nodules.

The material obtained in this way included whole and parts of animals, together with small amounts of plant material and coarse sand, which was all placed back in the original plastic bag together with the relevant sample label and at least twice the volume of ~10 % buffered formalin (formaldehyde solution) in seawater to fix and preserve the biological material. Preserved samples were then sealed in a plastic barrel pending further investigation.

3.2.5 Analyses of particle sizes and organic content

Analyses of particle sizes and organic content were done at an accredited geotechnical laboratory (EMU Ltd, Portsmouth). Particle size analysis was done via a combination of sieving for particles >63μm (based on British Standards Method BS 1377: 1990 Parts 1 and 2.) and laser-diffraction analysis for particles <63μm (based on based on British Standards Method BS ISO 13320: 2009).

Organic content was determined via mass loss on ignition (based on British Standards Method BS 1377: 1990 Part 3).

3.2.6 Investigation of macrofauna

In preparation for microscopic investigation, each sample of preserved fauna was poured from its storage bag on to the 1mm geological sieve. Any material stuck inside the bag was washed out on to the sieve with fresh water. This material was then washed again with fresh water to remove excess formaldehyde (a respiratory irritant and carcinogen). It was then transferred to a screw-topped plastic storage jar, together with its sample label, and the jar topped up with a 70% solution of Industrial Methylated Spirits (a further preservative).

Macrofauna were identified and counted with the aid of a dissecting microscope (a Brunel Microscopes BMSZ trinocular microscope providing magnification in the approximate range x10 to x70). Wherever possible, animals were identified to species level. To aid consistency of identification, photographs of reference specimens and close-ups of their diagnostic features were taken using a digital camera (Canon Eos 1100D) fitted to the third viewing tube of the microscope.

The data for each sample consisted of the abundances of the different types or 'taxa' of animals present.

Because of budgetary constraints and the time taken to identify and count all the animals in certain types of samples, it was only possible to analyse three of the five replicates that were collected from each site.

3.2.7 Statistical analyses

The first analysis of macrofaunal data from sediment cores was a test of the null hypothesis of no difference in the number of taxa among the four different 'soft' benthic habitats, *i.e.* *(i)* live maerl; *(ii)* sediment within seagrass beds; *(iii)* unvegetated clean fine sand and *(iv)* unvegetated silty fine sand. This was a univariate test, so the appropriate analysis was analysis of variance (ANOVA). The ANOVA design that was used (a two-factor nested design) also allowed a test of differences between the two replicate sites for each habitat. This analysis was carried out using the statistical software GMAV5 (EICC, The University of Sydney, Australia).

A further univariate test using the same design was done to test the null hypothesis of no difference in the total number of individual animals (*i.e.* all animals regardless of their identities) among habitats.

Where the factor 'habitat' was statistically significant in either of these ANOVA tests, a Student-Newman-Keuls (SNK) multiple comparison test was used to identify which combinations of habitats were significantly different from each other (*NB*: a significant ANOVA result does not imply that every group being compared is significantly different from every other group).

All subsequent analyses were multivariate analysis focusing on the composition of macrofaunal assemblages, the granulometry and organic content of the different habitats and the nature of any relationship between these two sets of data.

The first multivariate analysis was an ANOSIM test of the null hypothesis of no difference in assemblage composition among the four substratum types. As previously with photo-quadrat data, ANOSIM proceeded from a matrix of Bray-Curtis dissimilarity values among core samples calculated from 4^{th}-root transformed data (to suppress the influence of the more-abundant species; Clarke & Warwick 2001).

To compliment the ANOSIM test, Bray-Curtis dissimilarity values were summarised graphically via non-metric multidimensional scaling (nMDS). This generates a two- or three-dimensional pictorial representation of the relative differences in macrofaunal assemblages among locations. In a nMDS-plot, each sample (or the average of replicate samples, as appropriate) is represented by a symbol and the distance between symbols is proportional to the degree of difference in assemblage composition between samples.

An nMDS-plot presents a pattern of compositional differences that is actually multi-dimensional in nature (each species provides one dimension). Sometimes, the nMDS method is unable to make a good two-dimensional image of the true multi-dimensional pattern. When this happens, interpretation is difficult because the relative distances among different symbols on the nMDS plot do not accurately reflect the actual Bray-Curtis dissimilarities. The extent to which reality and its graphical representation by nMDS differ is expressed by the 'stress value'. An nMDS-plot with a stress-value of <0.15 is deemed to allow reliable interpretation of relative ecological differences among samples. When the stress value for a two-dimensional nMDS-plot is too high, plotting in three dimensions will often reduce 'stress' to <0.15. When the stress-value for any nMDS-plot is >0.15, any ecological interpretation based on that plot should be treated with caution.

ANOSIM was also used to test for environmental differences among habitats in terms of granulometry and organic content. Because of the particular mathematical properties of these data, the dissimilarity measure used was Euclidean distance rather than Bray-Curtis dissimilarity. Euclidean distance is a more geometrically straightforward measure of distance, which is deemed to be more appropriate for environmental data (Clarke & Warwick 2001). Before calculating Euclidean distances, it was first necessary to 'normalise' data so that all variables took values between the same upper and lower limits. Like the 4^{th}-root transformation, this ensures that the relative variation of different variables has greater influence on the overall pattern than absolute variation; Clarke & Gorley 2006.

Having separately analysed and summarised biological and environmental data, a PRIMER analysis called 'BIOENV' was done to test for a correlation between the spatial patterns apparent in these different data sets. This analysis compared the matrix of Bray-Curtis dissimilarity values based on macrofaunal data with the matrix of Euclidean distances calculated from the multivariate substratum data.

BIOENV finds the smallest subset of environmental variables that best explains the pattern (in this case, spatial) in the biological data. The results of this are only instructive when there is a moderate to strong correlation between the two data sets (*i.e.* the correlation co-efficient is in the range 0.35 to 1.0).

4 RESULTS

4.1 Photographic survey of sublittoral benthic habitats

4.1.1 Effect of habitat on assemblage composition

The factor 'habitat' (as defined in Section 2.1.8) was associated with significant variation in the composition of assemblages of flora and fauna seen in photo-quadrats (ANOSIM test statistic R = 0.303; *P* < 0.05).

Pairwise comparisons among assemblages in different habitats revealed significant differences (*P* < 0.05) between all pairwise combinations of assemblages except for one. The exception was the comparison between the rock assemblage and that on the 'mixed' substratum, which was only marginally non-significant (*P* = 0.053). Given, however, that both rock and 'mixed' assemblages were individually distinct from each of the remaining assemblages, it was decided that they should not be merged for the purpose of mapping. Thus all eight habitat/assemblage combinations featured in the biotope map for the harbour produced via GIS (Figure 10).

Figure 10. Biotope map of St Mawes Harbour based on the photo-quadrat survey.

4.1.2 Percentage cover of biotopes

Of the eight main biotopes identified in the photo-quadrat survey, only four were present to any significant extent within the harbour (Figure 11). In order of decreasing extent, these were *(i)* clean fine sand (40.7%); *(ii)* silty fine sand (27.0%); *(iii)* dense seagrass (17.3%); and *(iv)* dense/intermediate live maerl (9.8%). Cumulatively, these four biotopes covered 94.8% of the area surveyed.

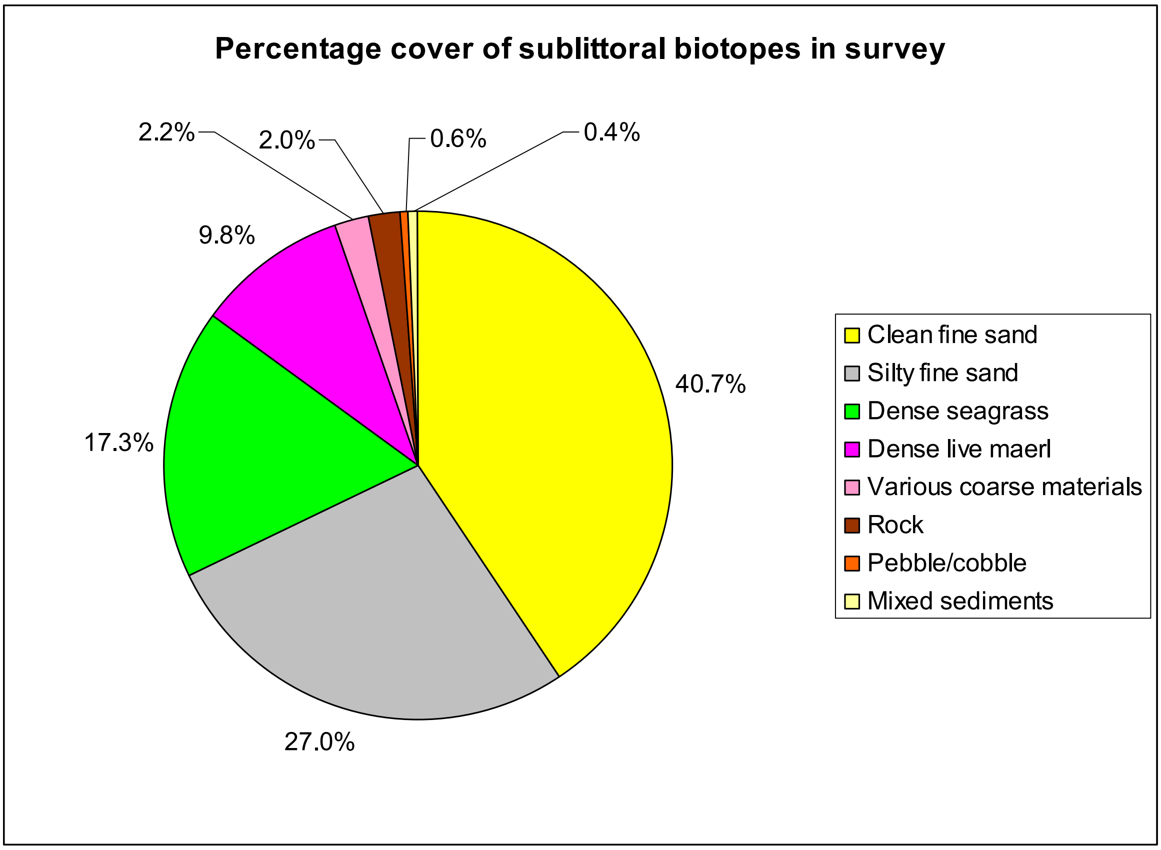

Figure 11. Estimates of percent cover of the each of the main seabed biotopes identified in St Mawes harbour, based on frequency of occurrence among photo-quadrats.

Figures on the extent of live maerl and seagrass biotopes underestimate the extent of live maerl and seagrass as species within the harbour because they exclude photo-quadrats showing only sparse presence (*i.e.* <20% live maerl, or <10 seagrass leaves). Given the importance of these species to this study, it is instructive to review the extent of their wider occurrence as minor components of other biotopes (Table 4).

Table 4. The frequency of occurrence of live maerl and seagrass as minor components of other biotopes in St Mawes harbour.

	Photo-quadrats with sparse live maerl as minor component (% of all		**Photo-quadrats with sparse seagrass as minor component**	
Biotope	No.	% of total no.	No.	% of total no.
Intermediate/dense live maerl			0	0.00
Dense seagrass	36	0.27		
Rock	2	0.01	1	0.01
Pebbles or cobbles	1	0.01	14	0.10
Various coarse materials	4	0.03	170	1.27
Clean fine sand	820	6.11	419	3.12
Silty fine sand	167	1.24	66	0.49
Mixed sediments	0	0.00	17	0.13
TOTAL	**1030**	**7.7**	**687**	**5.1**

The area where live maerl is sparse is thus ~79% of the area where it is present at intermediate or high density. Similarly, the extent of the area supporting sparse seagrass is 30% of the extent of the area supporting dense seagrass.

Combining the results in Table 4 with previous results on the extent of the live maerl and seagrass biotopes (Figure 11): the percentage of the survey area supporting any amount of live maerl is 17.5%, and the percentage supporting any amount of seagrass is 22.4%.

A final finding of interest here is the very small number of instances where live maerl and seagrass co-occurred (Table 5); only 73 photo-quadrats in the entire survey (0.5% of photo-quadrats). The vast majority of these were either instances of sparse live maerl in the seagrass biotope (36 photo-quadrats), or both sparse live maerl and sparse seagrass in the clean fine sand biotope (also 36 photo-quadrats).

Table 5. Instances of co-occurrence of live maerl and seagrass.

Circumstances of live maerl & seagrass co-occurrence	No. of photo-quadrats
Intermediate/dense live maerl biotope + sparse seagrass	0
Dense seagrass biotope + sparse live maerl	36
Co-occurrence in other biotopes:	
Rock	1
Pebbles or cobbles	0
Various coarse materials	0
Clean fine sand	36
Silty fine sand	0
Mixed sediments	0
TOTAL	**73**

4.1.3 Variation within biotopes

There was significant variation in assemblage composition within each of the eight biotopes identified. The numbers of significant clusters (*i.e.* biotope sub-types) within each of the eight biotopes ranged from two within the mixed substratum biotope up to five within the dense/intermediate seagrass biotope. In total, 28 different biotope sub-types were identified among the eight biotopes. The number of photo-quadrats in which the different sub-types were observed was highly variable. Eight sub-types occurred in 10 or fewer photo-quadrats. The 20 more-abundant sub-types occurred in 27 to 4,092 photo-quadrats. The key characteristics of each biotope sub-type and their frequencies of occurrence among photo-quadrats are listed in Table 6.

Table 6. Key characteristics of each of the 28 biotope sub-types and their frequencies of occurrence among photo-quadrats.

Parent biotope	Sub-type	Number of photo-quadrats	Key characteristics of biotope sub-type
Dense live maerl	1	5	High density live maerl
	2	539	Medium density live maerl
	3	773	Very high-density live maerl
Dense seagrass	4	10	Dense seagrass on fine sand with occasional sparse live maerl
	5	44	Dense seagrass with *Saccharina latissima* on mixed

			sediments
	6	27	Dense seagrass on mixed sediments with conspicuous silt and organic matter
	7	2238	Dense seagrass with *Saccharina latissima* on clean fine sediments
Rock	8	10	Mixed bedrock and sediment with *Ulva lactuca*, frequent *Polyides rotundus* and occasional sparse seagrass and live maerl
	9	3	Bedrock with *Ulva lactuca* and frequent *Chondrus crispus* and *Colpomenia peregrina*
	10	188	Bedrock with *Laminaria* spp.
	11	17	Mixed bedrock and sediment with *Laminaria* spp., *Ulva lactuca* and frequent *Corallina officinalis* and *Asparagopsis armata*
	12	52	Mixed bedrock and sediment with frequent *Laminaria* spp. and *Ulva lactuca*
Pebbles & cobbles	13	36	Mixed cobbles, pebbles, gravel/shell with frequent *Pomatoceros triqueter* and sparse live maerl
	14	23	Pebbles and mixed sediment with frequent *Polyides rotundus* and *Ulva lactuca*
	15	24	Cobbles, pebbles, silty mixed sediments with frequent *Polyides rotundus* and *Ulva lactuca*
Various coarse materials	16	2	Shells with *Laminaria* spp., and frequent *Chorda filum* and *Ulva lactuca*
	17	6	Coarse sand with small amounts of gravel/shell, pebbles and cobbles; plus frequent sparse live maerl, *Chondrus crispus*, *Laminaria* spp. and *Ectocarpus* spp.
	18	175	Mixed coarse sediments with frequent dead maerl, plus sparse live maerl, *Ectocarpus* spp. and *Saccharina lattisima*
	19	109	Mixed coarse sediments with frequent *Saccharina lattisima*
Clean fine sand	20	2	Fine sand with small amounts of coarse sand and shells, plus *Desmarestia ligulata* and *Ulva lactuca* and frequent sparse seagrass
	21	1361	Fine sand with sparse *Saccharina lattisima*
	22	4	Fine sand with small amounts of shells and coarse sand, plus *Saccharina lattisima*, frequent filamentous red/brown algae, and sparse seagrass, *Palmaria palmata*, *Cystoseira baccata* and *Chaetopterus variopedatus*
	23	4092	Fine sand with small amounts of coarse sand and gravel/shell, plus frequent *Saccharina lattisima* and *Ectocarpus* spp. and occasional sparse seagrass and live maerl
Silty fine sand	24	8	Fine sand with silt/organic matter and small amounts of coarse sand, plus frequent *Polyides rotundus* and filamentous red/brown algae
	25	1857	Fine sand with silt/organic matter, plus frequent filamentous red/brown algae and *Saccharina lattisima*
	26	1758	Fine sand with silt/organic matter and small amounts of coarse sand and gravel/shell, plus frequent

			filamentous red/brown algae
Mixed sediments	27	43	Mixed fine and coarse sediments with frequent *Laminaria* spp., *Ulva lactuca* and *Polyides rotundus* and occasional sparse live maerl
	28	14	Mixed fine and coarse sediments with conspicuous silt/organic matter, plus frequent sparse live maerl and *Saccharina lattisima*

4.2 Detailed investigations of benthic macrofauna

4.2.1 Number of species in different habitats

There was a significant effect of the factor 'habitat' on the number of different types of macrofaunal taxa in core samples (ANOVA F = 20.93, df = 3/4; $P < 0.01$). SNK multiple comparison tests showed that this resulted from a significant difference between two pairs of habitats (Figure 12). The two habitats within each pair were not significantly different. The pair of habitats with the greatest number of taxa were live maerl (mean = 28.5 $\pm$ 1.0 per core) and silty fine sand (mean = 18.5 $\pm$ 1.1 per core). The pair with fewest taxa were seagrass (mean = 16.0 $\pm$ 1.5 per core) and clean fine sand (mean = 6.7 $\pm$ 1.1 per core).

Differences between replicate sites of the same habitat were non-significant in all cases (ANOVA F = 2.34, df = 4/16, $P > 0.05$).

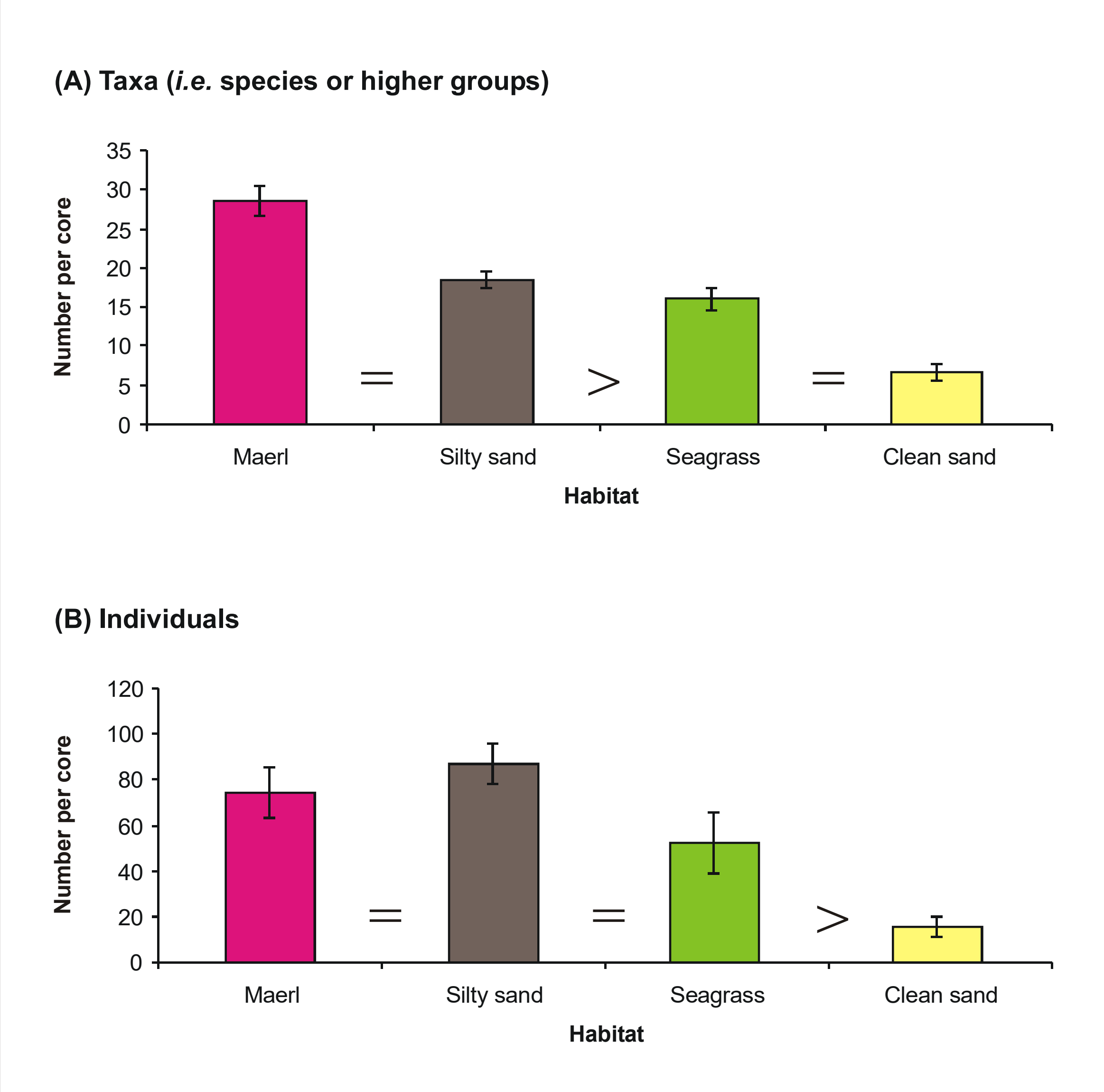

Figure 12. Comparisons of live maerl, seagrass, clean sand and silty sand habitats in St Mawes Harbour in terms of the mean (±SE) number of (A) macrofaunal taxa and (B) total individuals per core (10cm diameter x 10cm depth). The '=' and '>' symbols are placed to summarise the results of SNK multiple comparison tests.

4.2.2 Number of individuals in different habitats

There was a significant effect of the factor 'habitat' on the number of individuals (regardless of taxa) in core samples (ANOVA F = 9.89, df = 3/20; $P < 0.001$). SNK multiple comparison tests showed that this resulted from a significant difference between one habitat, clean fine sand, with relatively few individuals (mean = 15.2 ± 4.5 individuals per core) and a group comprising the other three habitats, which all had many more individuals (Figure 12). In order of decreasing abundance, these were: silty fine sand (mean = 86.8 ± 9.0 individuals per core); live maerl (mean = 74.2 ± 10.9 individuals per core); and seagrass (mean = 52.2 ± 13.4 individuals per core).

Differences between replicate sites of the same habitat were non-significant in all cases (ANOVA F = 1.20, df = 4/20, $P > 0.05$).

4.2.3 Differences in assemblage composition among habitats

ANOSIM revealed significant differences in the composition of macrofaunal assemblages among the four different types of benthic habitat sampled (ANOSIM R = 0.901; $P<0.01$). Pairwise comparisons showed that each assemblage was highly distinct, with each being significantly different from every other assemblage ($P<0.05$ in all cases) (Figure 13).

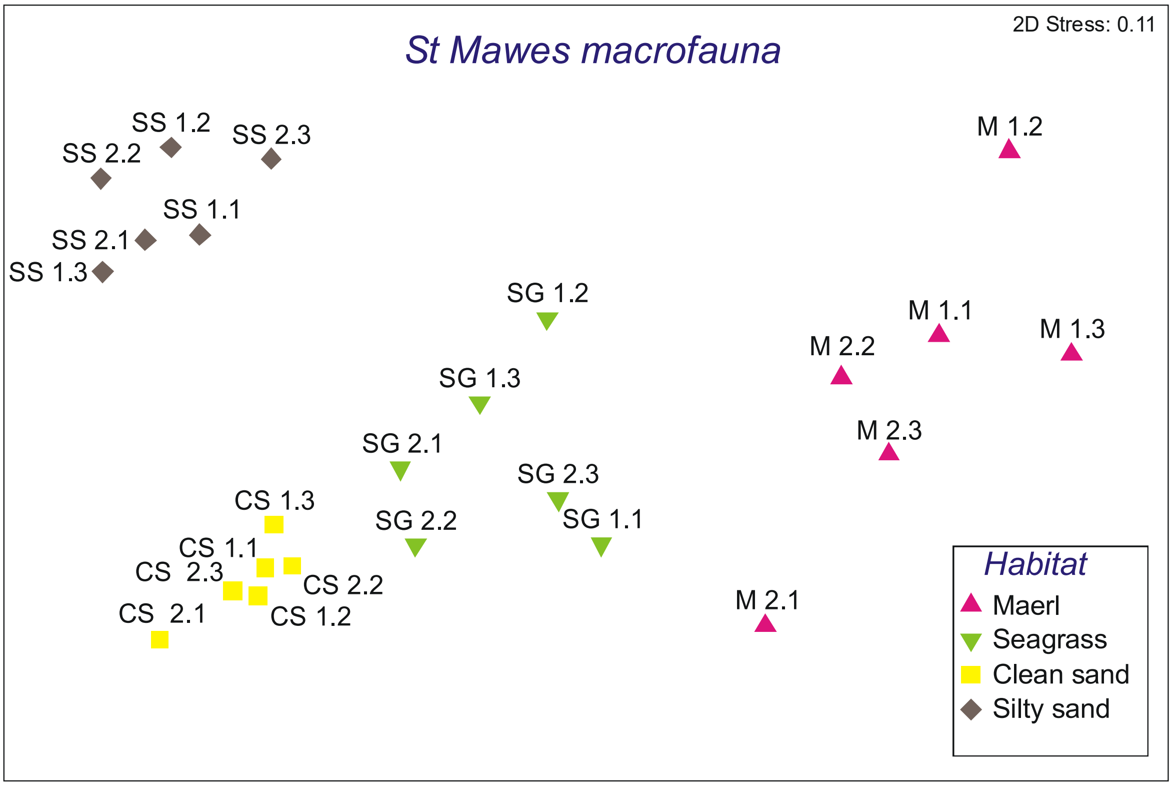

Figure 13. NMDS plot summarising multivariate differences in the composition of macrofaunal assemblages in cores from the four main soft benthic habitats in St Mawes Harbour.

As reflected in the nMDS plot and average Bray-Curtis dissimilarities (Table 7), the greatest difference in assemblage composition was between maerl *versus* silty fine sand. The least difference was between the assemblage in seagrass and that in clean fine sand.

Table 7. Average Bray-Curtis dissimilarities between all pairwise combinations of macrofaunal assemblages the four the types of habitat samples in St Mawes Harbour.

	Dissimilarity between assemblages in different habitats			
	Maerl	**Seagrass**	**Clean fine sand**	**Silty fine sand**
Maerl				
Seagrass	50.54			
Clean fine sand	56.32	41.96		
Silty fine sand	58.92	48.76	46.43	

Some types of assemblage showed greater variability in composition among core samples than others (Figure 13, Table 8). The most variable assemblage (*i.e.* least similarity among replicates) was that in the live maerl habitat. The least variable assemblage was that found in clean fine sand. Assemblages in seagrass and silty fine sand showed similar, intermediate levels of variability among replicates. Overall, there was a strong negative correlation (Spearman's R^2 = 0.87) between similarity among replicate samples and the number of taxa in each assemblage; *i.e.* greater macrofaunal diversity was associated with lower levels of similarity among replicates.

Table 8. Average Bray-Curtis similarity among replicates of each of the four types of macrofaunal assemblages sampled in St Mawes Harbour.

	Type of macrofaunal assemblage			
	Maerl	**Seagrass**	**Clean fine sand**	**Silty fine sand**
Similarity among replicates	61.67	66.69	79.07	70.73

SIMPER analysis identified the taxa that were most characteristic of each assemblage. Table 9 lists the taxa in each assemblage that made an above-average contribution to the overall similarity among replicate samples.

Table 9. Taxa that contributed more than average to compositional similarity among replicate core samples of each of the four types of macrofaunal assemblage investigated in St Mawes Harbour. Taxa are ranked in descending order of their individual contributions to the overall similarity among replicates of each assemblage.

Maerl

Average similarity among replicates = 61.67

Average similarity contribution per taxa = 0.80

Taxa	Abund.	% Sim. contrib.
Pisidia longicornis	12.8	6.2
CAPITELLIDAE	7.1	5.2
Amphipholis squamata	2.9	3.3
Janira maculosa	1.1	3.0
Aoridae spp	1.6	2.9
Notomastus latericeus	0.9	2.8
Platynereis dumerilii	0.7	2.6
MALDANIDAE	0.8	2.6
Nematonereis unicornis	0.9	2.6
Polynoidae sp.1	0.7	2.5
Tubificoides benedii	0.6	2.5
Athanas nitescens	0.6	2.1
Paraonidae sp.3	0.7	2.0
Paraonidae sp.1	0.6	1.8
Pholoidae sp.1	0.6	1.8
Mysella bidentata	0.3	1.7
Leucothoe spinicarpa	0.2	1.2
Ampithoe rubricata	0.2	1.1
Chlamys varia	0.1	1.1
Polynoidae sp.3	0.2	1.1
Polycirrus sp.1	0.2	1.1
Apseudes latreillii	0.1	1.0

Seagrass

Average similarity among replicates = 66.69

Average similarity contribution per taxa = 0.76

Taxa	Abund.	% Sim. contrib.
Lucinoma borealis	2.4	5.1
MALDANIDAE	1.3	4.8
NEMATODA	4.2	4.5
Dexamine spinosa	1.3	3.6
Apseudes latreillii	2.9	3.4
Oweniid sp1	0.5	2.6
CAPITELLIDAE	0.7	2.4
Angulus tenuis	0.4	2.3
Platynereis dumerilii	0.5	2.2
Idotea neglecta	0.3	2.1
Urothoe poseidonis	0.5	1.7
Echinocyamus pusillus	0.1	1.3
Hinia reticulata	0.1	1.3
Tubificoides benedii	0.1	0.9
Ampithoe gammaroides	0.1	0.8
Lacuna vincta	0.0	0.8

Clean sand

Average similarity among replicates = 79.07

Average similarity contribution per taxa = 0.73

Taxa	Abund.	% Sim. contrib.
Angulus tenuis	3.8	8.2
Bathyporeia pelagica	1.0	4.3
Urothoe poseidonis	0.3	1.9
Urothoe brevicornis	0.2	1.8
Moerella pygmaea	0.1	1.1
Massilina secans	0.1	1.1
Nephtys longosetosa	0.0	0.9
Mysella bidentata	0.0	0.9
Echinocardium cordatum	0.0	0.9

Silty sand

Average similarity among replicates = 70.73

Average similarity contribution per taxa = 0.79

Taxa	Abund.	% Sim. contrib.
Chaetozone gibber	20.2	7.9
Apseudes latreillii	16.0	6.6
Ampelisca tenuicornis	3.6	5.0
Phoronis muelleri	2.5	4.6
Magelona filiformis	2.9	3.9
Ampharetid sp1	1.3	3.2
Ampelisca brevicornis	0.6	2.8
Ampharetid sp2	0.5	2.7
Oweniid sp1	0.5	2.2
Angulus tenuis	0.5	1.9
Edwardsia claparedii	0.3	1.9
Massilina secans	1.3	1.8
CAPITELLIDAE	0.4	1.3
Elphidium crispum	0.2	1.2
Synaptidae spp	0.2	1.2
Nemertea sp.2	0.1	1.1
Tharyx sp.1	0.1	1.1

A short-list of the most important taxa in each assemblage was generated by incorporating taxa one at a time down the list in Table 9 until 20% of the overall similarity among replicates was accounted for. In each short-list below, taxa are listed in descending order of importance to the assemblage.

The short-list of the most-characteristic taxa in the maerl assemblage comprised five taxa: *(i) Pisidia longicornis* (long-clawed porcelain crab); *(ii)* Capitellidae (a family of polychaete worms); *(iii) Amphipholis squamata* (a brittle star)*; (iv) Janira maculosa* (an isopod crustacean); and *(v) Aoridae* spp. (a genus of amphipod crustaceans).

The short-list of the most-characteristic taxa in the seagrass assemblage also comprised five taxa: *(i) Lucinoma borealis* (a bivalve mollusc); *(ii)* Maldanidae (a family of polychaete worms); *(iii)* Nematoda (a Phylum of unsegmented worms, commonly known as roundworms), *(iv) Dexamine spinosa* (an amphipod crustacean); and *(v) Apseudes latreillii* (a tanaid crustacean).

The short-list of the most-characteristic taxa in the clean fine sand assemblage comprised eight taxa: *(i) Angulus tenuis* (a bivalve mollusc); *(ii; iii* and *iv) Bathyporeia pelagica*, *Urothoe poseidonis* and *U. brevicornis* (three species of amphipod crustaceans); *(v) Moerella pygmaea* (a bivalve mollusc); *(vi) Massilina secans* (a forminiferan protist); *(vii) Nephtys longosetosa* (a polychaete worm); and *(viii) Mysella bidentata* (a bivalve mollusc).

The short-list of the most-characteristic taxa in the silty fine sand assemblage comprised only four taxa: *(i) Chaetozone gibber* (a polychaete worm), *(ii) Apseudes latreillii* (a tanaid crustacean), *(iii) Ampelisca tenuicornis* (an amphipod crustacean); and *(iv) Phoronis muelleri* (a species of unsegmented worm-like organism, called a Phoronid).

It is notable that there was only one taxa that occurred in more than one short-list. This was the tanaid crustacean *Apseudes latreillii,* which was a key characterising species in both the seagrass and silty fine sand assemblages. *A. latreillii* was more important in the latter than in the former (6.56% similarity contribution *versus* 3.36%).

4.2.4 Differences in granulometry and organic content among habitats

ANOSIM based on Euclidean distances among samples revealed significant differences among habitats in terms of granulometry and organic content ($P<0.01$). Pairwise tests showed that, with only one exception, each habitat was significantly different from every other habitat. The exception was the contrast between seagrass and clean fine sand habitats, which was non-significant.

The most conspicuous subdivision of the habitats was between live maerl and the three sedimentary habitats (seagrass, clean fine sand and silty fine sand) (Figure 14). This was mainly attributable to the relatively large percentage of particles ≥1,000μm (=1mm) in the maerl habitat (67.8% *versus* 0.8-1.8% for the other three habitats) and the relatively high organic content of the maerl habitat (3.3% *versus* 1.3-1.8% for the other three habitats).

The main difference between seagrass, clean sand and silty sand habitats was in the relative proportions of particles >250μm *versus* <250μm. The clean fine sand habitat had the greatest proportion of particles >250μm (40%), silty fine sand had the least (13.9%) and the seagrass habitat was intermediate (24.7%). In respect of particles <250μm, the trend was reversed, with silty sand having the greatest proportion (86.1%), clean sand the least (59.9%) and seagrass intermediate (75.3%).

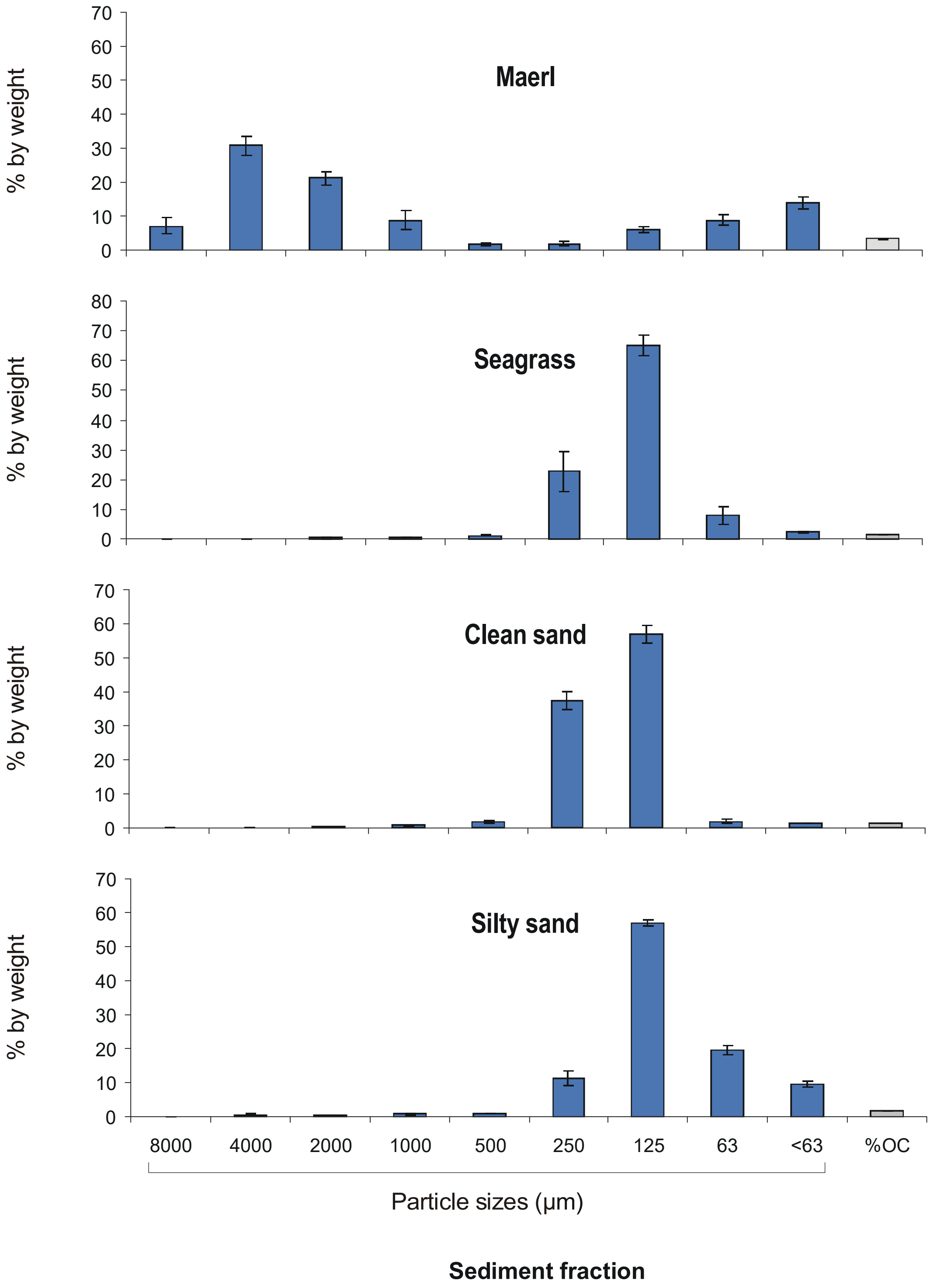

Figure 14. Particle size distributions (blue bars) and percent organic content (%OC) (grey bar) for each of the four types of benthic habitat that were sampled in St Mawes Harbour.

4.2.5 Relationship between assemblage composition and substratum properties

BIOENV analysis showed that differences among core samples in terms of assemblage composition were strongly correlated with differences in the granulometry and organic content of the substratum. Certain environmental variables were more important than others for explaining spatial variability differences in assemblage composition. A subset of five environmental variables produced the strongest correlation between environmental and biological distance matrices (correlation co-efficient = 0.788). These were % organic content and the following size fractions of particles: *(i)* <63μm; *(ii)* >125μm; *(iii)* >1000μm; and *(iv)* >2000μm.

Further analysis showed that percent organic content was of only minor importance in explaining the correlation. Excluding it affected the correlation co-efficient at only the third decimal place, reducing it to 0.783.

5 DISCUSSION

5.1 Survey of sublittoral benthic habitats

The photo-quadrat survey has vastly improved knowledge of the types and distributions of sublittoral benthic habitats within St Mawes Harbour compared to that from previous surveys (as summarised in the MNCR biotope map of Moore *et al.* 1999).

In respect of the two priority habitats that were the principal focus of this project – maerl and seagrass – the most notable new information was for seagrass. The 1999 MNCR biotope map for St Mawes Harbour showed only a single area of seagrass that was roughly in the centre of the outer harbour. The present survey confirmed the continued existence of this bed (as well as mapping its boundaries and variations in density more precisely), but also revealed several smaller beds of dense seagrass elsewhere in the harbour. These newly-mapped seagrass beds were long, relatively narrow beds lying adjacent and parallel to the north and eastern shores of the harbour. Between these large beds of dense seagrass, there were also extensive areas of sparse seagrass, which also didn't feature in the 1999 MNCR biotope map. The most likely explanation for these discrepancies is that the MNCR surveys were much less extensive and detailed.

As regards living maerl, we found that the 1999 MNCR biotope map is still broadly accurate. Consistent with the earlier map, we found that there is only one coherent bed within St Mawes Harbour and it is more-or-less in the position previously indicated; *i.e.* fringing the subtidal reef that extends south from Castle Point out to Lugo Rock. The main new information concerns the precise distribution of different densities of live maerl within the harbour. For instance, it is now known that the main bed of relatively dense live maerl extends ~200m further east into the harbour than indicated in the 1999 map (see Figure 5 *versus* Figure 10). Also, that in addition to this main bed, there is nearly the same area again of sparse live maerl present in other habitats.

The most significant new finding for other habitats concerned the large areas shown on the 1999 MNCR biotope map as either 'sublittoral muddy gravel' or 'sublittoral estuarine mud with kelp on available hard substrata'. The former was said to occur in the outermost area of the harbour (south of the live maerl), whereas the latter was said to occupy most of the inner harbour (north and east of the main seagrass bed).

In the outer area described previously as 'sublittoral muddy gravel' in the 1999 MNCR biotope map, we found clean fine sand. Subsequent granulometric analysis of core-samples showed that this sediment-type had less than 1.5% silt (*i.e.* particles <0.63μm) and less than 1.5% organic matter, confirming that this was not in any way muddy. To warrant classification as 'muddy' in the UK biotope classification, sands and gravels need to have a silt fraction in the range of 5-20%. The cause of this discrepancy between our finding and the 1999 MNCR map is unclear. There would seem to be only one of two possible explanations: *(i)* either the mud content of sediments in this area has declined greatly since the surveys that informed the 1999 map, or *(ii)* sediments in this area were misclassified in the MNCR exercise due to error and/or inadequate information. Based on direct personal knowledge of the seabed in this area from the period of the MNCR surveys, the latter seems most likely, but it is difficult to see how the classification of this area could have been so wrong given that there were apparently three sublittoral survey sites in the relevant area (Moore *et al.* 1999).

There was an almost identical discrepancy in relation to the inner area described in the 1999 MNCR map as 'sublittoral estuarine mud with kelp on available hard substrata'. Roughly half of this inner area (concentrated towards the northern side of the harbour) was the same clean fine sand that we found westwards of the central seagrass bed. The other half (near where the Percuil river enters the harbour) was silty fine sand. To the extent that there was hard substrata capable of supporting kelp in this area, it was limited to cobbles, pebbles and large shells (*e.g.* scallop or whelk). Pebbles and cobbles were more abundant closer to the shore (within 50m). Visual classification as silty sand was validated by subsequent granulometric analysis, which showed ~10% silt and ~2% organic matter. In the UK biotope classification, muds are classified as sediments containing >20% silt, so this habitat in St Mawes Harbour clearly does not qualify. The cause of this further discrepancy between our findings and the 1999 MNCR biotope map is again unclear, but we incline towards misclassification rather than environmental change.

Apart from bedrock, the other biotopes revealed by the photo-quadrat survey (*i.e.* 'pebble/cobble', 'mixed sediments' and 'various coarse materials') did not feature on the 1999 MNCR map of St Mawes Harbour. Nor were any similar biotopes indicated. This is probably because these biotopes were only present in very small patches, mainly in a narrow zone (10 to 50m wide) between MLW and the more-extensive biotopes that dominate the central sublittoral area of the harbour. This distribution highlights the fact that these other less-abundant biotopes combine materials of recent bedrock origin (*e.g.* cobbles and pebbles) with variable amounts of dead maerl and/or sand. The MNCR exercise was focused at too large a scale to be concerned with these minor transitional biotopes.

5.2 Detailed investigation of benthic macrofauna

5.2.1 Levels of biodiversity

The analysis of macrofauna in benthic core-samples confirmed the expectation that the live maerl habitat would be the most biodiverse habitat of the four that were compared. The high biodiversity of live maerl habitats is generally attributed to the three-dimensional structure of maerl nodules (thalli), which interlock to form a complex lattice with spaces in between that provide a wide range of niches for both infaunal and epifaunal invertebrates (Birkett *et al.* 1998).

Comparing the diversity of maerl habitats in St Mawes Harbour with similar habitats elsewhere is difficult, because so much depends on the method of sampling and the numbers of samples in the studies being compared. In terms of method of sampling, the key variables are the volume of benthic samples and the size of sieve-mesh used to trap animals extracted from the samples. The size and number of samples obtained are also critical variables because of the well-known rule in ecology that the number of species encountered increases (up to a point) in proportion to the total quantity of habitat that is sampled (Krebs 1985).

While the high biodiversity of maerl habitats is frequently remarked upon, studies like ours making standardised, contemporaneous comparisons of macrofauna between maerl habitats and other substrata appear to be lacking. This was remarked upon thus in a 1998 review of maerl biology and ecology by Birkett *et al.*: *"to our knowledge there have been no overall comparisons of the diversity of maerl fauna and flora with those in equivalent samples from other biotopes"*. The only similar study that we know of is that of Jackson *et al.* (2004), which compared live maerl, dead maerl, gravel and sand. Rather than sampling the general macrofauna, however, this study only sampled meiofaunal bivalve molluscs (*i.e.* bivalves in the size range 63-500μm). Animals of this size were far too small to have been retained on the 1mm sieve-mesh that we used. Jackson *et al.* (2004) found greatest diversity of meiofaunal diversity in maerl habitats *versus* gravel and sand. Unexpectedly, however, they found that dead maerl supported greater diversity than live maerl. It was suggested that this may have resulted from greater environmental variability in the dead maerl habitat.

There have been other macrofaunal studies of maerl habitats in the Fal estuary system (*i.e.* Posford Haskoning 2004a & b; Axeleson *et al.* 2008), but because of differences in sampling design and methods for obtaining and counting macrofauna, it is impossible to make meaningful comparisons with them. The studies of Posford Haskoning (2004a & b) and Axeleson *et al.* (2008) focussed on maerl habitats on the western bank of the lower Fal estuary. Maerl habitats in this area have complex histories of disturbance by commercial maerl extraction, navigational dredging and ship anchoring and as such comprise predominantly dead maerl. Where live maerl is present, it is generally only sparse (<20% cover). Each of these studies found a larger total number of macrofaunal taxa than we found in cores from dense live maerl in St Mawes Harbour (194 to 234 *versus* 78 for St Mawes Harbour), but they sampled approximately ten times as many cores and extracted animals used a finer (0.5mm) sieve-mesh, both of which would have added significantly to their final estimation of taxonomic diversity. As such the lower estimation of diversity in this study cannot and should not be taken as an indication that macrofauna in the live maerl habitat in St Mawes Harbour are less diverse than those in the predominantly dead maerl habitats on the western bank of the lower Fal.

As a final aside, it is worth noting that the investigation of images from the photo-quadrat survey revealed a further 22 macrofaunal taxa on dense live maerl. Had there been more time to scrutinise photo-quadrats, it is likely that more taxa could have been identified in this habitat.

After live maerl, the next most biodiverse habitat within St Mawes Harbour was silty fine sand. Given the common perception of seagrass beds as a highly biodiverse habitat (Davison *et al.* 2000, English Nature 2000), one might have expected that sediment amongst seagrass would have ranked more highly. It is relevant to note here that the sediment samples from within St Mawes seagrass beds did not include the seagrass shoots and leaves, which is where a significant portion of the biodiversity in seagrass beds resides (Hemminga & Duarte 2000). A similar study in NSW, Australia (Lindegarth & Hoskin 2001) that assessed the macrofaunal diversity of seagrass sediment samples that included shoots and leaves found 1.4 to 2.3 times more taxa than in similar unvegetated sediments nearby. Had seagrass in St Mawes Harbour been sampled in the same way, it is very likely that it would have appeared to be more biodiverse than silty sand. Sampling only the sediment part of the seagrass habitat in St Mawes allowed for a more standardised comparison with the other sedimentary/particulate habitats, but at the expense of ignoring part of the overall biodiversity of the seagrass beds.

The finding that macrofaunal diversity in silty fine sand was greater than in sediments among seagrass beds is most likely attributed to it having more very fine particles (9.5% of particles <63μm *versus* 2.3%, respectively) and slightly greater organic content (1.8% *versus* 1.5%). These very fine particles, which comprise inert silts and clays and dead organic matter, are the main food resource for deposit-feeding infauna, which is one of the most important functional groups of sediment-dwelling animals (a well-known example being the lugworm, *Arenicola marina*). Deposit-feeders mainly derive nutrition from the single-celled algae and bacteria that live on these very-fine particles. The greater the proportion of fine particles, the greater the total surface area for microbes to live on and hence the greater the food value to deposit-feeders (Etter & Grassle 1992, Thrush *et al.* 2003). It is likely therefore, that the greater macrofaunal diversity of silty fine sand in St Mawes Harbour was partly due to it being more favourable for deposit-feeders than the sediment among seagrass beds. It should be noted, however, that diversity would not necessarily be expected to continue increasing with increasing silt/clay content as this would change other sediment properties (*e.g.* reduced dissolved oxygen content) that would be unfavourable for other types of animals. Compared to estuarine sediments more broadly, silty fine sand in St Mawes Harbour has a relative small silt/clay fraction.

The greater availability of particulate food for deposit feeding animals in silty fine sand and maerl habitats is also the most likely explanation for why these habitats supported a greater abundance of animals overall (*i.e.* regardless of species) compared to seagrass and clean fine sand.

Wave-exposure may partly explain why silty fine sand had greater macrofaunal diversity than the sediment in seagrass beds. The sites where seagrass sediments were sampled were slightly more wave-exposed than those where silty fine sand was sampled (Figure 10). High wave-energy is associated with sediment mobility, which is known to reduce infaunal diversity (McLachlan 1996, Gray 2002). This results from both the direct, physical effect of waves and moving particles on small, often-delicate fauna and the indirect effect of silt and organic matter being washed out of the sediments. Seagrass plants reduce sediment mobility, however, so this explanation would only apply if there was still significant mobility notwithstanding this stabilising effect.

The fact that unvegetated clean fine sand in the outer area of St Mawes Harbour had much lower macrofaunal diversity than sand from nearby seagrass beds is consistent with reduced sediment mobility in the latter. In terms of particle size distribution and organic content, these different sediments were statistically indistinguishable. The large difference in diversity between similar sediments with *versus* without seagrass highlights the importance of conserving habitat-forming species like seagrass and maerl.

Lastly in relation to seagrass, it is important to note that seagrass is also present within the inner parts of the harbour where adjacent unvegetated sediments are silty fine sand (*e.g.* in the shallow intertidal area along the western shore of Polvarth Point). Sediments within these inner harbour seagrass beds are likely to be siltier and have a higher organic content than those in the two outer harbour sites where cores for macrofauna were sampled. If that is true, then sediments in these inner seagrass beds are likely to support a greater diversity of macrofauna than those further out in the harbour, but this would need to be tested via further core-sampling and analysis.

5.2.2 Composition of assemblages

The finding that each broad habitat type supported a statistically distinct assemblage of sediment infauna is important for management of St Mawes harbour because it means that significant loss or disturbance of any one of these habitats would significantly diminish the overall biodiversity of the harbour.

Broadly speaking, the pattern of faunistic difference among habitats reflected the pattern of difference in terms granulometry and organic content. Hence, maerl and silty fine sand were the most distinct in terms of granulometry and organic content and they supported the most distinct assemblages. Similarly, clean fine sand and seagrass bed sediments were statistically indistinguishable in terms of granulometry and organic content and also had the most similar assemblages.

Surveys revealed four newly-recorded species for St Mawes Harbour that are officially recognised as ‘species of conservation concern’. The reference list of ‘species of conservation concern’ used here was compiled in 2013 by Dr Keith Hiscock of the Marine Biological Association of the UK. It combines information from several such lists that have been drafted for various purposes over the years.

The newly-recorded species of conservation concern in St Mawes Harbour were *(i)* the sea anemone *Aiptasia mutablis* (‘nationally scarce’ and a Nationally Important Marine Feature (NIMF)); *(ii)* the bivalve mollusc *Callista chione* (‘nationally rare’); *(iii)* the amphipod *Leucothoe spinicarpa* (a NIMF); and *(iv)* the brown alga *Asperococcus compressus* (‘nationally scarce’). For information, the Nationally Rare and Scarce list was that of Sanderson (1996a & b) and the NIMF list was that of Hiscock & Harris (2007)).

Six individuals of *Leucothoe spinicarpa* were found in sediment cores from one of the two live maerl sites (Site ‘M2’; Figure 8). The other three species of conservation concern were seen in photo-quadrats. There were seven *Callista chione*, all in clean fine sand, mainly towards the mouth of the harbour on the southern side. There were three *Aiptasia mutablis*, all in the inner, south-eastern corner of the harbour. There were 23 observations of *Asperococcus compressa*, again mainly in the inner, south-eastern corner of the harbour.

5.3 Human impacts

This study was not designed to test *a priori* hypotheses about potential human impacts on the ecology of St Mawes Harbour, nor is it capable of proving whether any pattern observed in the data was the result of human disturbance. Nevertheless it is valid to discuss the results of this study in the context of what is known about human uses of St Mawes Harbour and to highlight issues of concern where further research or other action may be warranted.

5.3.1 Impacts of moorings and anchoring

As mentioned in the introduction, by far the greatest environmental threat to marine life on the seabed of St Mawes Harbour is physical disturbance by boat moorings and anchoring activity (English Nature 2000, Coyle & Wiggins 2010, Fal & Helford SAC Management Forum 2012). In terms of specific habitats, maerl and seagrass beds are the greatest concern (English Nature 2000). This is because of their sensitivity to mechanical disturbance and their ecological value to other species, both in terms of productivity and the habitat they provide.

When the present St Mawes investigations were being planned there was no empirical information on the ecological impacts of boating activity and infrastructure within the Fal & Helford SAC. During 2011/12, however, research on this topic was carried out by the University of Plymouth as part of a collaborative project (the Recreational Boating Study) run by local harbour authorities, moorings operators, Natural England and Cornwall Council. The project was not fully comprehensive in that it did not investigate impacts of anchoring, and did not cover all of the areas and habitats impacted by moorings. It focussed on the main habitats affected by moorings in the lower parts of the Fal and Helford estuaries; *i.e.* muddy gravel, fine sand and seagrass. The resultant report (Latham *et al.*

2012) strongly validated concern about the ecological impacts of moorings within the Fal & Helford SAC. Results showed that where mooring ground-chains sweep the seabed there are significant changes in topography, granulometry and the composition of infaunal assemblages. In terms of topography, it was found that the scouring effect of a mooring chain creates a circular depression in the seabed 20-40cm lower than the surrounding area. These depressions were clearly visible in the output from a detailed bathymetric survey of Falmouth Harbour that was presented in Latham *et al.* 2012 and reproduced here in Figure 15, below. Latham *et al.* (2012) found that these depressions resulted chiefly from the loss of fine particles. Sediments within mooring 'scars' were, on average, coarser-grained than sediments outside the scar. They suggested that mud and silt was stirred into suspension by ground-chain movement and then carried away by tidal and wave-driven currents.

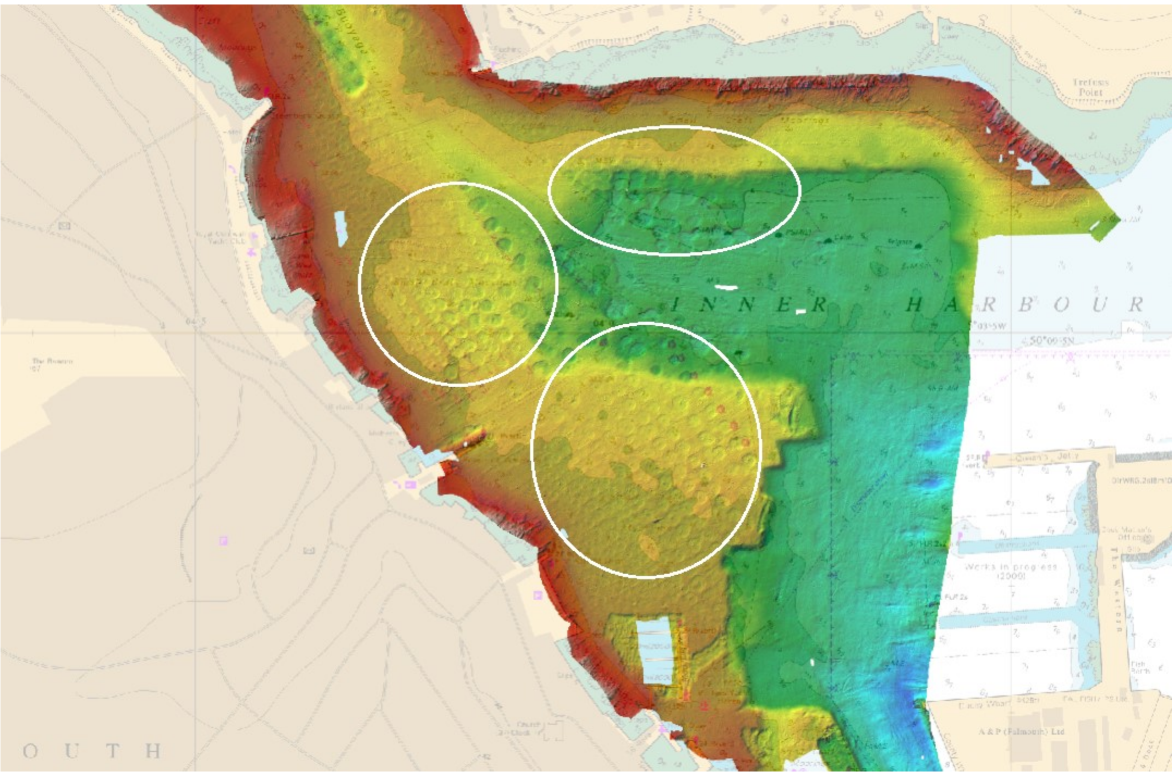

Figure 15. Detailed bathymetric data of the Falmouth Inner Harbour mooring areas shows clear circular depressions (20-40cm depth) around the locations of the moorings. The main areas of mooring scour are highlighted by white rings. Source: 2010 Falmouth Harbour Commissioners commissioned Coastwise bathymetric survey. Reproduced from Latham *et al.* (2012).

Another potential explanation overlooked by Latham *et al.* (2012) is that ground-chain scouring removes and then inhibits biological overgrowth of the seabed (*e.g.* by seagrass or algae), leaving sediments more exposed to erosion during storms.

Latham *et al.* (2012) also addressed the often-overlooked, but ecologically significant issue that mooring blocks smother the natural seabed (with a typical footprint of ~1.5m^2), removing the water-sediment interface and introducing hard substratum into areas (in the Fal and Helford estuaries, at least) where natural benthic habitats are based predominantly on soft substrata.

In terms of sediment infauna, Latham *et al.* (2012) found evidence of impacts of mooring chains on the abundance and diversity of organisms out to a distance of 5m from mooring blocks and evidence of more-subtle impacts on the composition of assemblages from 5m to 11m out. Their study also found that responses varied among animal groups. The main difference was between crustaceans, which showed a significant effect of distance from moorings, *versus* molluscs and annelid worms, which did not. The apparent sensitivity of crustaceans to physical disturbance from moorings chains reported by Latham *et al.* (2012) was consistent with the findings of a similar study by Herbert *et al.* (2009).

Another important finding by Latham *et al.* (2012) was that moorings had lesser impacts in unvegetated sandy sediments (which happened to be in St Mawes Harbour) than in muddier sediments (in Falmouth and Mylor). The explanation put forward was that the sandy sediments in St Mawes Harbour were naturally more wave-exposed and thus their fauna were more adapted to physically disturbed environments than those in Falmouth and Mylor.

Applying the main findings of Latham *et al.* (2012) to the current number of chain moorings in St Mawes Harbour, which is 150 (according to Table 10 in Latham *et al.* (2012), allows their cumulative impact to be estimated. Thus, it would appear that St Mawes Harbour moorings are responsible *(i)* for reducing the overall abundance and diversity of sediment infauna in 11,781 m^2 (or ~1.2 hectares) of seabed and *(ii)* for significantly altering the composition of infaunal assemblages over an additional 45,239m^2 (or ~4.5 hectares). Hence, the total area within St

Mawes Harbour that is currently expected to show detectable impacts of moorings is 57,020m^2 (or ~5.7 hectares).

Treating the subtidal area of St Mawes Harbour as an approximate rectangle and using average measurements of its length and width, the total subtidal area for the Harbour is approximately 566,900 m^2 (or ~56.7 hectares). This would indicate that ~10% of the harbour is impacted by moorings, with 2% being severely impacted (reduced diversity and abundance) and a further 8% being moderately impacted (changed assemblage composition).

As much as one third of the damage that moorings have caused to the seabed of St Mawes Harbour appears to have happened since designation of the Fal & Helford SAC. According to the St Mawes Pier & Harbour Company (the private Harbour Authority), in 2000, shortly after the SAC was designated, there were 100 moorings in the Harbour (P. Marsden, personal communication). The current figure of 150 moorings reported by Latham *et al.* (2012) thus represents a 33% increase since SAC designation.

With respect to vessel anchoring, there is no published data on the trend in activity within St Mawes Harbour over recent years, or its distribution. It is generally believed, however, that it has increased very significantly in the last 20-30 years due to increased provision of facilities for storing boats on the water both locally and regionally (*i.e.* moorings, pontoons and marinas).

Without knowing the distribution of different habitats within the harbour prior to recent increases in boating-related impacts, one cannot reliably assess the extent to which they have been impacted. Of the two habitats that are most vulnerable to physical disturbance, maerl and seagrass, seagrass is likely to have suffered the most damage. This is because its general distribution within the harbour encompasses much more of the area where moorings and anchoring activity are concentrated than is the case for maerl.

Broadly speaking, moorings and anchoring activity are concentrated in the more-sheltered inner (eastern) half of the harbour. Seagrass is distributed around the periphery of this area, but is sparse, patchy or more often absent altogether in the central area where moorings and anchoring activity are concentrated. In a few places, seagrass still extends amongst moorings; *e.g.* off Tavern Beach on north side of the harbour (personal observation). In such places, however, ground chains have scoured conspicuous bare patches in the seagrass. There is no obvious natural reason (*e.g.* depth, wave exposure) why seagrass should not cover more of the inner area of the harbour. As such, it is plausible that the current distribution of seagrass reflects the impact of moorings and anchoring within the harbour.

Approximately 10 moorings close to the northern shore of the harbour encroach on dense living maerl. These appear to have killed all the maerl within the sweep of their ground chains.

5.3.2 Implications of moorings impacts for the Fal & Helford SAC

St Mawes Harbour is not unique within the Fal & Helford SAC in having had increased numbers of moorings since SAC designation. In both estuaries, the number of moorings has increased in most mooring areas, post-designation. Latham *et al.* (2012) estimated both the total number of permanent, subtidal chain moorings currently in the SAC (1263), and the total area potentially impacted (up to 48 hectares). They did not, however, attempt to estimate how much either had increased since SAC designation. Consequently, one is unable to assess whether the damage from moorings is significant relative to conservation objectives for the SAC and thus whether current management is adequate.

This notable omission by Latham *et al.* (2012) may be related to the fact that their work was largely funded and co-ordinated by commercial moorings providers in the SAC. Any requirement to reduce moorings numbers to restore unacceptable damage to the SAC would be detrimental to their interests.

A further obstacle to good management of moorings in the Fal & Helford SAC is that the condition of the subtidal sandbanks feature of the SAC, which is the main feature impacted by moorings, has not been properly assessed by Natural England. Under Article 17 of the Habitats Directive, the UK Government is required to assess the condition of each SAC feature once every six years. As reported previously (Section 2.4), the condition of the subtidal sandbank feature of the SAC was not assessed in the first 6-year period (to 2006). A small amount of work was undertaken during the second 6-year reporting phase, but this mainly involved reviewing existing information, rather than new surveys (Natural England 2013). This existing information was mostly neither current, nor spatially comprehensive and was originally obtained for reasons other than condition assessment. Inevitably, therefore, it was not fully fit for purpose. For unknown reasons, the work of Latham *et al.* (2012) was not included. The current situation is that the condition of the subtidal sandbank feature remains largely unassessed. The precise status of current condition assessments for the various attributes and subfeatures of subtidal sandbanks in the Fal & Helford SAC is summarised in Table 10, below.

While ecological information is generally lacking, the threats to subtidal sandbank communities in the Fal & Helford SAC are well-known, including that from moorings. Table 10 reports Natural England's observation that maerl, gravel/sand and mixed sediment communities in the SAC are all threatened by *"shallow surface abrasion/ mechanical damage to seabed surface"*. The specified threats are moorings in the case of gravel/sand and mixed sediment and ship anchoring in the case of maerl. This is consistent with an earlier risk assessment (Natural England 2010), which noted that the condition of the subtidal sandbank feature of the SAC was *"possibly unfavourable"* condition due to *"physical damage"* from *"commercial shipping"* (*i.e.* ship anchoring) and *"recreation"* (*i.e.* and mooring and anchoring disturbances).

Given the limited ecological information, it might seem unsurprising at first that Natural England has not assessed the condition of the subtidal sandbank communities threatened by physical disturbance in the Fal & Helford SAC. The relevant EU guidance (European Union – Directorate General Environment 2012) indicates, however, that conclusions of 'unfavourable condition' might have been more appropriate in this case. The guidance recognises that while comprehensive and rigorous condition assessment surveys are clearly optimal, they are not always possible. It thus allows that, where there is a clear threat to a SAC feature, expert opinion alone may be sufficient to conclude unfavourable condition.

Table 10. Summary of latest condition assessment for component attributes and subfeatures of the subtidal sandbank feature of the Fal & Helford SAC (Natural England 2013).

	Assessments for component attributes		**Overall**	
Sub-feature	**Attribute**	**Assessment**	**assessment**	**Two main threats**
Eelgrass bed communities	Characteristic species - epiphytic community	Not assessed	Favourable	▪ Shallow surface abrasion/ mechanical damage to seabed surface ▪ Marine water pollution
	Nutrient status of eelgrass community - green algal mats	Not assessed		
	Extent of eelgrass community	Favourable		
	Characteristic species - density of *Zostera marina*	Favourable		
Maerl bed communities	Nutrient status of maerl bed communities – green algal mats	Not assessed	Not assessed	▪ Shallow surface abrasion/ mechanical damage to seabed surface (*e.g.* ship anchoring)
	Species composition of maerl bed communities	Not assessed/Partial (6-25% in unfavourable/recovering condition)		
	Distribution of maerl bed communities	Not assessed/Partial (6-25% in unfavourable/recovering condition)		
	Extent of maerl bed communities	Not assessed		
Gravel and sand communities	Species composition of characteristic biotopes	Not assessed	Not assessed	▪ Shallow surface abrasion/ mechanical damage to seabed surface (*e.g.* moorings) ▪ Marine water pollution (*e.g.* heavy metals)
Mixed sediment communities	Species composition of characteristic biotopes	Not assessed	Not assessed	▪ Shallow surface abrasion/ mechanical damage to seabed surface (*e.g.* moorings) ▪ Marine water pollution (*e.g.* heavy metals)

This is consistent with the precautionary principle, which applies to all European environment legislation (under Article 191 of the EU Lisbon Treaty). Had Natural England made a precautionary assessment of unfavourable condition for the communities they know are threatened by moorings and anchoring activity in the Fal & Helford SAC, this would have been a powerful impetus for improved management. By avoiding making a condition assessment, however, despite the obvious threats, Natural England have allowed potentially inadequate management to continue.

5.3.3 Other human impacts

Other than mooring scars, the only other visible human impact in St Mawes Harbour seen during surveys was the effect of boat propeller wash in the shallow approaches to the quay (mainly due to the Falmouth-St Mawes ferry). This hydraulic disturbance has removed most of the fine sand, leaving only large pebbles and cobbles supporting a sparse covering of ephemeral epibiota, mainly filamentous algae. Because pebbles and cobbles in shallow water are easily moved and abraded by water movement, they provide a much more precarious substratum for organisms to settle on than bedrock and boulders.

5.3.4 Suggestions for management and future research

The three main achievements of this study were *(i)* to identify the range of benthic habitats present within St Mawes Harbour; *(ii)* to accurately map their distribution; and *(iii)* to describe their species composition and diversity. It is important now to consider how these findings could potentially contribute to environmental management of the harbour and to propose what further ecological research might be of value to the Trust, in light of its broad aims.

As stated previously, the main ongoing threat to the ecology of St Mawes harbour is physical disturbance of the seabed from boat moorings and anchoring activity. This is of greatest concern for seagrass and maerl habitats because of the vulnerability of their founding species and, in the case of maerl, its rarity. The results of this study could be used in several ways to reduce the impacts of moorings and anchoring on these habitats. In each case, the support and cooperation of the St Mawes Pier & Harbour Company, the private harbour authority and moorings operator in St Mawes, would be required.

One possibility might be to use the results of this study to re-arrange some of the existing moorings in the harbour in a more environmentally-sensitive way. For instance, by removing them from areas where seagrass and maerl appear to thrive and re-locating them to areas where they do not.

Given the relatively high diversity of animals present in unvegetated silty fine sand, there may also be a case for removing moorings from some areas of this habitat. The best habitat to place moorings in would be unvegetated clean fine sand, which was by far the least biodiverse of the habitats studied. Unfortunately, however, it mainly occurs in the outer harbour, which is more wave-exposed than the areas where moorings are currently situated.

Were there to be any rearrangement of moorings along such lines, it would be highly instructive to monitor potential ecological recovery of benthic habitats in places where moorings were removed.

The Trust would not wish to see any further increase in the number of moorings in the harbour, but were the harbour authority minded to place additional moorings, they could use the results of this study to deploy them in areas that minimised the likely impact on biodiversity in the harbour.

A further suggestion would be to use the results of this study to identify sensitive areas where the harbour authority, and potentially local vessel-users, might discourage others from anchoring. This could be done in a variety of ways including having harbour officials disseminate information to visiting boats, or by placing information buoys to identify areas where boats should not anchor. Such a scheme has operated for some years in the Helford estuary to protect a vulnerable seagrass bed.

Although there are no known plans for any other type of development within the harbour (*e.g.* a new quay, marina, or aquaculture installation), it is possible that such schemes may emerge in the future. In such an event, this study would serve as useful baseline information for any environmental impact assessment that was required. Were any such development to proceed, there should be rigorous monitoring to assess the actual impacts on the harbour's ecology. The actual impacts of human activities are often very different to those that are predicted beforehand (Osenberg & Schmitt 1996).

Aside from the potential to contribute to improved management of moorings and other potential developments, the main value of this study is the opportunity it presents to raise general awareness and interest in the ecology of St Mawes Harbour and the ways in which humans can affect it, for better or for worse. The Trust aims to present and interpret the results of this study in a variety of ways to engage and inform locals and visitors in these issues (*e.g.* via meetings, the media, publications, educational activities, etc.).

No scientific study is fully comprehensive and this is no exception. So for instance, this study was confined to benthic habitats and ignored other aspects of the harbour's marine ecology, such as fish, plankton, seabirds, seals and cetaceans. Developing a more complete picture of the marine life of St Mawes Harbour would require these to also be studied. The present surveys were also limited in the sense that they were done during only one part of one year – late spring/early summer 2010. Hence, results provide only a snapshot of the habitats and species present at that point in time.

All of the habitats and species that were studied can be expected to show various forms of short-, medium- and long-term variation. While features such as maerl and seagrass beds would not be expected to show significant variation in extent from day-to-day, or even month-to-month, they may change with seasonal events (*e.g.* winter storms) and would almost certainly vary from year-to-year due to these and other factors (*e.g.* long-term changes in water clarity and temperature and the abundance of competitors for space and light). At the other extreme, animals like the small worms, bivalves and crustaceans found within sediment cores would be expected to show large changes in abundance from week-to-week and even day-to-day, due to their short life-cycles. Had core samples been taken at a different time of year, or at the same time in a different year, it is likely that the types and abundances of species would have been markedly different. Hence, obtaining a more complete and accurate picture of the ecology of St Mawes harbour would require the measurement of some of these temporal variations. Amongst the random variations that are normal for populations of marine plants and animals, there would undoubtedly be various trends and cycles uncovered, which would be fruitful areas for further research on their potential causes. Greater understanding of the range of species that live in or frequent the harbour, together with their natural variations and their causes, would all be very useful for environmental management of the harbour.

The effects of human activities and disturbances within the harbour would also be worthy subjects for further research. While Latham *et al.* (2012) included St Mawes Harbour in their study of the impact of chain moorings, they did not attempt to characterise the way in which the different habitats in the harbour have been affected. This would be very useful knowledge when deciding where best to place moorings within St Mawes harbour.

The amount and distribution of anchoring disturbance is much harder to estimate than it is for moorings because it is a largely unregulated, fleeting activity, typically lasting no more than a few hours. While the direct impact of any single anchoring event is likely to be smaller than that caused by a single mooring, anchoring can occur more-or-less anywhere in St Mawes Harbour, so the cumulative extent of seabed affected by anchoring could be much greater. It would be worthwhile therefore to carry out periodic surveys of the harbour to record the distribution of anchoring activity within the harbour. To be useful, this would need to include the busiest times for vessel anchoring, which in the Fal are generally when good weather coincides with weekends and holiday periods in the spring, summer and autumn. As well as identifying areas where anchoring should perhaps be discouraged, this work would also identify sites of high *versus* low anchoring activity that could be compared to assess the ecological impact of this activity. As with potential re-location of moorings, if the harbour authority decided to ban or discourage anchoring in certain sensitive areas, it would be instructive to monitor potential recovery of the habitats in these areas.

Finally, in the interest of promoting further research in St Mawes Harbour, the Trust will make available all of the raw data collected for this study to any individual or group that wishes to use it. This includes the 13,000+ digital photo-quadrats of the seabed that were obtained. Use of these resources will only be constrained by the requirement that they not be used commercially and that any publication or other product that makes use of them fully acknowledges the Trust and CMER's contribution and provides a link to the Trust's website. Clearly, much use has already been made of these data and resources, but it is very possible that further good use can be made of them, particularly the photo-quadrats. Because of the large number of photo-quadrats, it was impossible to extract every piece of ecological information from each photo-quadrat. As such, others may well be able to extract additional useful information from these images and are encouraged to do so.

6 REFERENCES

Austen M (2010). View from Melanie Austen, Chief Scientific Advisor to the Marine Management Organisation Board on the appropriate assessment for harbour works, capital dredge, and maerl mitigation in Falmouth (10.11.2010). Published on-line at: http://www.marinemanagement.org.uk/licensing/public_register/cases/documents/falmouth/mmo_csa.pdf

Backhurst MK & Cole RG (2000). Biological impacts of boating at Kawau Island, north-eastern New Zealand. *Journal of Environmental Management* 60: 239–251.

Birkett DA, Maggs C & Dring MJ (1998). *Maerl: an overview of dynamics and sensitivity characteristics for conservation management of marine SACs.* Report from Scottish Association of Marine Science (SAMS) for the UK Marine SACs Project.

Carrick District Council (2005). *Dredging protocol. Baseline document Fal & Helford estuaries.* Cornwall Council, Truro, Cornwall.

Clarke KR & Gorley RN (2006). *PRIMER version 6: User manual and tutorial.* PRIMER-E, Plymouth.

Clarke KR & Warwick RM (2001). *Change in marine communities: an approach to statistical analysis and interpretation.* 2nd edition. PRIMER-E, Plymouth.

Connor DW, Brazier DP, Hill TO & Northen KO (1997a). *Marine Nature Conservation Review: marine biotope classification for Britain and Ireland. Volume 1. Littoral biotopes.* Version 97.06 . JNCC Report, No. 229. JNCC, Peterborough.

Connor DW, Dalkin MJ, Hill TO, Holt RHF & Sanderson WG (1997b). *Marine Nature Conservation Review: marine biotope classification for Britain and Ireland. Volume 2. Sublittoral biotopes.* Version 97.06 . JNCC Report, No. 230. JNCC, Peterborough.

Connor DW, Allen JH, Golding N, Howell KI, Lieberknecht LM, Northen KO & Reker JB (2004). *The Marine Habitat Classification for Britain and Ireland, Version 04.05.* JNCC, Peterborough (internet version: www.jncc.gov.uk/MarineHabitatClassification).

Coyle MD & Wiggins SM (2010). *European Marine Site Risk Review.* Natural England Research Reports, Number 038. Natural England, Peterborough.

Davies J & Sotheran I (1995). *Mapping the distribution of benthic biotopes in Falmouth Bay and the lower Fal-Ruan estuary.* English Nature, Peterborough. (English Nature Research Report, No. 119a).

Davison DM, Hughes DJ (1998). *Zostera Biotopes (volume I). An overview of dynamics and sensitivity characteristics for conservation management of marine SACs.* Scottish Association for Marine Science (UK Marine SACs Project). Published on-line at: http://www.ukmarinesac.org.uk/pdfs/zostera.pdf

Doody JP (1992). Sea defence and nature conservation: threat or opportunity. Journal of Aquatic Conservation: *Marine and Freshwater Ecosystems* 2/3: 275-283.

Doody JP (2004). 'Coastal squeeze' – an historical perspective. *Journal of Coastal Conservation* 10: 129-138.

Eleftheriou A & McIntyre A (2005). *Methods for the study of marine benthos* (Third Edition). Blackwell Science, Oxford.

English Nature (1997). *Site citation: Lower Fal and Helford Site of Special Scientific Interest (SSSI).* Published on-line at: http://www.english-nature.org.uk/citation/citation_photo/2000174.pdf

English Nature (2000). *English Nature's advice for the Fal and Helford European marine site given under Regulation 33(2) of the Conservation (Natural Habitats &c.) Regulations 1994.* Published on-line at: http://publications.naturalengland.org.uk/file/3959221

English Nature, Scottish Natural Heritage, Countryside Council for Wales, Environment & Heritage Service (Northern Ireland), JNCC & Scottish

Association of Marine Science (2001). *Guidelines for Developing Conservation Objectives for Marine SACs - Learning from the UK Marine SACs Project 1996-2001.* English Nature, Peterborough.

Etter RJ, Grassle JF (1992). Patterns of species diversity in the deep sea as a function of sediment particle size diversity. *Nature* 360: 576-578.

European Commission (2012). *Natura 2000 network.* Published on-line at: http://ec.europa.eu/environment/nature/natura2000/index_en.htm

Fal & Helford SAC Management Forum (2012). *Fal & Helford Special Area of Conservation Management Scheme.* Cornwall Council, Truro.

Goldberg ED (1986). *TBT: an environmental dilemma.* Environment 28: 17-44.

Gray JS (2002). Species richness of marine soft sediments. *Marine Ecology Progress Series* 244: 285–297.

Hayward PJ & Ryland JS (2000). *Handbook of the marine fauna of north-west Europe.* Oxford University Press, Oxford, UK.

Hemminga MA & Duarte CM (2000). *Seagrass ecology.* Cambridge University Press, Cambridge.

Herbert RJH, Crowe TP, Bray S & Sheader M (2009). Disturbance of intertidal soft sediment assemblages caused by swinging boat moorings. *Hydrobiologia* 625: 105-116.

Hiscock K & Harris R (2007). *Nationally Important Marine Features and Biodiversity Action Plan Marine Priority Habitats and Species: Supplementary Report. Report to the Joint Nature Conservation Committee from the Marine Biological Association.* Plymouth: Marine Biological Association. JNCC Contract F90-01-892.

Hiscock S (1986). *A field guide to the British red seaweeds.* Occasional publication No.13 of the Field Studies Council.

Jackson CM, Kamenos NA, Moore PG & Young M (2004). Meiofaunal bivalves in maerl and other substrata; their diversity and community structure. *Ophelia* 58: 48-60.

JNCC (2006). *Common Standards Monitoring for Designated Sites: First Six Year Report.* Peterborough, JNCC.

JNCC (2008). *Statement on Common Standards Monitoring (CSM).* Published on-line at: http://jncc.defra.gov.uk/page-2198

JNCC (on-line, cited 2012a). *Marine Nature Conservation Review (MNCR).* Published on-line at: http://jncc.defra.gov.uk/default.aspx?page=1596

JNCC (on-line, cited 2012b). *Non-native species; flora: Sargassum muticum*. Published on-line at: http://jncc.defra.gov.uk/page-1677

JNCC (2012c). *Supporting documentation for the DRAFT Third Report by the United Kingdom under Article 17 on the implementation of the Directive from January 2007 to December 2012 Conservation status assessment for Habitat: H1110 - Sandbanks which are slightly covered by sea water all the time.* Published on-line at: http://jncc.defra.gov.uk/pdf/Article17Consult/H1110_ENGLAND.pdf

Krebs CJ (1985). *Ecology: the experimental analysis of distribution and abundance.* Third edition. Harper Collins Publishers Inc., New York.

Langston WJ & Burt GR (2007). *A review of TBT sediment data in the Fal and Helford SAC.* Report to Environment Agency. Marine Biological Association of the UK, Plymouth.

Langston WJ, Chesman BS, Burt GR, Hawkins SJ, Readman J & Worsfold P (2003). *Site Characterisation of South West European Marine Sites: Fal and Helford Estuaries candidate Special Area of Conservation. (Report to the Environment Agency and English Nature on a study carried out by the Plymouth Marine Science Partnership).* Marine Biological Association Occasional Publication No. 8. April 2003. Marine Biological Association of the UK, Plymouth.

Latham H, Sheehan E, Foggo A, Attrill M, Hoskin P, & Knowles, H. (2012). *Fal and Helford Recreational Boating Study: Environmental impact of recreational boating infrastructure on benthic fauna.* Falmouth Harbour Commissioners, Falmouth, UK on behalf of the Fal and Helford Recreational Boating Study Project Partners.

Lindegarth M, Hoskin MG (2001). Patterns of distribution of macro-fauna in different types of estuarine, soft sediment habitats adjacent to urban and non-urban areas. *Estuarine, Coastal and Shelf Science* 52: 237–247.

Martin S, Clavier J, Guarini J-M, Chauvaud L, Hily C, Grall J, Thouzeau G, Jean F & Richard J (2005). Comparison of *Zostera marina* and maerl community metabolism. *Aquatic Botany* 83: 161–174.

McLachlan A (1996). Physical factors in benthic ecology: effects of changing sand particle size on beach fauna. *Marine Ecology Progress Series* 131: 205-217.

Miossec L, Le Deuff R-M, Goulletquer P (2009). Alien species alert: *Crassostrea gigas* (Pacific oyster). *ICES Cooperative Research Report* No. 299.

Montefalcone M, Chiantore M, Lanzone A, Morri C, Albertelli G & Bianchi CN (2008). BACI design reveals the decline of the seagrass Posidonia oceanica induced by anchoring. *Marine Pollution Bulletin* 56: 1637–1645.

Moore JJ, Smith J & Northen KO (1999). *Marine Nature Conservation Review: Sector 8 – Inlets in the western English Channel.* JNCC, Peterborough. (Coasts and seas of the United Kingdom. MNCR series).

Natural England (2009). *Condition assessment summary for the Lower Fal & Helford Intertidal SSSI.* Published on-line at: http://www.sssi.naturalengland.org.uk/Special/sssi/reportAction.cfm?report=sdrt13&category=S&reference=2000174

Natural England (2012a). *Sites of Special Scientific Interest.* Published on-line at: http://www.naturalengland.org.uk/ourwork/conservation/designatedareas/sssi/default.aspx

Natural England (2012b). *Fal & Helford European Marine Site - Risk Assessment (RA).* Unpublished report. Natural England, Pydar House, Truro, Cornwall, TR1 1XU.

Natural England (2013). Excel spreadsheet file '*Fal Sandbanks Art 17 2013.xlsx*'. Contains 2013 Article 17 (Habitats Directive) assessment for the subtidal sandbank feature of the Fal & Helford SAC. Provided to M Hoskin by Natural England on 22 March 2013 in response to a request under the Environmental Information Regulations 2004 (Natural England's request reference no. 1855).

Osenberg CW & Scmitt RJ (1996). *Detecting ecological impacts caused by human activities.* In: Detecting ecological impacts: concepts and applications in coastal habitats (Osenberg CW & Scmitt RJ, Eds.). Academic Press, New York. Pp 3-15.

Pizzolla P (2008). *Sargassum muticum, Wireweed. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme.* Marine Biological Association of the United Kingdom, Plymouth. Published on-line at: http://www.marlin.ac.uk/speciesinformation.php?speciesID=4296

Powell HT, Holme NA, Knight SJT & Harvey R (1978). *Survey of the littoral zone of the coast of Great Britain: Report on the shores of Devon and Cornwall.* (Contractor: Scottish Marine Biological Association/Marine Biological Association Intertidal Survey Unit.). Nature Conservancy Council, CSD Report, No. 209.

Primack RB (1993). *Essentials of conservation biology.* Sinauer Associates Inc., Sunderland, Massachusetts, USA.

Rayment W (2008). *Crepidula fornicata, Slipper limpet. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme.* Marine Biological Association of the United Kingdom, Plymouth. Published on-line at: http://www.marlin.ac.uk/speciesimportance.php?speciesID=3086

Rostron D (1987). *Surveys of harbours, rias and estuaries in southern Britain: Falmouth.* (Contractor: Field Studies Council Oil Pollution Research Unit, Pembroke.) Nature Conservancy Council, CSD Report, No. 623. (FSC Report, No. FSC/OPRU/49/85.)

Royal Haskoning (2009). *Falmouth Cruise Project Environmental Statement.* Report to Falmouth Harbour Commissioners and Falmouth Docks & Engineering Company. Haskoning UK Ltd. – Environment, Exeter.

Sanderson WG (1996a). *Rare marine benthic flora and fauna in Great Britain: the development of criteria for assessment.* Joint Nature Conservation Committee (report, no. 240), Peterborough.

Sanderson WG (1996b). Rarity of marine benthic species in Great Britain: development and application of assessment criteria. *Aquatic Conservation* 6, 245-256.

Spalding Associates (Environmental) Ltd (2000). *Survey of intertidal landclaim in the Fal & Helford estuaries cSAC.* Report to English Nature. Spalding Associates (Environmental) Ltd, Truro.

Thrush SF, Hewitt JE, Norkko A, Nicholls PE, Funnell GA & Ellis JI (2003). Habitat change in estuaries: predicting broad-scale responses of intertidal macrofauna to sediment mud content. *Marine Ecology Progress Series* 263: 101–112.

Troost K (2010). Causes and effects of a highly successful marine invasion: Case-study of the introduced Pacific oyster *Crassostrea gigas* in continental NW European estuaries. *Journal of Sea Research* 64: 145–165.

UK BAP Steering Group (2007b). *UK Biodiversity Action Plan - Priority Habitat Descriptions.* Published on-line at: http://www.ukbap.org.uk/library/UKBAPPriorityHabitatDescriptionsfinalAllhabitats20081022.pdf

Walker DI, Lukatelich RJ, Bastyan G & McComb AJ (1989). Effect of boat moorings on seagrass beds near Perth, Western Australia. *Aquatic Botany* 36: 69–77.

7 ACRONYMNS

ANOSIM	Analysis of similarities
ANOVA	Analysis of variance
BAP	Biodiversity Action Plan
CSM	Common Standards Monitoring
ERCCIS	Environmental Records Centre for Cornwall & Isles of Scilly
EU	European Union
FHC	Falmouth Harbour Commissioners
GIS	Geographic Information System
GPS	Global Positioning System
HSE	Health & Safety Executive
JNCC	Joint Nature Conservation Council
MCA	Maritime & Coastguard Agency
MHW	Mean High Water
MLW	Mean Low Water
MMO	Marine Management Organisation
MNCR	Marine Nature Conservation Review
NE	Natural England
NIMF	Nationally Important Marine Feature
nMDS	Non-metric Multi-Dimensional Scaling
PRIMER	Plymouth Routine In Multivariate Ecological Research
SAC	Special Area of Conservation
SE	Standard Error
SMB	Surface Marker Buoy
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
TBT	Tri-Butyl Tin